AJSM PreView, published on June 24, 2015 as doi:10.1177/0363546515588179

Performance Demands in Softball Pitching

A Comprehensive Muscle Fatigue Study

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Background: Monitoring pitch count is standard practice in minor league baseball but not in softball because of the perception that fast-pitch softball pitching is a less stressful motion.

Purpose: To examine muscle fatigue after fast-pitch softball performances to provide an assessment of performance demand.

Study Design: Descriptive laboratory study.

Methods: Bilateral strength measurements (handheld dynamometer) were made on 19 female softball pitchers (mean age [±SD], 15.2 ± 1.2 years) before and after pitching a game (mean number of pitches, 99 ± 21; mean innings pitched, 5 ± 1). A total of 20 tests were performed on the dominant and nondominant sides: forearm (grip, wrist flexion/extension, pronation/supination, elbow flexion/extension), shoulder (flexion, abduction/adduction, external/internal rotation, empty can test), scapula (middle/lower trapezius, rhomboid), and hip (hip flexion/extension, abduction/adduction). Fatigue (percentage strength loss) was categorized based on bilateral versus unilateral presentation using paired *t* tests: bilateral symmetric (significant on dominant and nondominant and not different between sides), bilateral asymmetric (significant on dominant and nondominant but significantly greater on dominant), unilateral asymmetric (significant on dominant only and significantly greater than nondominant), or unilateral equivocal (significant on dominant only but not different from nondominant).

Results: Bilateral symmetric fatigue was evident for all hip (dominant, 19.3%; nondominant, 15.2%) and scapular tests (dominant, 19.2%; nondominant, 19.3%). In general, shoulder tests exhibited bilateral asymmetric fatigue (dominant, 16.9%; nondominant, 11.6%). Forearm tests were more variable, with bilateral symmetric fatigue in the elbow flexors (dominant, 22.5%; nondominant, 19.2%), and wrist flexors (dominant, 21.6%; nondominant, 19.0%), bilateral asymmetric fatigue in the supinators (dominant, 21.8%; nondominant, 15.5%), unilateral asymmetric fatigue in the elbow extensors (dominant, 22.1%; nondominant, 11.3%), and unilateral equivocal fatigue in the pronators (dominant, 18.8%; nondominant, 15.2%) and grip (dominant, 11.4%; nondominant, 6.6%). The mean (±SD) pitch velocity was 49 ± 4 mph, with a small loss of velocity from the first to last inning pitched (3.4% ± 5.0%, $P < .01$).

Conclusion: Fast-pitch softball pitching resulted in profound bilateral fatigue in the hip and scapular muscles, with more selective fatigue in the shoulder and arm muscles.

Clinical Relevance: These findings emphasize the importance of strength in the proximal musculature to provide a stable platform for the arm to propel the ball.

Keywords: shoulder; manual muscle test; handheld dynamometer; strength testing

There has been limited research on the softball pitching motion with respect to the physical demands of the action and injury risk. The fast-pitch softball pitching motion has been described in terms of 6 phases based on a side view of the pitcher (Figure 1)[17]: phase 1 (windup) consists of counterclockwise downward movement to a 6 o'clock position, phase 2 (preparatory) corresponds to upward movement from 6 to 3 o'clock, phase 3 (acceleration) corresponds to upward movement from 3 to 12 o'clock, phase 4 (power) corresponds to downward movement from 12 to 9 o'clock, phase 5 (release) corresponds to movement from 9 o'clock to ball release, and phase 6 (deceleration) corresponds to movement from ball release to completion of the follow-through motion.[9,15] This coordinated movement can result in significant stress on the musculoskeletal system.[1,17,24,25] For example, the fast-pitch softball pitching motion places

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The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546515588179

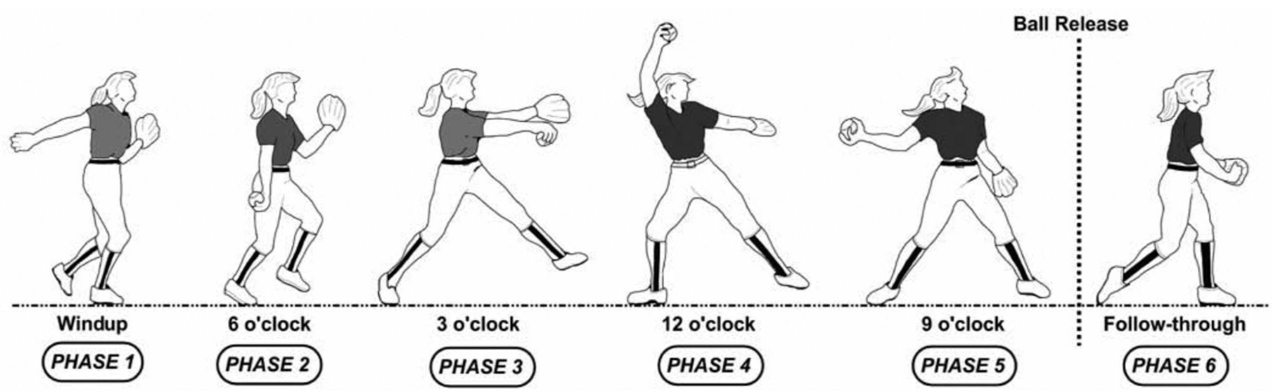

Figure 1. Windmill pitching phases. Image adapted with permission from Rojas et al.[17]

significant stress on the biceps labrum complex during the release phase.[1,17] In addition, shoulder distraction forces at release and follow through are comparable with what is seen with baseball pitching.[24,25] Not surprisingly, there is a significant risk of injury, with 73% of collegiate softball pitchers sustaining an injury in a single season.[4]

While Little League baseball has imposed specific regulations with regard to pitch count limits and required days of rest between pitching outings,[8] no such guidelines exist for youth softball pitchers because softball pitching is regarded as a less stressful motion.[7] Unfortunately, the physical demands of softball pitching are not well understood. Electromyographic (EMG), kinematic, and kinetic analyses of the pitching motion have been examined in laboratory settings.[1,3,15,17,24,25] However, these analyses do not provide an indication of the performance demand for pitching a complete game. The performance demand for baseball pitching has been examined in collegiate pitchers by recording upper and lower body strength on the day before a game and immediately after a game.[13] In that study, marked fatigue was apparent in the shoulder musculature, with minimal fatigue evident in the scapular and hip muscles.[11] The purpose of this study was to examine the performance demand for softball pitching by documenting the upper and lower extremity fatigue patterns associated with a real-game softball fast-pitch performance. Youth pitchers were studied because there are currently no pitch count or rest day regulations for youth softball pitchers, and consequently, they commonly pitch multiple games per day and on consecutive days.

METHODS

Nineteen softball pitchers were recruited (mean age [±SD], 15.2 ± 1.2 years). Informed consent and assent were obtained from parents and subjects before inclusion in the study, which was approved by institutional review board. Inclusion criteria included (1) being a female fast-pitch softball pitcher aged 14 to 18 years, (2) pitching a minimum of 4 innings in the index game, (3) being available for pregame testing 24 to 48 hours before pitching performance, (4) being available for postgame testing, and (5) not having pitched in a game in the 48 hours before the index game. A total of 20 strength tests were performed using a handheld dynamometer (Lafayette MMT) (grip strength was assessed with a Jamar grip dynamometer). All strength tests were conducted using the same technique on each subject. Each subject was informed of the testing procedure before testing.

Strength Testing Protocol

The strength tests included 7 forearm tests (grip, wrist flexion/extension, forearm pronation/supination, elbow flexion/extension), 6 shoulder tests (flexion, abduction/adduction, external/internal rotation, empty can test), 3 scapular tests (middle/lower trapezius, rhomboid), and 4 hip tests (hip flexion/extension, abduction/adduction). With the exception of grip strength, a break test was performed for all strength tests.

Forearm Tests. A standardized grip strength measurement was performed with a neutral glenohumeral position and the elbow at 90° of flexion. Wrist flexion/extension and forearm supination/pronation were measured with the subject seated and the elbow flexed at 90°.[5] The dynamometer was placed on the palmar surface of the metacarpal heads for flexion and pronation and the dorsum of the wrist for extension and supination. Elbow extension was measured with the subject supine. The shoulder was abducted to 90°, and the elbow was flexed to 90°. The dynamometer was placed on the dorsal side proximal to the wrist.

Shoulder Tests. Shoulder internal rotation (IR) and external rotation (ER) strength were measured with the subjects in the supine position and with the arm at 90° of shoulder abduction and elbow flexion. For ER, the dynamometer was placed on the dorsal side of the wrist, slightly proximal to the wrist joint. For IR, the dynamometer was placed on the volar side of the wrist, slightly proximal to the wrist joint. Shoulder flexion and abduction strength measurements were performed in the standing position. The subject's arm was placed at 90° of flexion in the sagittal plane for flexion testing and 90° of abduction in the frontal plane for abduction testing. The empty can test was performed with the arm at 90° of abduction and 30°

anterior to the frontal plane with full glenohumeral IR. The empty can test positioning is thought to evaluate supraspinatus muscle strength.[2,9,10,20,21] Shoulder adduction testing was performed in the prone position with the arm by the side, in slight extension, and with the palmer surface facing medially. Pressure was applied slightly proximal to the palmar side of the wrist into abduction and flexion.

Scapular Tests. Scapular stabilizers were tested in the prone position. Lower and middle trapezius tests were set up according to Donatelli et al.[2] The lower trapezius muscle group was tested with the shoulder abducted to 145° with full glenohumeral joint ER. The middle trapezius muscle group was tested with the shoulder abducted to 90° with full glenohumeral ER. Rhomboid testing was performed with the upper extremity horizontally abducted to 90° with full glenohumeral IR (thumb down) and the scapula adducted.[6]

Hip Tests. Hip abduction and adduction were tested in the side lying position. The dynamometer was placed proximal to the knee joint for hip abduction and on the distal medial femur just proximal to the knee for hip adduction. Hip extension was tested in the prone position with the dynamometer placed just proximal to the ankle joint. Hip flexion was performed while the subject was seated with the dynamometer proximal to the patella.[5] All lower extremity break tests were replicated for both dominant and nondominant lower extremities. The dominant lower extremity is the extremity ipsilateral to the dominant upper extremity.

The starting side (dominant vs nondominant) was randomly selected. The order of tests was as follows: shoulder flexion, abduction, empty can, IR, ER; hip flexion, abduction, adduction, extension; shoulder adduction, middle trapezius, lower trapezius, rhomboids; grip strength; elbow flexion/extension, wrist flexion/extension, forearm pronation/supination. The average of 2 repetitions in each strength test was recorded.

Most of the strength tests have been performed previously on high school[22,23] and collegiate baseball pitchers[13] with some modifications. These studies have shown the handheld dynamometry break test techniques to be sufficiently reliable to detect fatigue effects[13] and differences between dominant and nondominant sides.[13,22,23]

Range-of-Motion Tests. Passive glenohumeral IR and ER range of motion (ROM) were measured goniometrically with the patients supine at 90° of shoulder abduction with 90° of elbow flexion. ER was measured with the patient in the supine position. The patient's back was supported on a foam pad allowing for full ROM, and the patient's scapulae were stabilized by body weight in the supine position. Patients were considered at the end range when the examiner manually detected scapulothoracic motion. IR was measured in a similar fashion. Arms were passively internally rotated and considered at the end range when scapular motion or shoulder protraction was detected. To prevent muscular guarding or apprehension, measurements were repeated 3 times until a repeatable measurement was recorded. Excellent reliability for IR and ER ROM using this technique has been reported (intraclass correlation coefficient [ICC], 0.91-0.99; 95% limits of agreement, 5°-9°).[14] Since this supine 90°-90° position has previously been used to measure ER and IR ROM in adolescent baseball pitchers,[22,23] it was used again here to provide a direct comparison of ROM between adolescent baseball and softball pitchers.

TABLE 1
Classification of Fatigue on the Dominant Versus Nondominant Sides

	Fatigue on Dominant Side	Fatigue on Nondominant Side	Fatigue Greater on Dominant vs Nondominant Side
Unilateral asymmetric	Yes	No	Yes
Unilateral equivocal	Yes	No	No
Bilateral asymmetric	Yes	Yes	Yes
Bilateral symmetric	Yes	Yes	No

During the pitching performance, pitch counts and velocity of pitches were recorded. Within 7 minutes of completion of pitching performance, the ROM and strength measurements were repeated in the same order as pregame testing.

Statistical Analysis

Dominance effects (dominant vs nondominant) at baseline (pregame testing) were tested using paired *t* tests. Fatigue was quantified as the percentage change in strength values from pregame to postgame for all tests. One-sample *t* tests were used to determine if fatigue was significantly different from 0 for each test. Fatigue was defined as bilateral symmetric, bilateral asymmetric, unilateral asymmetric, or unilateral equivocal based on the following definitions (Table 1) Bilateral symmetric fatigue refers to significant fatigue on the dominant and nondominant sides and no significant difference in fatigue between sides. Bilateral asymmetric fatigue refers to significant fatigue on both the dominant and nondominant sides with significantly greater fatigue on the dominant side. Unilateral asymmetric fatigue refers to significant fatigue on the dominant side only and dominant side fatigue significantly greater than the nonsignificant fatigue on the nondominant side. Unilateral equivocal refers to significant fatigue on the dominant side but not significantly different from the nonsignificant fatigue on the nondominant side.

Differences in fatigue between the 4 different joints were assessed with side (dominant vs nondominant) by joint (forearm, shoulder, scapula, hip) repeated-measures analysis of variance, with fatigue values averaged across tests for each joint and Bonferroni corrections for between joint pairwise comparisons. Based on the intersubject variability in strength loss in upper and lower extremity muscle groups in baseball players,[13] it was estimated that there was 80% power to detect 11% postgame fatigue, or an 11% difference in fatigue between dominant and nondominant sides, at an α level of .05, with a sample of 19 pitchers. Mean ± SD is reported in the text, and mean ± SE is displayed in the figures.

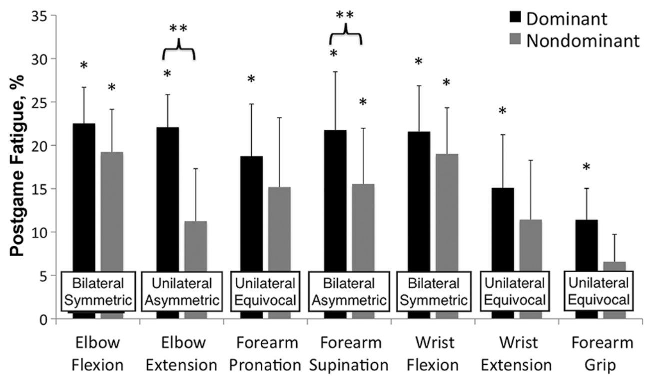

Figure 2. Postgame muscle fatigue for the forearm strength tests on the dominant and nondominant sides. *Significant fatigue for the respective strength test ($P < .05$); **fatigue on the dominant side significantly greater than that on the nondominant side ($P < .05$). Mean ± SE displayed.

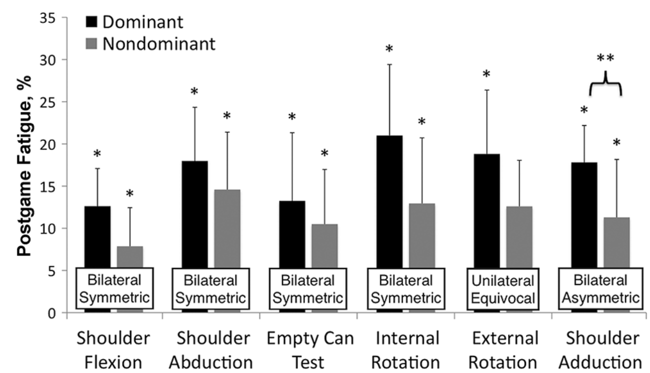

Figure 3. Postgame muscle fatigue for the shoulder strength tests on the dominant and nondominant sides. *Significant fatigue for the respective strength test ($P < .05$); **fatigue on the dominant side significantly greater than that on the nondominant side ($P < .05$). Mean ± SE displayed.

RESULTS

Pitchers threw 99 ± 21 pitches over 5 ± 1 innings. The mean pitch velocity was 49 ± 4 mph, with a small loss of velocity from the first to last inning pitched (3.4% ± 5.0%, $P < .01$).

Forearm Tests

At baseline, the dominant side was stronger than the nondominant side for elbow flexion (5.9% ± 8.3%, $P < .01$), elbow extension (16.8% ± 11.5%, $P < .01$), forearm pronation (5.4% ± 11.4%, $P < .05$), forearm supination (9.3% ± 9.4%, $P < .001$), and grip strength (13.9% ± 13.1%, $P < .0001$), with no side-to-side difference for wrist flexion (6.8% ± 14.4%, $P = .08$) or extension (2.7% ± 19.0%, $P = .24$). Postgame fatigue was apparent in all 7 forearm tests (Figure 2). Fatigue was bilateral asymmetric for forearm supination, unilateral asymmetric for elbow extension, bilateral symmetric for elbow flexion and wrist flexion, and unilateral equivocal for forearm pronation, wrist extension, and grip strength.

Shoulder Tests

At baseline, the dominant side was stronger than the nondominant side for shoulder flexion (7.8% ± 8.4%, $P < .001$), abduction (10.2% ± 7.5%, $P < .0001$), adduction (11.6% ± 6.6%, $P < .0001$), and the empty can test (8.3% ± 13.6%, $P < .01$), with no side-to-side difference for shoulder IR (5.3% ± 18.6%, $P = .40$) and ER (3.6% ± 16.9%, $P = .54$) strength. Postgame fatigue was apparent in all 6 shoulder tests (Figure 3). Fatigue was bilateral asymmetric for shoulder adduction; bilateral symmetric for flexion, abduction, IR, and the empty can test; and unilateral equivocal for ER.

Scapular Tests

At baseline, the dominant side was stronger than the nondominant side for the middle trapezius (5.0% ± 7.9%, $P < .01$) and lower trapezius tests (8.3% ± 11.3%, $P < .01$), but the difference was not significant for the rhomboids (6.8% ± 15.6%, $P = .08$). Postgame fatigue was apparent in all 3 scapular strength tests (Figure 4), and fatigue was bilateral symmetric for all 3 tests.

Hip Tests

At baseline, the dominant side was stronger than the nondominant side for hip flexion (6.4% ± 7.5%, $P < .01$) and hip abduction (7.3% ± 7.3%, $P < .001$), with no significant difference for hip adduction (3.2% ± 12.1%, $P = .20$) and hip extension (3.0% ± 11.2%, $P = .52$). Postgame fatigue was apparent in all 4 hip strength tests (Figure 5), and fatigue was bilateral symmetric for all 4 tests.

Fatigue Comparisons Between Joints

When average fatigue for each joint was compared between joints and between dominant versus nondominant sides, it was apparent that fatigue was not different between joints ($P = .44$), averaging 14% ± 24% in the shoulder, 19% ± 15% in the scapula, 16% ± 19% in the forearm, and 17% ± 19% in the hip. Overall, there was significantly greater fatigue on the dominant versus nondominant side (19% ± 17% vs 15% ± 19%, $P < .01$). When examining each joint separately, it was apparent that fatigue was significantly greater on the dominant versus nondominant side in the shoulder (17% ± 24% vs 12% ± 23%, $P < .001$) and forearm (19% ± 18% vs 14% ± 21%, $P < .05$). Fatigue was not significantly different between dominant and nondominant sides in the scapula (19% ± 16% vs 19% ± 16%, $P = .99$) and hip (19% ± 17% vs 15% ± 22%, $P = .26$).

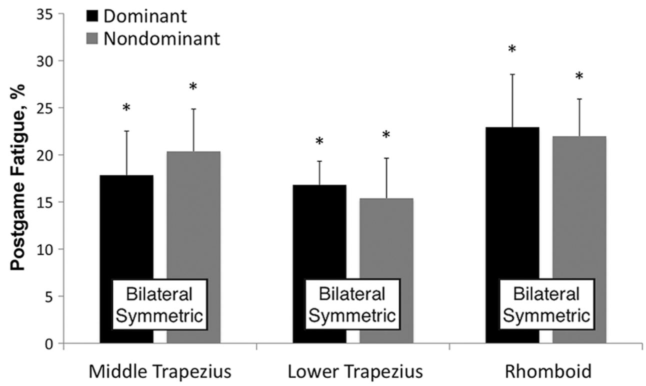

Figure 4. Postgame muscle fatigue for the scapular strength tests on the dominant and nondominant sides. *Significant fatigue for the respective strength test ($P < .05$). Mean ± SE displayed.

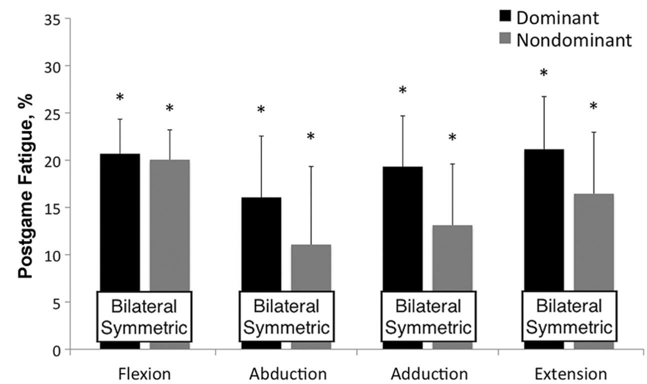

Figure 5. Postgame muscle fatigue for the hip strength tests on the dominant and nondominant sides. *Significant fatigue for the respective strength test ($P < .05$). Mean ± SE displayed.

ROM Tests

At baseline, there was no difference in glenohumeral ROM between the dominant and nondominant sides for IR (78° vs 79°; difference, 1.7° ± 7.9°, $P = .50$) or ER (89° vs 85°; difference, 3.4° ± 7.3°, $P = .06$). After the pitching performance, ROM increased on the dominant side by 6.9° ± 11.2° for IR ($P < .05$) and 9.3° ± 13.2° for ER ($P < .01$) with nonsignificant changes on the nondominant sides (IR: 2.5° ± 14.5°, $P = .45$; ER: 6.7° ± 15.0°, $P = .07$). The changes in the dominant side were not significantly different from the nondominant side ($P = .06$ [IR] and $P = .19$ [ER]).

Additional Results

Fatigue was unrelated to the number of pitches thrown, the number of innings completed, or the loss of velocity from first to final inning. Similarly, fatigue was not correlated with the age of the pitcher.

DISCUSSION

Since the inception of fast-pitch softball, the conventional wisdom has been that the underhand motion is more “natural” than the overhand throwing motion. Coaches who propagate this notion expect their pitchers to throw several games over the course of a weekend. However, the motion used for fast-pitch softball is a violent, powerful motion that incorporates the entire body. This is evident by the substantial fatigue exhibited by numerous upper and lower extremity muscle groups after a pitching performance.

Mullaney et al[13] showed that fatigue in college baseball pitchers occurred primarily in the dominant shoulder (12%), with minimal scapular fatigue (6%) and hip fatigue (4.5%). While softball pitching also resulted in substantial fatigue in the dominant shoulder of these adolescent pitchers (17%), there was bilateral scapular (19%) and hip muscle fatigue (19%). The fatigue effects of softball pitching cannot be directly compared with the baseball data from Mullaney et al[13] given the age differences in the study samples (15 vs 21 years). However, it is clear that fast-pitch softball pitching fatigues the entire kinetic chain.

Previous research on the demands of the softball fast-pitch motion used EMG analyses to quantify the magnitude of muscle contractions.[15,17] Rojas et al[17] found that biceps brachii activity during the windmill pitch was twice as high as that during the baseball pitch (38% vs 19% maximum voluntary contraction [MVC]). Of note, this study[17] reported higher pitch velocities (53 ± 5 mph) than in the present study (49 ± 4 mph). In the present study, not all pitches thrown were fastballs. Higher values for peak biceps brachii activity during softball pitching (100% MVC) were reported by Oliver et al.[15] Elbow flexion fatigue in the present study was 23%, which was somewhat higher than the average fatigue on the dominant arm for all forearm tests (19%) and shoulder tests (17%), thus highlighting the demand on the elbow flexors. Peak gluteus maximus and medius activity during the softball pitch was shown to be very high (approximately 200% and 120%, respectively).[15] These data are consistent with the marked fatigue in hip extension (21%) and abduction (19%) demonstrated in the present study. Similarly, high triceps brachii and rhomboid EMG activity during the softball pitch (approximately 160% and 170% MVC)[15] is consistent with the marked fatigue in dominant elbow extension (22%) and rhomboid test (23%) in the present study.

Unfortunately, injury incidence in softball pitchers has not been extensively studied, and little is known about injury risk factors. In collegiate softball, 11% of all game-related injuries were to pitchers.[11] In addition, Hill et al[4] reported that 73% of pitchers sustained an injury in a season, and one of the recommendations was to limit the number of pitches thrown per week. The extent to which fatigue or inadequate recovery between games contributes to increased injury risk warrants further study. From a performance standpoint, the current fatigue data point to the importance of whole-body conditioning in softball pitchers. Hip strengthening, and strengthening of other muscle groups around the trunk, is as important as shoulder and scapular strengthening for these athletes.

Baseline shoulder strength and ROM data for these softball pitchers demonstrate clear differences compared with similar-aged baseball pitchers.[22,23] With regard to ROM, baseball pitchers were characterized by a gain in ER and a loss of IR on the dominant versus nondominant arm. By contrast, softball pitchers had symmetrical ROM in ER and IR, which is consistent with previous findings.[18] With regard to strength, high school baseball pitchers were slightly stronger on the dominant versus nondominant side in IR (7%) with symmetrical strength in ER, supraspinatus, and scapular retraction. By contrast, softball pitchers had greater strength in the dominant supraspinatus (8%) and scapular muscles (middle trapezius, 5%; lower trapezius, 8%), with symmetrical strength in IR and ER. These differences between baseball and softball pitchers highlight the different demands of the motions.

The high degree of bilateral fatigue in the upper extremity muscles of these softball pitchers does not seem to fit with the unilateral demands of the pitching motion. However, a crossover effect of muscle fatigue from exercised to nonexercised muscle has been demonstrated in both upper extremity[12] and lower extremity[16] muscle groups. It is possible that part of the fatigue was central, as opposed to peripheral, such that the fatigue induced by the repetition of pitching compromises the ability to voluntarily activate motor units. Greater central fatigue has previously been demonstrated in children versus adults,[19] so such an effect would not be surprising in these young pitchers.

Future research is required to establish whether specific strength measures, or fatigue effects, are associated with increased risk of injury in fast-pitch softball pitchers. Considering the significant performance demand of softball pitching, the rationale for not having limits on pitch counts or having mandatory rest days may need to be reconsidered.

While this study is the first to examine muscle fatigue patterns in fast-pitch softball pitchers, there are some limitations to be considered. Recovery of strength was not studied, and it is not known if these fatigue effects are transient or prolonged. The extent to which pitching more than 1 game per day or pitching on consecutive days compounds fatigue is not known. Furthermore, the effect of these fatigue effects on subsequent performance or injury risk is not known. Thus, the fatigue data do not provide specific evidence to support the introduction of pitch counts or rest days for fast-pitch softball pitchers. Direct comparison of softball pitching fatigue to fatigue after baseball pitching performances is not possible because fatigue patterns have yet to be studied in adolescent baseball pitchers. While pitch velocity was studied here, it would have been useful to have other performance indicators such as ball/strike ratio to examine the extent to which fatigue might affect performance. Lastly, the order of strength tests was not randomized, and thus, a progressive central fatigue may have affected later tests. The extent to which this might have confounded observed fatigue effects is not known. The test order was the same for pre- and postgame testing. A fixed test order was used to assist the tester in consistently replicating the exact maneuvers for each test and minimize repositioning of the subjects.

In conclusion, fast-pitch softball pitching results in marked muscle fatigue throughout the kinetic chain. For this reason, we believe that bilateral strength training for the hip and scapular muscles is as important as training the shoulder muscles in adolescent fast-pitch softball pitchers.

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