



Mean muscle activation comparison between fastballs and curveballs with respect to the upper and lower extremity

Megan Smidebush^{a,b,*}, Ethan Stewart^a, Robert Shapiro^b, Harish Chander^a, Adam Knight^a

^a Kinesiology, Mississippi State University, Starkville, MS, USA

^b Kinesiology and Health Promotion, University of Kentucky, Lexington, KY, USA

ARTICLE INFO

Article history:

Accepted 29 July 2019

Keywords:

Baseball
Biomechanics
Electromyography
Lower extremity
Pitching
Upper extremity

ABSTRACT

Baseball research on muscle activity (upper and lower extremity) during the throwing motion is important to understanding pitching mechanics for the future. Therefore, it is the purpose of this research study to compare the lower extremity muscle and upper extremity muscle activation patterns associated with the curveball pitch and the fastball pitch from the stretch position. Twelve skilled (NCAA collegiate level) pitchers volunteered to be in this study, with a mean age of 22.3 ± 4.53 years, mean height of 1.74 ± 0.13 m, and mean mass of $89.0 \text{ k} \pm 10.97$ kg. The pitchers were fitted with six surface electromyography (EMG) bipolar electrodes on the stride leg biceps femoris, medial gastrocnemius, ipsilateral side lower trapezius, upper trapezius, triceps brachii and biceps brachii. Each pitcher underwent maximum voluntary isometric contraction (MVIC) testing and then performed the fastball & curveball pitching sequence. All EMG variables of interest were normalized using MVIC data and compared between pitching type. A repeated measures ANOVA was conducted for all muscle activity as well. If significance was found a pairwise analysis (Bonferroni) was performed between pitch type, using SPSS ($p < 0.05$). Significant differences in the mean muscle activity for the fastball and curveball pitched from the stretch were observed. A higher level of muscle activity was found for the stretch fastball when compared to the stretch curveball. This study was able to provide a baseline measurement of muscle activity; however, kinematics and kinetics should be measured in future studies.

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1. Introduction

Previous research has reported that efficient energy transfer from the lower extremity to the upper extremity is of the utmost importance in achieving proper pitching mechanics (Fleisig et al., 1995; Kibler, 1991; Matsuo et al., 2002; Myers et al., 2005; Oliver and Keeley, 2010a; Sabick et al., 2004b; Stodden et al., 2005). Upper body kinetics research has determined that while pitching, there needs to be an increase in muscular strength with a decrease in the amount of muscle activation to efficiently perform the skill (Dillman et al., 1993; Fleisig et al., 1995, 1999; Reinold et al., 2008; Sabick et al., 2004b). Among previous research examining differences in novice and elite athletes with regards to their muscle activity while pitching, there have been studies that looked specifically at the muscle activity in the lower extremity and trunk. Previous research has described that the lower extremity and trunk musculature must be activated prior to arm motion in an attempt to produce the proper motor patterns utilized during

the pitching motion (Cordo and Nashner, 1982; Kibler et al., 2006; Yamanouchi, 1998). Therefore, it is the activation of certain muscles during various parts of the pitching motion as well as the segmental movements of the body during the pitch that allows for success. Further research is needed on the combination of muscle activation involving both the upper extremity and the lower extremity during a pitch.

Previous research studies on adolescent and youth baseball pitchers have reported that there are larger moments at the shoulder and elbow as well as a higher load placed on the shoulder and elbow for a fastball when compared to a curveball (Dun et al., 2008; Nissen et al., 2009). Studies have suggested that the shoulder and elbow of baseball pitchers are put at an increased risk of injury with an association to pitch type, pitch mechanics, and pitch counts (Fleisig et al., 1995; Sabick et al., 2004a, 2004b). These findings are in contrast to a long standing conviction from both coaches and players that the curveball places the arm at a higher risk of injury than the fastball (Nissen et al., 2009).

The biomechanical differences between different pitch types has been sparsely studied (Fleisig et al., 1999, 2006). Much research has been conducted on the change-up pitch (Fleisig

* Corresponding author at: 139 Graduate Hill Drive, Starkville, MS 39759, USA.
E-mail address: mms826@msstate.edu (M. Smidebush).

et al., 2006), but little research has been done on pitching a curveball. Measuring the muscle activity responsible for adjusting the mechanics while throwing the curveball pitch when compared to a fastball pitch would greatly assist in understanding the role of muscle activation in baseball pitching as well as help to explain the lower moment and joint load found in previous studies that examined the curveball (Dun et al., 2008; Nissen et al., 2009). A broad range of research has been conducted on baseball pitching, which include just one factor at a time. A multifaceted research study is needed to help gain a better understanding of the muscle mechanics for different pitch types and their muscle activation in both the upper and lower extremities. It has been commonly thought by baseball players and coaches that curveballs have different mechanics, which increase the risk of player injury compared to a fastball (Dun et al., 2008; Fleisig et al., 2006). There have been no studies that previously examined this question.

1.1. Purpose

Previous baseball literature has focused on a fastball pitch and the stretch delivery (very little research on the curveball in comparison to other pitches). Further studies have investigated the curveball by itself, but not in relation to any other pitch type. It is the purpose of this study to compare the lower extremity and upper extremity mean muscle activation patterns associated with the curveball pitch and the fastball pitch when pitching from the stretch position.

1.2. Hypothesis

We hypothesized that the muscle activation of the upper trapezius, lower trapezius, biceps brachii, triceps brachii, biceps femoris and gastrocnemius will show diverse activation patterns between the stretch fastball and stretch curveball during the pitching points. The muscle activity associated with the stretch fastball pitch will be significantly greater than when compared to the stretch curveball.

2. Methodology

2.1. Participants

Participants were chosen based on their current status as baseball pitchers. Participants were only considered if they were between the ages of 18–30, had no current pain that might hinder their ability to play baseball and had not had any injuries in the previous three months. The age, body height and body mass of each pitcher was recorded. Participants ranged in age from 18 to 30, mean height was 1.74 m and body mass was 89 kg. There were nine right-handed pitchers and three left-handed pitchers that participated in this research study (see Table 1).

2.2. Maximum voluntary isometric contraction testing

An MVIC (Hermens et al., 2000) for each muscle being studied was obtained for each participant prior to completing the pitching analysis. The muscles tested have been reported to be the most important for baseball pitching (Jobe et al., 1984, 1983; Oliver and Keeley, 2010a, 2010b; Oliver et al., 2018; Yamanouchi,

1998). Each participant had bipolar surface electrodes placed over the stride leg biceps femoris and medial gastrocnemius. Bipolar electrodes were placed on the ipsilateral side (throwing arm side) lower trapezius, upper trapezius, triceps brachii (long head) and biceps brachii. A ground electrode was placed over the patella. Prior to electrode placement, the skin was shaved and cleansed to decrease electrical impedance. After the placement of the electrodes, muscle specific tests were conducted to find the MVIC. Each MVIC test consisted of one familiarization test followed by three actual trials. Table 2 shows the six muscles tested, placement of the electrodes on the muscles and the MVIC test performed (Hermens et al., 2000). Locations for electrode placement and the test to calculate MVIC based on SENIAM guidelines (Hermens et al., 2000). All the EMG data acquired for each of the muscles were collected for the duration of the pitch (first moment of movement to the conclusion of the follow through). This was further broken down into the individual pitch points (described in the following paragraph).

The pitch was broken down into four points: foot contact (FC), maximal external rotation (MER), ball release (BR) and maximal internal rotation (MIR). The wind-up begins with the initial movement of the contralateral lower extremity and it culminates with the elevation of the lead leg to its highest point with separation of the throwing hand from the glove. The pitcher's center of gravity was over his back leg. The stride phase begins once the lead leg reaches its maximum height, the ball was removed from the glove, and this phase ends when the lead leg was in contact with the pitching mound (FC). The cocking phase occurs between lead foot contact with the mound and the point of maximal external rotation of the throwing shoulder (MER). The acceleration phase was the time between the maximal external rotation of the shoulder and the release of the ball (BR). Arm deceleration occurs from when the ball was released and maximum internal humeral rotation and elbow extension. Follow through was when the body continues to move forward with the arm until all motion has ceased (MIR) (Fleisig et al., 1995; Werner et al., 1993).

2.3. Pitching analysis

Prior to performing the fastball and curveball pitching sequences, each participant was fitted with a standardized neutral running shoe (Nike, 602171404, Beaverton, OR) to wear for the duration of the data collection. Kinematic data were collected to allow for time syncing the EMG activity for the duration of the pitch points. The motion capture component of the pitching analysis was completed using 6 Eagle and 4 Raptor Motion Analysis cameras (Motion Analysis Corp, Santa Rosa, CA) recording at 200 Hz. The participants pitched into a net placed inside the lab while pitching from a mound. A warm-up period of 10 pitches allowed the participants to become acclimated to the lab (Fleisig et al., 1996, 1995). Prior to these 10 warm-up pitches, the participants could warmup as much as they wanted outside of the laboratory. Participants were then instructed to pitch ten times from the stretch position. Five of the pitches from the stretch position were pitched as a fastball while the other five were pitched as a curveball. For this study, only the pitches from the stretch position were included in the analysis. All the pitchers were familiar and comfortable with pitching both a fastball and curveball, as well

Table 1
Demographic data (Mean \pm SD) for age, height, mass and pitching arm.

Subject Number	Age (years)	Height (m)	Mass(kg)	Right Handed	Left Handed
12	22.3 \pm 4.53	1.74 \pm 0.13	89.0 \pm 10.97	9	3

Table 2

List of muscles tested, placement of electrodes and specific test to obtain MVIC (Hermens et al., 2000).

Muscle	Location of Surface Electrode	MVIC Test
Lower Trapezius	The electrode was placed at 2/3 on the line from the trigoum spinea to the 8th thoracic vertebra, in the direction of the line between T8 and the acromion	Depression, lateral rotation of the inferior angle and adduction of the scapula. The arm was placed diagonally overhead with the shoulder laterally rotated. Applied pressure against the forearm in the downward direction
Upper Trapezius	The electrode was placed at 50% on the line from the acromion to the spine on vertebra C7, in the direction of the line between the acromion and the spine on vertebra C7	Elevated the acromial end of the clavicle and scapula; extended and rotated the head and neck toward the elevated shoulder. Applied pressure against the shoulder in the direction of depression and against the head in the direction of flexion anterolaterally
Triceps Brachii	The electrode were placed at 50% on the line between the posterior crista of the acromion and the olecranon at 2 finger widths medial to the line	Extended the elbow while applying pressure to the forearm in the direction of flexion
Biceps Brachii	The electrode was placed on the line between the medial acromion and fossa cubit at 1/3 from the fossa cubit	Placed one hand under the elbow to cushion it from table pressure and flexed the elbow slightly below or at a right angle, with the forearm in supination. Pressed against the forearm in the direction of extension
Biceps Femoris	The electrode was placed at ½ of the line between the ischial tuberosity and the lateral epicondyle of the tibia	Leg curl against resistance at the ankle
Gastrocnemius	Electrode was placed at 1/3 of the line between the head of the fibula and the heel.	Plantar flexion of the foot with emphasis on the pulling the heel upward more than pushing the forefoot downward.

as throwing them on a regular basis. The motion capture system collected marker trajectories during each pitch.

2.4. Data processing

Raw sEMG signal were filtered using a fourth order low-pass Butterworth filter with a cut-off frequency of 13 Hz, rectified, then passed through a high-pass Butterworth filter followed by using a finite impulse response with 101 points using Hamming window and smoothed with a root-mean-square moving average of 10 ms per window. MVIC values were obtained using a 100 ms window to find the highest average of each trial and then averaged together (Hermens et al., 2000). sEMG data obtained during the pitch were analyzed to find the mean muscle activity using the MVIC obtained for each muscle of each specific participant for three pitches and then averaged. Data were then averaged for each pitch to compare.

2.5. Statistical analysis

Mean muscle activity were compared using a repeated measure analysis of variance with a Sidak confidence level adjustment. A Mauchly's Test of Sphericity was conducted for all peak and mean muscle activity as well. If significance was found a pairwise analy-

sis (Bonferroni) was performed to establish between which pitch type and pitch delivery the significance was occurring. All statistical analysis was performed using SPSS statistical software (SPSS Inc., Chicago, IL) with a significance level of $p < 0.05$.

3. Results

Mean values and the standard deviations of muscle activation (% MVIC) are presented in Fig. 1 for the fastball and curveball thrown from the stretch position for the following muscles: biceps brachii, triceps brachii, upper trapezius, lower trapezius, gastrocnemius and biceps femoris. All the mean muscle data are represented in terms of % MVIC. If the repeated measures' analysis of variance (Mauchly's test of Sphericity) ran for the mean muscle activity showed significance, further analysis was performed with a pairwise Bonferroni analysis. The pitch (Fig. 2) was broken down into the four pitch points (foot contact (FC), max external rotation (MER), ball release (BR) and max internal rotation (MIR) (the stars indicate a significance differences with a value of $p < 0.01$).

3.1. Foot contact

There was a significant increase in the mean muscle activation of the triceps brachii, upper trapezius, lower trapezius, biceps femoris, and gastrocnemius for the stretch fastball compared to the stretch curveball at the foot contact pitching point. These results can be seen in Fig. 1.

3.2. Maximal external rotation

The mean muscle activation for the biceps brachii, upper trapezius, lower trapezius, biceps femoris and gastrocnemius were significantly greater for the stretch fastball when compared to the stretch curveball. No significance was found for triceps brachii mean muscle activity. These results can be seen in Fig. 1.

3.3. Ball release

A significant increase was observed in the mean muscle activation for the biceps brachii, triceps brachii, upper trapezius, lower trapezius, biceps femoris, and gastrocnemius for the stretch fastball when compared to the stretch curveball. These results can be seen in Fig. 1.

3.4. Maximal internal rotation

The stretch fastball had a significant increase in the mean muscle activation of the biceps brachii, triceps brachii, lower trapezius and biceps femoris when compared to the stretch curveball. There was no significant difference found for the upper trapezius or gastrocnemius. These results can be seen in Fig. 1.

4. Discussion and implications

The purpose of this study was to compare the lower extremity muscle and upper extremity muscle activity patterns associated with the curveball pitch and the fastball pitch from the stretch position. The discussion is further broken down into the two pitch types: fastball and curveball.

4.1. Stretch fastball

The stretch fastball had a significant increase in muscle activation in four or more of the six muscles in all the four pitching points ($p < 0.01$). For the mean muscle activation of the biceps

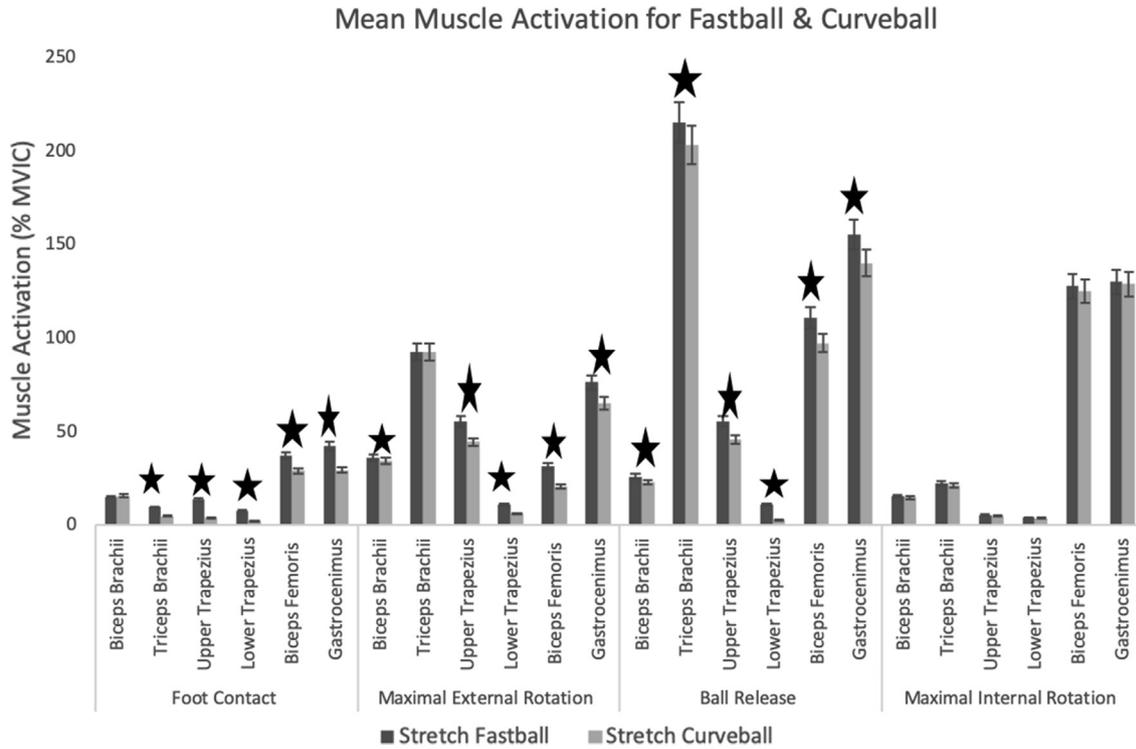


Fig. 1. Mean muscle activation for fastball and curveball.

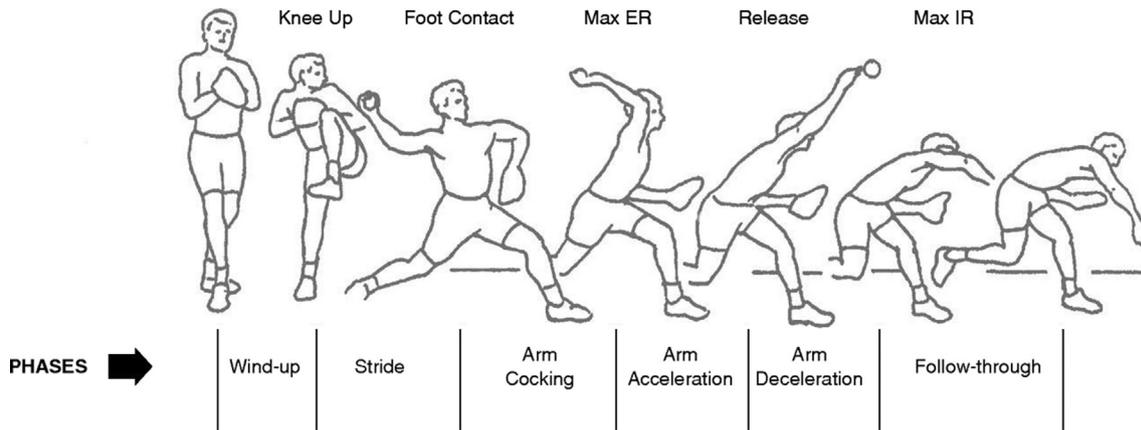


Fig. 2. Pitching phase figure (Fleisig et al., 1995).

brachii, the stretch fastball had a significant increase for maximal external rotation point, ball release point and maximal internal rotation point points ($p < 0.01$). For the triceps brachii, the stretch fastball had a significant increase in muscle activity during the foot contact, ball release, and maximal internal rotation points ($p < 0.01$). The upper trapezius had a significant increase in muscle activity for the stretch fastball during the foot contact, maximal external rotation, and ball release points ($p < 0.01$). A significant increase in muscle activity was also seen for the foot contact, maximal external rotation, ball release and maximal internal rotation points for the lower trapezius points ($p < 0.01$). The biceps femoris showed a significant increase in the muscle activity for the stretch fastball at foot contact, maximal external rotation, ball release, and maximal internal rotation points ($p < 0.01$). The gastrocnemius had a significant increase in mean muscle activity for the foot contact, maximal external rotation, and ball release points ($p < 0.01$).

4.2. Stretch curveball

The stretch curveball had no significant difference in the mean muscle activation from the stretch fastball for the biceps brachii at foot contact, triceps brachii at maximal external rotation, and gastrocnemius at maximal internal rotation.

4.3. Overall discussion

In agreement with Werner et al. (1993) the biceps brachii muscle activation was increased for a fastball pitched from the stretch when compared to the curveball. This muscle activity finding by Werner et al. (1993) was in support of the biceps brachii muscle activity and triceps brachii muscle activity seen in this current study. The findings from the current study are in agreement with the results from Jobe et al. (1983) that the triceps muscle activity can be observed to be over 200% of the MVIC amount whereas

the biceps brachii activity stays relatively close to a peak value of 33–36% of the MVIC (Jobe et al., 1983). In a previous conducted study on throwing, the triceps brachii were suggested to help facilitate the prevention of excessive elbow flexion and control for the movement of the elbow while also allowing for rotation at the shoulder (Roberts, 1971). A larger amount of muscle activation in the triceps brachii and biceps brachii when throwing a fastball may be indicative of the larger load and increased moment found for the elbow and shoulder in a previous study (Nissen et al., 2009). The curveball for all six of the muscles tested was found to have a lower or significantly lower amount of muscle activity ($p > 0.01$) when compared to the fastball. This lower muscle activation seen in the curveball may be in support of the lower moments and loads placed on the shoulder and elbow that was reported in a previous study (Nissen et al., 2009). This decrease in load, muscle activation, and moment at the shoulder and elbow for a curveball is in support of the idea that this pitch type alone does not directly increase the risk of injury (Nissen et al., 2009).

A pitcher must have enough muscular strength in order to maintain proper pitching mechanics. Previous research has reported a fluctuation in the activity of the gastrocnemius and biceps femoris throughout the pitching cycle (Campbell et al., 2010), and the current study found similar fluctuations in the mean and peak muscle activity for the same muscles during the pitching motion. In the current study, the increase in muscle activity and large normalized activation levels indicate that the biceps femoris and gastrocnemius play a role in dynamic muscle strength that is needed to throw an effective pitch, and the activity of these muscles warrants more attention in future studies that examine pitching. Research has found that the muscle activation from the lower extremity will dictate the amount of muscle activation utilized in the upper extremity while pitching (Campbell et al., 2010; Keeley et al., 2015; Nakata et al., 2013). This significant increase in the activity of the biceps femoris and gastrocnemius for the fastball when compared to the curveball may have a high association with the increase in upper extremity muscle activation and in turn lead to a larger load and moment at the elbow and shoulder while pitching.

This is the first research study that has specifically looked at the curveball and fastball when thrown from the stretch in relation to the muscle activation patterns of both the upper and lower extremities. The previous research that was discussed in the introduction led to the conclusion that the muscle activation patterns for successfully completing a baseball pitch must follow a proximal to distal pattern. It was also discussed that muscles will be active at different parts of the pitch (during different phases and points) to efficiently be able to pitch a baseball. This current study agrees with all the previous research that there is a proper pitching muscle activation that must be completed to accurately pitch a baseball. However, this study also examined the muscle patterns for both a fastball and a curveball to determine if there are differences in muscle activation patterns between the two pitches. The results revealed that both the curveball and the fastball followed the same pattern of muscle activation, but there was a significantly greater amount of muscle activity (% MVIC) for the fastball when compared to the curveball ($p < 0.01$). The significant increase in the activity of the lower extremity muscles for the fastball is likely connected to the significant increase in upper extremity muscle activation. The higher level of muscle activity reported for the fastball in the current study may explain the increase in joint load and joint moment that was reported in previous studies for the fastball (Nissen et al., 2009). These findings are contrary to the belief of most coaches and baseball pitchers that the stretch fastball would have a lower amount of muscle activation when compared to the curveball. A common misconception in baseball is that when a curveball is pitched, there is an increase in the risk of injury to

the shoulder and elbow. This study, as well as previous studies that have examined the fastball, demonstrate that greater demands are placed upon the soft tissue structures of the shoulder and elbow when throwing a fastball compared to a curveball.

(Dun et al., 2008; Fleisig et al., 2006; Nissen et al., 2009). Although an increase in muscle activity cannot directly lead to an increased risk for injury, it is a factor that should be investigated further. For coaches and pitchers, it could indicate a need to throw a wider range of pitches in a game or practice versus always throwing a fastball, and to focus on improving the strength and endurance of these specific muscles.

5. Conclusion

This has been the first study to examine two different pitch types and how the activity of selected muscles may differ during these two types of pitches. Based on the findings from this study, muscle activity does contribute to the differences seen in pitch type. Significant differences were seen in mean muscle activity for the biceps brachii, triceps brachii, upper trapezius, lower trapezius, gastrocnemius and biceps femoris. These findings are in agreement with the results from Jobe et al. (1984) that the triceps brachii muscle activity can be observed to be over 200% of the MVIC amount whereas the biceps brachii muscle activity stays relatively close to a peak value of 33–36% of the MVIC. The implication of an increase in muscle activity and greater than 100% MVIC indicate that the lower extremity muscles are beneficial for the pitching motion and should be examined in future literature as they play a role in the dynamic muscle strength needed in order to complete a pitch from a stretch position. Since different muscle activation patterns were found between the two pitch types, coaches should consistently monitor their pitchers to make sure they are using proper mechanics while throwing a fastball and curveball from the stretch position. For researchers, additional research should be conducted on the muscle activation levels and patterns during different types of pitches. This study was able to provide a baseline measurement of comparing the fastball and the curveball the stretch, however, kinematics and kinetics should be measured in future studies for a broader understanding of the different pitch types.

Declaration of Competing Interest

We know of no conflicts of interests that are associated with this publication, and there has been no significant financial support for this work that could have influenced the outcome.

Acknowledgments

I would like to thank David Smidebush and Michael Stewart for their help in the construction of the pitching mound that was used in this study.

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