Decreased Shoulder and Elbow Joint Loads During the Changeup Compared With the Fastball and Curveball in NCAA Division I Collegiate Softball Pitchers

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Background: Baseball leagues have implemented pitch count and pitch type restrictions based on biomechanical concepts associated with pitch type. Softball has not yet adopted these practices, although softball pitchers continue to pitch at a high volume and learn multiple pitches at a young age.

Purpose: To examine shoulder and elbow kinetics between the fastball, curveball, and changeup, as well as to provide descriptive upper extremity pain data in National Collegiate Athletic Association (NCAA) softball pitchers.

Study Design: Descriptive laboratory study.

Methods: Study participants consisted of 27 female NCAA Division I softball pitchers (age, 20.2 ± 1.9 years; height, 175.7 ± 5.7 cm; weight, 83.6 ± 12.7 kg). The participants pitched 3 balls of each pitch type, and kinetic data were recorded. A one-way within-participants repeated-measures multivariate analysis of variance was used to determine significant differences in kinetics and pitch speed between pitch types.

Results: Results revealed a statistically significant main effect for pitch type (Wilks $\lambda = .087$; $F = 36.523$; $P < .001$). Post hoc testing showed that the changeup produced less anterior elbow force compared with the fastball ($P < .001$) and the curveball ($P = .012$). In addition, the changeup produced less shoulder distraction force compared with the fastball ($P < .001$) and the curveball ($P = .001$). Additionally, there was a significant difference in pitch speed between all 3 pitch types ($P = .006$). The curveball revealed no statistically significant kinetic differences compared with the fastball.

Conclusion: The fastball and curveball placed similar stress on the upper extremity in collegiate softball pitchers. However, in comparison with the changeup, the fastball and curveball placed increased stress on the upper extremity. More research is needed to fully explain the differences seen between pitch type and injury risk.

Clinical Relevance: Sports medicine professionals, coaches, and athletes should use the current study results to note these differences in shoulder distraction and elbow anterior forces between softball pitch types. The study results can be used as a reference and basis for future research investigating kinetic differences across varying pitch types.

Keywords: kinetics; pitch types; windmill softball pitching

Softball pitching is a strenuous task and is therefore associated with high injury rates. In a prospective cohort study of high school softball athletes, it was found that 61% of injuries directly attributed to pitching involved the upper extremity.[36] Most arm injuries in softball are an accumulation of stresses from repetitive pitching events.[3,12,13,23,26,30,34,39] Though injury rates in softball are comparable with those of baseball,[12,27-29,31,34] there are no imposed regulations regarding pitch volume, inning limitation, or consecutive game exposure like those implemented in baseball. Unlike baseball, softball teams typically rely on 1 pitcher for an entire season, and it is common for a single pitcher to throw multiple games within a single day for 2 to 3 consecutive days.[35] In addition to regulations regarding pitch counts for youth pitchers, baseball governing bodies have also made recommendations concerning pitch types that advise against off-speed breaking pitching until proper fastball mechanics have been achieved.[7,9,24,25] These concerns regarding pitch types are the result of the increased shoulder and elbow injury occurrence in youth baseball

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pitchers.[7,9,24,25] Despite large participation, extreme pitch volume, consecutive days of pitching, and high injury rates, windmill pitch kinetic mechanics and different pitch types have not yet been investigated in youth softball pitchers.

As upper extremity injury rates increase in softball,[12,28,34] it is important to understand how windmill pitch biomechanics are affected by different pitch types and how these factors influence injury in the throwing shoulder and elbow. Though research regarding the mechanics of the windmill pitch is evolving, there is still a need to further examine windmill pitching biomechanics, joint loads, and injury susceptibility. The limited data in the existing softball literature indicate that trunk kinematics vary among pitch type.[5] Most prior investigations have focused on descriptive kinematic and kinetic data while pitching the fastball,[4,16,40,41] with a small number of studies examining select trunk and shoulder kinematics and kinetics in relation to pain prevalence for the rise-ball and changeup pitches.[17-19] Therefore, there are limited data examining joint loads about the upper extremity and pain prevalence across multiple pitch types.

As most overuse softball injuries involve the upper extremity in pitchers,[23,33,35] further investigation into the joint loads occurring at the shoulder and elbow is warranted. Therefore, the purpose of this study was to examine shoulder and elbow kinetics between the fastball, curveball, and changeup, as well as to provide descriptive upper extremity pain data in collegiate softball pitchers. It was hypothesized that the curveball would elicit the greatest amount of shoulder and elbow kinetics due to the mechanical nature of this pitch.

METHODS

A total of 27 female NCAA Division I softball pitchers (age, 20.2 ± 1.9 years; height, 175.7 ± 5.7 cm; weight, 83.6 ± 12.7 kg) from across the United States were recruited to participate. Recruitment was targeted to the softball schedule of Auburn University, specifically those teams who traveled to the university to compete. Inclusion criteria required that all participants (1) were actively competing on their team's roster as a pitcher, (2) had to be injury- and surgery-free during the past 6 months, and (3) have no history of surgery to the pitching arm. Injury was defined as being diagnosed by an athletic trainer or physician resulting in time lost from practice or competition. All testing protocols were approved by an institutional review board, and informed written consent was obtained from each participant before data collection.

On the day of testing, participants reported to the Sports Medicine and Movement Laboratory before engaging in any throwing or vigorous physical activity. A health history questionnaire was completed asking the questions, "Do you currently experience any pain?" and "If yes, where is your pain?"[17-19] Kinetic data were collected using an electromagnetic tracking system (Flock of Birds; Ascension Technologies Inc). A total of 14 electromagnetic sensors were attached to the participants using previously established methodologies.[18,22]

Digitized joint centers for ankle, knee, hip, shoulder, T12-L1, and C7-T1 were used to develop a linked segment model.[20,21,43,44] The global axis system was based on the fact that all participants were right-handed. The positive Y-axis was in the vertical direction; anterior to the Y-axis and in the direction of movement was the positive X-axis; and orthogonal and to the right of the X- and Y-axes was the positive Z-axis. All participants were right-handed. Raw data regarding sensor positioning and orientation were transferred from the global system to a locally based coordinate system. Euler angle sequences consistent with the International Society of Biomechanics standards and joint conventions were used to define position and orientation of the body segments.[43,44] Trunk motion was relative to the global axis using the Euler sequence of $ZX'Y''$, shoulder motion was relative to the trunk utilizing the Euler sequence of $YX'Y''$, while the elbow motion was relative to the humerus and defined using the Euler sequence of $ZX'Y''$. All raw data were independently filtered along each global axis using a fourth-order Butterworth filter with a cutoff frequency of 13.4 Hz.[20,21,42]

Following sensor setup, each participant was given an unlimited time to perform their individual prethrowing warmup (mean time, 7 minutes). Testing required each participant to throw 3 fastballs, 3 curveballs, and 3 changeups to a catcher located at regulation distance (43 ft [13.11 m]). Fastballs are pitches that typically have no change in trajectory, while curveballs typically curve along the horizontal plane in the direction away from the pitching arm. Changeups are thrown so that there is less pitch speed in an attempt to confuse the batter. A pitch was deemed successful and the trial was saved if the ball was in the strike zone, as determined by the catcher. Pitch speed was recorded to the nearest mile per hour using a calibrated radar gun (Stalker Pro II; Stalker Radar).

Two kinetic parameters were calculated with The MotionMonitor software (Innovative Sports Training) as previously described.[2,7-11,17,18,37,38] Kinetic parameters were calculated as maximal external mass normalized

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Ethical approval for this study was obtained from Auburn University (protocol No. 15-474 EP 1512).

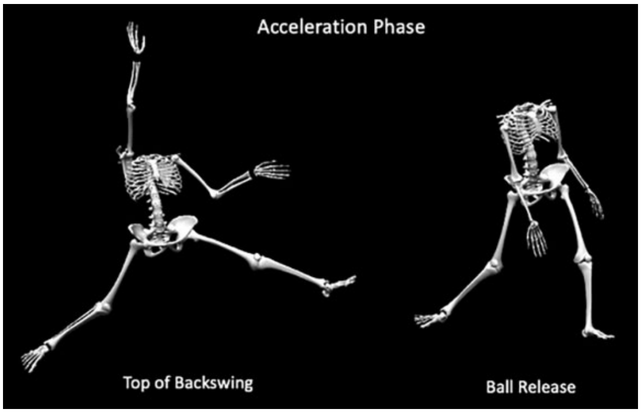

Figure 1. Acceleration phase of a softball pitch as seen using MotionMonitor Software.

TABLE 1
Health History Questionnaire Answers

Question	No. of Pitchers
"Do you currently experience any pain?"	
No	14
Yes	13
"If yes, where is your current pain?"	
Upper extremity	4
Lower extremity	4
Multiple places	5

forces during the acceleration phase and included elbow anterior force and shoulder distraction force of the pitching arm. Data were analyzed during the acceleration phase, as research has established this phase exhibits the largest throwing arm forces and torques throughout the pitch.[1,18,41] The acceleration phase is defined as the duration of time from the top of the backswing to ball release (Figure 1). Specifically, we extracted peak values of elbow anterior and distraction force during this phase. The large anterior force seen near the end of the acceleration phase is larger than any observed posterior elbow force.[4]

Statistical Analysis

A one-way within-participants repeated-measures multivariate analysis of variance was used to determine significant differences in kinetics and pitch speed between pitch types (fastball, curveball, and changeup) using SPSS statistical software (SPSS 25; IBM Corp).

RESULTS

Answers from the health history questionnaire can be found in Table 1.

Results revealed a statistically significant main effect for pitch type (Wilks $\lambda = .087$; $F = 36.523$; $P < .001$). Post hoc testing revealed a significant difference for elbow anterior force between the fastball and changeup ($P < .001$) and between the curveball and changeup ($P = .012$). Additionally, for shoulder distraction force there was a significant difference between the fastball and changeup ($P < .001$) and the curveball and changeup ($P = .001$). There were no significant kinetic differences between the fastball and curveball. Results also revealed a significant difference in pitch speed between the fastball and curveball ($P = .006$), fastball and changeup ($P < .001$), and curveball and changeup ($P < .001$) (Table 2).

TABLE 2
Kinetic Differences Between Pitch Types[a]

Variable	Fastball[b]	Curveball[c]	Changeup
Elbow anterior force, N/kg	4.76	4.13	3.15[b,c]
Shoulder distraction force, N/kg	10.71	10.12	8.84[b,c]
Pitch speed, miles/h (km/h)	56 (90)	55 (89)[b]	42 (68)[b,c]

[a]External shoulder force: compression (–) distraction (+); external elbow force: anterior (+) posterior (–).
[b]Statistically significant difference compared with fastball.
[c]Statistically significant difference compared with curveball.

DISCUSSION

The primary purpose of this study was to examine shoulder and elbow kinetics between the fastball, curveball, and changeup, as well as to provide descriptive upper extremity pain data in collegiate softball pitchers. The study results provide insight into the varied kinetics experienced at the elbow and shoulder between different pitch types and can inform practice surrounding the use of these pitches in softball pitchers. The results of the study were in partial agreement with our hypothesis that the curveball, due to the mechanical nature of the pitch, would cause increased kinetic values more than the fastball and changeup. While the curveball did elicit significantly higher elbow anterior force and shoulder distraction force than the changeup, the same was true for the fastball. Although, there were no significant kinetic differences between the fastball and curveball, there were significant differences in pitch speed between each pitch type, with the fastball being the fastest, and the changeup being the slowest.

Previous research examining softball pitchers has reported an association between increased injury risk and increased kinetic values. Therefore, it can be suggested that pitches that accrue less force at the shoulder and/or elbow may be safer to throw. As a result of the fastball revealing greater shoulder distraction force and anterior elbow force compared with the changeup, it may be suggested that the changeup might cause less stress on the throwing arm. Distraction force is becoming a more-suspected culprit of the throwing shoulder pain exhibited by many softball pitchers. This force is particularly present during the acceleration phase of the pitch, while the throwing arm is undergoing rapid circumduction and is behind the plane of the body.[14] Anterior elbow stress, while not currently discussed in softball throwing literature, can also be anticipated as problematic for pain in pitchers. Again, during the acceleration phase, the force is directed anteriorly onto the elbow, stressing extension at the elbow joint. While the elbow joint extends some during the acceleration phase, it is also responsible for providing flexion near ball release.[41] Increased anterior elbow stress may inhibit a pitcher from properly flexing their elbow near ball release and it may increase the stress of elbow flexors, such as the biceps brachii, which are already particularly susceptible to injury.[6,32] Further research is needed to examine elbow position and pain throughout the windmill pitch, to better identify how certain pitch types may predispose an athlete to a higher risk of injury.

The difference in elbow and shoulder kinetics between pitch types may likely result from lower pitch speed in the changeup compared with the fastball and curveball. Previous studies have found lower pitch speed related to decreased forces[15] and, therefore, could be the link between lesser shoulder distraction and anterior elbow force displayed during the slowest pitch–the changeup. Although pitch speed has previously been related to increased kinetics, sports medicine practitioners need to understand it is unlikely that a pitcher will want to decrease performance (lower pitch speed) to lessen injury risk. Therefore, pitchers and sports medicine practitioners must be able to balance increased workload (increase pitch speed) and injury risk through other modifiable factors, such as musculature strength and proper mechanics, or by imposing guidelines, similar to what has been done in baseball. More research is needed to fully explain the differences seen between pitch type, but our study results suggest the changeup does not increase risk of upper extremity injury in softball pitchers. There were no significant kinetic differences between the fastball and curveball, suggesting that these pitches place similar stress on the upper extremity. While baseball studies have stated that youth pitchers report higher pain measures associated with breaking ball pitches, it is important to understand the different vernacular of pitch types per sport. Within softball, curveballs are normally slower than fastballs, while changeups are noticeably slower than fastballs. In baseball, breaking balls are displayed on a spectrum of speed and can be most closely related to changeups in softball. As a result, baseball and softball findings among different pitch types are in contrast. While slower pitches in baseball are most commonly associated with pain, the current study found changeups to elicit smaller kinetic values, which are shown to be less associated with pain.[18] Therefore, while breaking ball pitches may be avoided among young baseball pitchers, softball pitchers might look to develop changeups as a first specialty pitch. To better inform athletes and coaches on the risks associated with certain pitch types, future research should examine throwing shoulder and elbow torques to determine if these variables display larger differences between other pitch types, such as the rise- or drop-ball, in youth softball pitchers.

Due to the inadequate sample size of reported pain, the authors cannot make definitive associations between kinetics and pain. However, descriptive data again highlights the high number of pitchers who experience pain while pitching. While research points to overuse being a common mechanism of pain, it may be difficult to determine which pitch is causing the most pain, while pitch types are frequently mixed in both practice and game situation. Further research needs to be conducted to better understand how certain pitch types might influence measures of pain. More research is also needed to prospectively track pitch biomechanics with measures of pain.[21] It is possible that pitchers with throwing arm pain conduct less advantageous mechanics, such as a decreased arm circle speed, in an attempt to alleviate pain. This decreased arm circle speed may result in decreased external forces at both the shoulder and elbow. It is unknown if these decreased forces during the acceleration phase are a subsequent response to the upper extremity pain or a cause of the pain.

Limitations

The limitations of this study include the cross-sectional study design, the laboratory setting, and the population used. First, the cross-sectional design of the study disallows us to fully analyze pain measures and softball kinetics. Therefore, the kinetics observed per pitch type may be in response to pain or the cause of pain. Second, the laboratory setting in which data were collected may not be able to accurately simulate an in-game intensity and may lack the competitive aspect as experienced on the field. As a result, the pitchers may present altered biomechanics within the laboratory setting. Third, participants in this study included only collegiate pitchers; therefore, it is unknown if the results of the current study can be applied to various skill and age levels. Younger pitchers' pitch types may present altered differences because their specialty pitches are less developed. These preliminary findings warrant an investigation into other kinetic parameters. Investigating whole-body kinematics and kinetics and the relationships with pain would also be beneficial.

CONCLUSION

The fastball and curveball place similar stress on the upper extremity in collegiate softball pitchers, while the changeup presents the least amount of upper extremity stress. As a result, it might be suggested that pitchers focus on developing a successful changeup as a first specialty pitch, to avoid potentially harmful kinetics. Sports medicine professionals, coaches, and athletes should use the current study results to note these differences in shoulder distraction and elbow anterior forces between pitch types. Study results can be used as a reference for future research to investigate kinetic differences across varying pitch types. Additional research is needed to determine differences in injury risk and pain between pitch types.

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