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Case Report

Low Thigh Muscle Coactivation and High Ball Velocity in an Elite Windmill Softball Pitcher

Thigh Muscle Activation and Throwing Velocity

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Abstract

Aim: To examine whether strength and thigh muscle activation patterns were associated with throwing velocity in a collegiate fast-pitch softball pitcher with national-level experience. **Methods:** Five female pitchers from a college team in Ontario, Canada, participated for comparison. The team's top pitcher, recently selected for national team training, was classified as elite; the remaining four were categorized as high-performance. Upper- and lower-body strength was estimated using one-repetition maximum tests. Surface electromyography (EMG) of the rectus femoris (RF) and biceps femoris (BF) was recorded during windmill pitches, while ball velocity was measured with radar. The maximum peak-to-peak RMS EMG signal, as well as timing of activation and inactivation, were analyzed across pitchers. **Results:** The elite pitcher demonstrated the highest average throwing velocity (59 mph vs. 54 mph) and greater overall strength. She also displayed a distinct three-phase activation pattern of thigh musculature with minimal coactivation, while the high-performance pitchers showed less distinct patterns and greater overlap of RF and BF activity. **Conclusion:** This case highlights that both superior strength and a distinct thigh activation profile may contribute to higher throwing velocity in elite softball pitchers. Further research integrating EMG with biomechanical video analysis may clarify how neuromuscular coordination supports performance.

Keywords: fast-pitch; throwing speed; muscle activation patterns; electromyography

Introduction

Fast-pitch softball is a technically challenging sport that is popular in North America and around the World. It involves a great deal of strength and power when throwing, running and hitting, like those in baseball. The most obvious difference between the two sports arises from the technique used by pitchers to deliver a pitch. Fast-pitch softball pitchers employ what is often referred to as the 'windmill' pitch as opposed to the overhand nature of ball delivery used by baseball pitchers. A plethora of research aimed at examination of the baseball pitch is readily available, yet research examining the windmill pitch mainly addresses injury prevention rather than factors associated with pitching velocity. Given that throwing velocity is an important factor in the ability of a team to win in baseball (Kohmura, Aoki et al. 2008) it reasons that the same is true for fast-pitch softball.

Throwing velocity depends on both the strength and the efficiency of force transfer through the kinetic chain. In the windmill pitch, the non-stride leg pushes off the pitching rubber and plays a pivotal role in propelling the pitcher toward home plate. In baseball, greater force production by the non-stride leg has been linked to higher throwing velocities (MacWilliams, Choi et al. 1998), and velocity differences across performance levels have been associated more with strength and muscle mass than mechanics (Fleisig, Barrentine et al. 1999). Similar principles likely apply in fast-pitch

softball, where stride force and effective ground-to-ball energy transfer are critical. Oliver et al. (2010) showed that efficient throwing kinetics in the windmill motion are directly related to velocity through coordinated force transfer from the ground to the torso, arm, and ball. Despite these insights, little is known about how thigh muscle activation patterns contribute to velocity in softball pitchers, which provides the context for the current case.

Previous studies have examined upper extremity muscle function and the biomechanics of the windmill pitch (Oliver, Dwelly et al. 2010; Oliver and Plummer 2011). However, research on lower-limb contributions remains limited. For example, Oliver and Plummer (2011) reported a positive relationship between pitching velocity and non-stride leg gluteal activity, suggesting that hip stabilization may enhance force transfer to the upper body. Yet, no published studies have assessed the activation of the knee extensors or flexors of the non-stride leg during the windmill pitch. Given that stride length is correlated with higher ball velocity (Guido, Werner et al. 2009), the activation patterns of these thigh muscles are likely critical for effective energy transfer and propulsion. This gap provides the rationale for the present case study, which examined thigh muscle activation in an elite pitcher compared with her teammates.

This case study originated from a request by the head coach of a collegiate women's fast-pitch softball team, who sought to understand why his top pitcher consistently threw at higher velocities than her teammates. The goal was to use these insights to inform a strength and conditioning program aimed at improving performance across the team. The coach hypothesized that the elite pitcher's advantage was due to greater overall strength but also questioned whether she "moved differently", which was interpreted as exhibiting distinct neuromuscular activation patterns. At present, little research has examined how lower-body strength or thigh muscle activation relates to throwing velocity in the windmill pitch, limiting the applicability of current training approaches. This case study therefore explored whether differences in strength and thigh muscle activation patterns could help explain the superior velocity of the elite pitcher.

Methods

Four female fast-pitch softball pitchers from an Ontario College participated in the study. The team's top pitcher had recently returned from a Team Canada Women's softball training camp. She is defined in the current study as an *elite* pitcher and the remaining three pitchers as *high-performance*. The experimental procedures were approved by the Research Ethics Board (#11-001) at the University of Ontario Institute of Technology and in accordance with the Tri-Council guideline in Canada with full disclosure of potential risks to participants.

The focal athlete in this case study was the top pitcher on a collegiate women's fast-pitch softball team in Ontario, Canada. She was 23 years old, 171 cm tall, and weighed 145 lbs, with 10 years of pitching experience. At the time of testing, she had recently attended a Canadian national team training camp, providing context for her classification as an elite-level pitcher. She routinely pitched in starting roles for her college team and trained at least five times per week, including both on-field and strength and conditioning sessions. Three of her collegiate teammates, classified as high-performance pitchers, were included for comparison.

Off-Field Measurements

Each athlete attended a separate session at the University fitness centre to have their estimated one-repetition maximum (E1RM) assessed for both the upper- and lower-body, using bench press and leg press movements, respectively. The strength testing was performed by Canadian Society for Exercise Physiology - Certified Exercise Physiologists[®] (CSEP-CEP) using the guidelines outlined by the CSEP (Canadian Society for Exercise Physiology 2006). A standard protocol was used for both the bench and leg press E1RMs. A warm-up of 5-10 repetitions at ~40-60% of the participants E1RM was performed. This was followed by 1 set of up to 10 repetitions at ~60-80% of their E1RM. If the participant was able to perform more than 10 repetitions they rested for 3-5 minutes, the weight was

increased, and they performed the set again. The % of 1RM is determined from the number of repetitions completed. The weight lifted is divided by the %1RM as estimated in the table. Testing for the bench and leg press exercises were conducted on Atlantis equipment (P-337 flat bench press with pivot and the C-401 40 degree leg press).

On-Field Measurements

General Procedure

Each pitcher was instructed to throw fastballs to the catcher behind home plate from a pitching rubber located at a standard distance of 43 feet from home plate. Only pitches deemed strikes by the catcher were assessed (4 per pitcher). Pitches were assessed following a standard team warm-up and in a non-fatigued state. A radar gun (Stalker ATS II, Stalker Sports) situated behind home plate was used to determine ball velocity.

Electromyography

To assess the activity of the thigh musculature, EMG recordings of a knee extensor (rectus femoris (RF)) and a knee flexor (biceps femoris (BF)) were made using pairs of Ag-AgCl surface electrodes (Meditrace™ 130 ECG conductive adhesive electrodes) placed 2 cm apart (centre to centre). A ground electrode was placed over the patella. All measurements were made from the side of the body ipsilateral to throwing arm (non-stride leg). Thorough skin preparation for all recording electrodes included removal of dead epithelial cells with abrasive (sand) paper around the designated areas followed by cleansing with an isopropyl alcohol swab. Electrodes were attached to leads inserted into a portable EMG preamplifier secured around the athlete’s waist. The portable system was attached to the main amplifier and acquisition unit (Biopac Systems, MP100WSW; Holliston, MA). EMG data was collected on-line at 2000Hz, amplified (1000x) and filtered (10-1000Hz). The amplitude of the root mean square (RMS) of the EMG signal at a window of 30 ms was evaluated and used as a measure of muscular intensity of effort.

The activation pattern and relative intensity of the thigh muscle activation was assessed. The threshold for EMG onset for each muscle was set at 3x the standard deviation of the average rectified EMG signal at rest, prior to obtaining the RMS. Because the EMG signals did not always return to baseline between pitching phases, visual identification, a valid measure to assess EMG (Hodges and Bui 1996) onset and offset, was also used. To determine the relative intensity of muscle activity we used a dynamic normalization method (Jacobson, Gabel et al. 1995). The maximum peak-to-peak RMS of the EMG signal obtained in one of the four pitching trials for each muscle was deemed the maximum for that muscle. The RMS of the EMG for all other trials were made relative to the maximum value obtained for that muscle.

Results

Strength and throwing velocity

The results of the strength testing and throwing velocities are presented in Table 1. The athletes were ranked on each of the E1RM tests from 1 to 4, with 1 being the athlete with the highest value and 4 the athlete with the lowest. The average rank was then calculated [(bench press rank + leg press rank)/2] (see Table 1). Due to the low sample size (n=4), correlational statistics were not performed. It seems clear, however, that based on the results of these pitchers, the higher the overall strength (average rank) the higher the throwing velocity. The team's elite pitcher ranked number 1 for both E1RM tests and had the highest average throwing velocity (59 ± 1.5mph) when compared to the average of the high-performance pitchers (54 ± 1.2mph).

Table 1. Summary of strength and throwing velocities for the elite and high-performance pitchers.

Electromyography activation pattern

The pattern of thigh muscle activation between the elite and high-performance pitchers was consistently different. Figure 2 illustrates representative examples of EMG profiles of both RF and BF of the *elite* pitcher (A) and a *high-performance* (B) pitcher (A and B: top trace rectus femoris and bottom trace biceps femoris). The black bars below the traces in A and B represent the time period from the onset to the offset of EMG in the muscle. The shaded bars represent timeframes when the RF and BF are turned on simultaneously (i.e. coactivation). The throwing velocities were 60mph and 55mph for A and B, respectively. Note the distinct bursting pattern in the EMG profile of the elite pitcher compared to the high-performance pitcher. The initiation of the pitch is characterized by activation in the BF, which then essentially turns off at the same point when the RF turns on. Once the RF turns off the BF again turns on. Note that there is very little overlap of the activation for RF and BF. In distinct contrast, there is no clear phase distinction in the high-performance pitcher. It appears the BF turns on, followed by a slight decrease in activation and then turns on again. The RF, however, seems to reach its highest activation at the same time as the reactivation of the BF. Note the overlap of RF and BF activation times.

Electromyography relative intensity

There were distinct differences in the relative intensity of muscle activation between RF and BF, as indicated in Figure 2. Figure 2 shows the mean activation values of the RF and BF during each of the three phases as described in Fig. 1, for the elite versus the high-performance pitchers. The relative activation levels of RF and BF are very similar for the elite and high-performance pitchers during phases 1 and 3 (Fig. 2A and C). A notable difference was observed, however, during phase 2 (Fig. 2B), whereby there is an obvious difference between the two groups with respect to the BF and to a lesser extent, the RF. The average BF activation level is 4.3% of its maximum in the elite pitcher as compared to 44% in the high-performance pitchers. In the same phase, RF activation is 53% of its maximum in the elite pitcher as compared to 41% in the high-performance pitchers. It is also noted that the average activation of BF for the high-performance pitcher’s ranged from 43-47% of its maximal activation during the pitch (over the 3 phases). In contrast, the average activation of BF for the elite pitcher ranges from 4-38% of maximum.

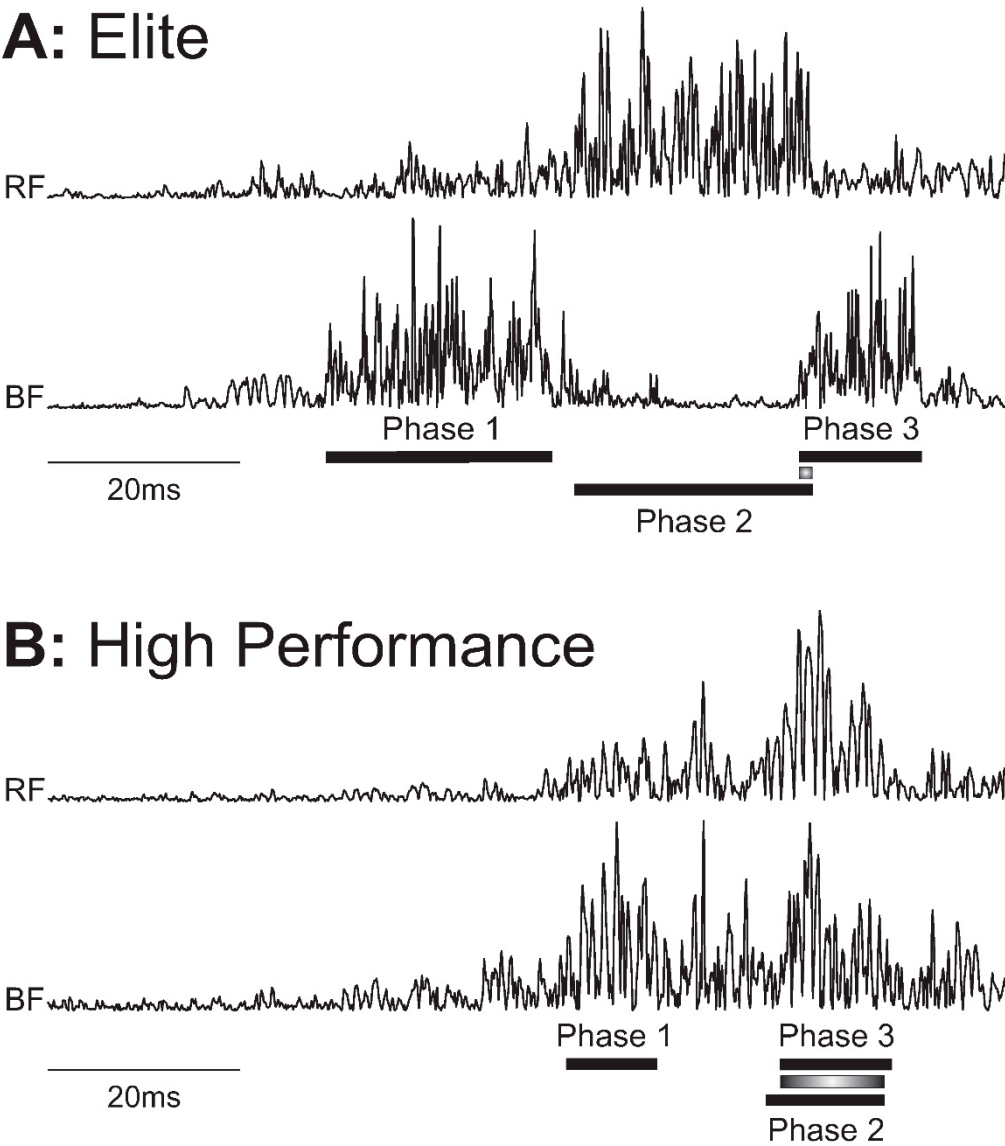


Figure 1. Thigh muscle activation patterns during the windmill pitch. (A) Electromyographic (EMG) bursting patterns of the rectus femoris (RF; knee extensor) and biceps femoris (BF; knee flexor) in the elite pitcher. (B) Representative EMG patterns from a high-performance pitcher. The pitch was divided into three phases based on EMG bursting: • Phase 1: Initial increase in BF activity above baseline. • Phase 2: Increase in RF activity above baseline. • Phase 3: Second increase in RF activity above baseline. These phases were more distinct in the elite pitcher (A) than in the high-performance pitcher (B). Black bars below the BF traces indicate the onset and offset of each phase, while shaded bars highlight overlap (coactivation) between Phases 2 and 3. The elite pitcher threw at 60 mph, compared with 55 mph for the high-performance pitcher. Notably, the elite pitcher (A) showed relative quiescence in BF activity during Phase 2 compared with the prolonged activation in the high-performance pitcher (B).

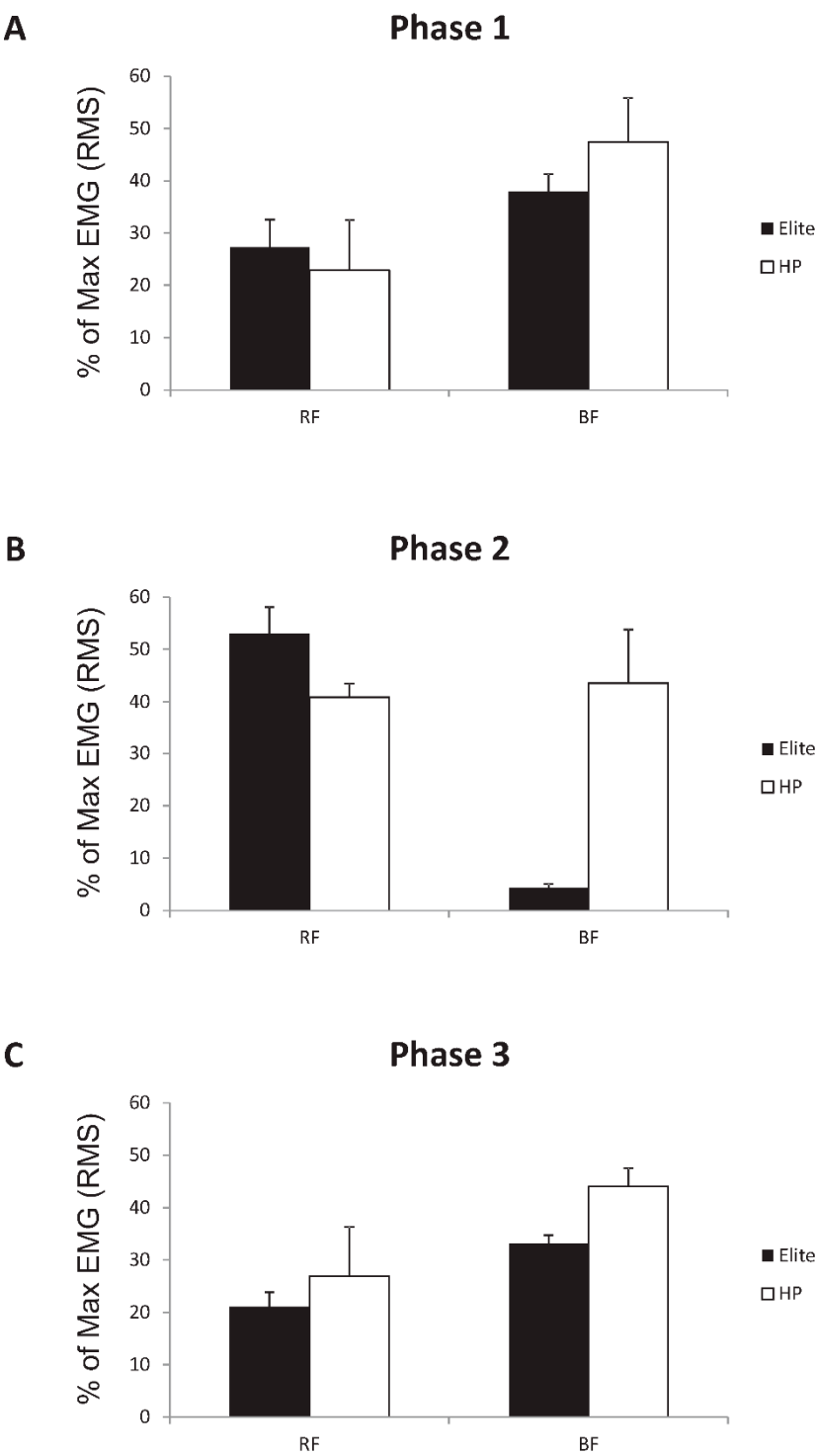


Figure 2. Phase-dependent muscle activation. Group data for RF and BF activation during each of the 3 phases of the windmill pitch (mean $\pm$ SE). The black bars represent the elite pitcher (n=1) and the white bars are the high-performance pitcher (n=3).

Discussion

The purpose of this case study was to examine the relationship between strength, thigh muscle activation patterns, and throwing velocity in a collegiate fast-pitch softball pitcher with national-level experience. Compared with her high-performance teammates, the elite pitcher demonstrated both greater overall strength and higher average velocity. The most notable observation, however, was

her distinct thigh muscle activation profile during the windmill pitch, which differed markedly from the patterns seen in the other pitchers.

The stride and pitching arm contribute to pitching velocity by generating ground reaction forces through the non-stride leg, which transfer momentum up the kinetic chain and ultimately to the ball (Oliver and Plummer 2011). Previous work has shown that the stride serves as a key initiator of this force transfer and is positively correlated with higher velocities (Stodden, Langendorfer et al. 2006) (Guido, Werner et al. 2009). In the present case, the elite pitcher demonstrated the greatest strength across all tests, supporting the link between non-stride leg strength and velocity. Her superior strength likely enhanced propulsion, contributing to her higher throwing velocity compared with teammates. While lower-body strength appeared most influential, upper-body strength also likely played a role. Although these values were estimated, they provide useful insight into how overall strength may support velocity in elite pitchers.

In addition to strength, effective velocity depends on both high muscle activation and coordinated, sequential activation of the lower limb (Oliver, Dwelly et al. 2010). Oliver and Plummer (2011) reported that greater gluteal activation during the windmill pitch was positively correlated with throwing velocity, likely reflecting stabilization of the plant leg that enables efficient energy transfer up the kinetic chain. Their findings, however, were based on a controlled laboratory setting, whereas the current case was conducted in the field, where activation patterns may differ.

In this case, the elite pitcher exhibited strong rectus femoris activation with relatively low biceps femoris activity, a pattern that may have allowed more efficient transfer of energy to the upper body (see Figure 2A and Figure 2B). Antagonistic coactivation is known to reduce agonist force output (Psek and Cafarelli 1993), and the extended hamstring activity seen in the high-performance pitchers may have opposed knee extension forces, limiting velocity. Although coactivation is common in ballistic movements (Osternig, Hamill et al. 1986), reduced coactivation may reflect a training adaptation and improved coordination (Rutherford & Jones, 1986).

From a practical perspective, the elite pitcher's reduced hamstring involvement may not only enhance velocity but also help delay fatigue and decrease injury risk, particularly given the demands of pitching multiple games with minimal rest. By contrast, the greater and prolonged biceps femoris activity observed in her teammates may partly explain their lower throwing velocities and potentially increase fatigue over time.

Conclusion

Although many factors likely contribute to windmill pitching velocity, this case highlights a striking difference in thigh muscle activation between an elite pitcher and her high-performance teammates. These findings suggest that neuromuscular coordination of the thigh may play an important role in velocity and warrants further study. Future work could integrate biomechanical video analysis with EMG recordings to better identify how specific muscles contribute across the distinct phases of the windmill pitch.

Practical Applications

A high pitching velocity gives the batter less time to react and both stride length and forward momentum play an important role in increasing speed. Greater lower-body strength and power help the pitcher drive toward home plate, but this case study highlights that strength alone may not be enough. The elite pitcher's distinct sequential activation of the thigh musculature suggests that efficient coordination, not just force production, is critical for maximizing velocity and ensuring effective transfer of momentum through the kinetic chain.

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