Single-Leg Squat and Reported Pain in Collegiate Softball Pitchers

Katherine M. Everhart,* MS, Kenzie B. Friesen,† PhD, Nicole M. Bordelon,* PhD, Anthony W. Fava,* MS, Hillary A. Plummer,‡ PhD, David M. Shannon,§ PhD, and Gretchen D. Oliver,*|| PhD

Investigation performed at the Sports Medicine & Movement Laboratory, School of Kinesiology, Auburn University, Auburn, Alabama, USA

Background: Single-leg squat (SLS) performance is related to altered mechanics related to injury during the windmill softball pitch; however, it is unknown if SLS kinematics differ between softball pitchers with and without upper extremity pain.

Purpose/Hypothesis: The purpose of this study was to compare knee valgus, trunk rotation, trunk lateral flexion, and trunk flexion during an SLS in collegiate softball pitchers with and without self-reported upper extremity pain. It was hypothesized that those who reported upper extremity pain would show increased compensatory trunk and knee kinematics compared with those without pain.

Study Design: Controlled laboratory study.

Methods: A total of 75 collegiate softball players (mean age, 20.4 ± 1.7 years; mean height, 173.3 ± 7.7 cm; mean weight, 79.1 ± 11.6 kg) participated and were placed in pain (n = 20) or no-pain (n = 55) groups. Participants performed an SLS once per side. Kinematic data were collected at 100 Hz using an electromagnetic tracking system. A 2 (pain vs no pain) × 2 (descent vs ascent) × 2 (drive leg vs stride leg) mixed-design multivariate analysis of variance with Wilks lambda distribution was used to determine differences in drive-leg and stride-leg lower body mechanics between the descent and ascent phases of the SLS between the pitchers in the current study with and without pain.

Results: There was no significant effect in the 3-way interaction between upper extremity pain, side, and phase ($\Lambda = 0.960$; $F[4, 70] = 0.726$; $P = .577$; $\eta^2 = 0.04$). However, there were large effects for the phase × side interaction ($\Lambda = 0.850$; $P = .021$; $\eta^2 = 0.150$). There was a main effect of phase ($\Lambda = 0.283$; $P < .001$; $\eta^2 = 0.717$).

Conclusion: Study findings indicated that SLS mechanics do not differ between collegiate softball pitchers with and without reported upper extremity pain. Drive-leg mechanics showed more stability in the SLS than stride-leg mechanics.

Clinical Relevance: Softball pitchers are at risk of upper extremity injury. It is important to identify mechanisms that may lead to pain in order to mitigate the risk of injury.

Keywords: lumbopelvic hip complex; upper extremity pain; windmill softball pitch

According to previous injury surveillance programs observing National Collegiate Athletic Association (NCAA) softball, most injuries occur at the shoulder and involve pitching or throwing movements.[18,29] An optimal windmill pitch utilizes a full body dynamic movement that efficiently transfers energy through the kinetic chain to the upper extremity.[2,32] Energy across the kinetic chain is transferred in a proximodistal manner through the lower extremities, trunk, humerus, forearm, and finally hand to maximize velocity immediately before ball release.[14,17,19,31,32] The key link to efficient energy flow through the kinetic chain is a stable lumbopelvic-hip complex (LPHC).[1,6] The LPHC includes the proximal lower extremities, hips, pelvis, trunk, and surrounding musculature of the gluteus and abdomen.[1,10] The LPHC is responsible for 50% to 55% of kinetic energy generation and force in the throwing motion.[4,6] Inefficient energy generation in the proximal lower extremities and LPHC has resulted in compensation and altered mechanics in the distal upper extremity during explosive movements to maintain performance.[3,5,12,30] Additionally, it is known that over time, the undue stress the upper extremity experiences may lead to symptoms of upper extremity pain or overuse injury. Therefore, early identification of faulty movement patterns associated with upper extremity pain or injury risk is pertinent.

Several studies to date have associated performance on a single-leg squat (SLS) test to compensatory mechanics in pitching.[5,21,26] Wasserberger et al[30] reported that youth baseball pitchers who minimized knee valgus during the

The Orthopaedic Journal of Sports Medicine, 11(1), 23259671221144757
DOI: 10.1177/23259671221144757

SLS displayed less knee valgus at stride foot contact and at ball release. Prior literature using an SLS test within softball pitchers found links between SLS and pitch compensatory mechanics, with potential implications for pain development.[7] Other studies using an SLS test confirm the association between poor performance on an SLS test and susceptibility to upper extremity injury.[11,21,30] When an athlete is performing an SLS test, LPHC stability can be assessed based on measures of knee valgus, trunk rotation, trunk lateral flexion, and trunk flexion.[5] Thus, the SLS is identified as an analytic tool to observe LPHC stability.[7,29] The SLS has also been used as a tool to assess bilateral differences and implications for softball pitchers.

LPHC stability is vital for dynamic upper extremity movements such as pitching. While LPHC instability during pitching is known to cause overcompensation and greater dependence on the upper extremity, a direct comparison between SLS mechanics among those pitchers currently experiencing upper extremity pain and those who are pain-free has yet to occur. Since research currently indicates a link between poor SLS performance and pitch mechanics, there may be similar links between poor SLS performance and propensity for upper extremity pain during the windmill pitch. Because research has identified variables of knee valgus, trunk rotation, trunk flexion, and trunk lateral flexion to predict instability, these variables can be used to assess SLS function.

The purpose of this study was to compare knee valgus, trunk rotation, trunk lateral flexion, and trunk flexion during an SLS in collegiate softball pitchers with and without self-reported upper extremity pain. It was hypothesized that those who reported upper extremity pain would show increased compensatory trunk and knee kinematics during the SLS than those without pain.

METHODS

This study used a cross-sectional design that consisted of 75 NCAA Division I collegiate softball pitchers (mean age, 20.4 ± 1.7 years; mean height, 173.3 ± 7.7 cm; mean weight, 79.1 ± 11.6 kg). Data were collected during their competitive spring season. The institutional review board of Auburn University approved all testing protocols. Before collection, participants completed a survey indicating if they were currently experiencing upper extremity pain/discomfort. Participants simply answered "yes" or "no" and specified which part of their upper extremity was experiencing pain. If participants selected that they were experiencing upper extremity pain, they were placed into the pain group. Participants reported to the laboratory, and all procedures were explained to each participant and informed consent was obtained before data collection.

Testing Procedure

Fourteen electromagnetic sensors were placed onto the participant: (1) posterior trunk at the first thoracic vertebral (T1) spinous process; (2) posterior pelvis at the first sacral vertebra; (3-4) flat broad portion of the acromion, bilaterally; (5-6) upper arm at the deltoid tuberosity, bilaterally; (7-8) posterior distal forearm, bilaterally; (9) dorsal side of the dominant hand along the third metacarpal; (10-11) lateral thigh about midway between the greater trochanter and lateral condyle of the knee, bilaterally; (12-13) lateral shank midway between the lateral condyle of the knee and lateral malleolus, bilaterally; and (14) dorsal side of the nondominant foot, along the second metatarsal. A movable 15th sensor was attached to a stylus for digitization of bony landmarks on the participant. The digitized lateral and medial aspect of each joint and the midpoint between the lateral and medial aspect were used to create a linked segment model.[15,16,33,34] A previously established rotation method was used to estimate shoulder and hip joint centers.[9,28] Raw data regarding sensor position and orientation were independently filtered along each global axis using a fourth-order Butterworth filter with a cutoff frequency of 13.4 Hz.

After sensor attachment and digitization, participants performed an SLS on each leg. Participants were instructed to cross their arms over their chest, flex their nonstanding knee to 90°, and squat as low as possible while maintaining balance and an upright trunk (Figure 1). Once peak depth was attained, participants ascended back up to a standing position without letting their nontesting leg contact the floor or their other leg. Participants were not coached on the SLS, so as to not alter the participant's preferred movement pattern.[5] However, participants were able to practice the SLS until they felt comfortable enough to perform the test.

The SLS was marked at the following events: (1) start of descent, (2) maximum knee flexion, and (3) end of ascent.[30] The SLS was then divided into 2 phases: (1) descent phase, start of decent to maximum knee flexion; and 2) ascent phase, maximum knee flexion to end of ascent. Both the drive leg and stride leg were tested. The stride leg refers to the leg that undergoes ground foot contact just before ball release while pitching. Data were processed using MATLAB (Version 9.4.0.813654 [R2018a]; The

||Address correspondence to Gretchen D. Oliver, PhD, Sports Medicine & Movement Laboratory, School of Kinesiology, Auburn University, 301 Wire Road, Auburn, AL 36849, USA (email: goliver@auburn.edu).

*Sports Medicine & Movement Laboratory, School of Kinesiology, Auburn University, Auburn, Alabama, USA.

†Faculty of Kinesiology, University of Calgary, Calgary, Alberta, Canada.

‡San Diego Padres, San Diego, California, USA.

§Educational Research and Evaluation, Auburn University, Auburn, Alabama, USA.

Final revision submitted September 15, 2022; accepted September 26, 2022.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

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

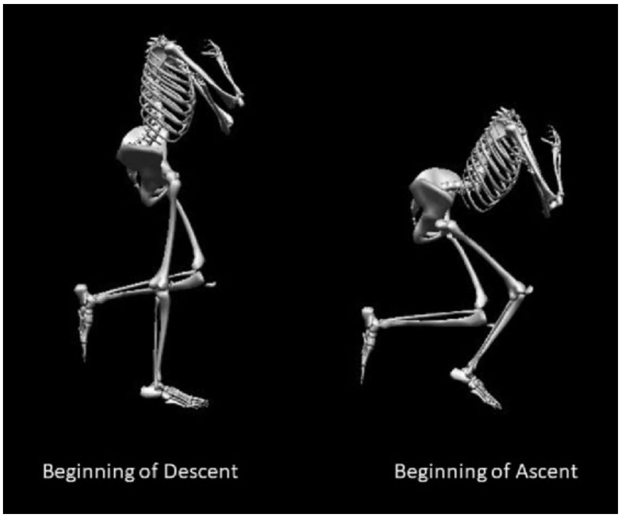

Figure 1. Digitized participant performing single-leg squat.

MathWorks) and were analyzed using SPSS (Version 28.0; IBM Corp). Peak knee valgus, trunk flexion, trunk lateral flexion, and trunk rotation toward the testing leg were extracted as variables for analysis.

Data Collection and Analysis

Kinematic data were collected using an electromagnetic tracking device (Flock of Birds; Ascension Technologies Inc) synchronized with The MotionMonitor software (Innovative Sports Training) at 100 Hz. The world axis was oriented with the Y-axis representing the vertical direction, the X-axis being anterior to the Y-axis and in the direction of movement, and the Z-axis orthogonal and to the right of the X and Y axes. The Euler sequence of $ZX'Y''$ was used for kinematic parameters. Position and orientation of body segments were in line with recommendations from the International Society of Biomechanics.[33,34]

A 2 $\times$ 2 $\times$ 2 (pain $\times$ side $\times$ phase) repeated mixed-design multivariate analysis of variance with Wilks lambda (Λ) distribution was used to determine differences in peak drive- and stride-leg lower body mechanics during the 2 phases of the SLS (descent and ascent) between collegiate pitchers with and without upper extremity pain. The between-participant factor was upper extremity pain, and the within-participant factors were side (drive leg and stride leg) and phase (descent and ascent). The alpha level was set a priori to .05.

RESULTS

Twenty athletes were placed in the pain group (mean age, 20.2 ± 0.17 years; mean height, 172.74 ± 0.97 cm; mean weight, 78.33 ± 1.59 kg), and 55 athletes were placed in the no-pain group (mean age, 20.95 ± 0.58 years; mean height, 174.89 ± 1.98 cm; mean weight, 81.08 ± 2.45 kg). There was no significant effect in the 3-way interaction between upper extremity pain, side, and phase on the combined dependent variables ($\Lambda = 0.960$; $F[4, 70] = 0.726$; $P = .577$; $\eta^2 = 0.04$). Effects and interactions associated with whether an athlete was experiencing pain were not statistically significant and resulted in small effect sizes. However, effects for the phase $\times$ side interaction were found ($\Lambda = 0.850$; $P = .021$; $\eta^2 = 0.150$). Table 1 provides a summary of the peaks associated with the significant interaction. There was also a main effect of phase ($\Lambda = 0.283$; $P < .001$; $\eta^2 = 0.717$).

TABLE 1
Peak Values of Kinematic Variables Between Side and Phase of the Single-Leg Squat[a]

Dependent Variable	Descent	Ascent
Drive leg		
Knee valgus	–6.51 ± 1.36[b]	–6.99 ± 1.38[b]
Trunk rotation	11.33 ± 5.67	10.3 ± 6.51
Trunk lateral flexion	–2.71 ± 1.25[b,c]	–21.73 ± 1.48[c]
Trunk flexion	–21.87 ± 1.45[c]	–3.04 ± 1.43[b,c]
Stride leg		
Knee valgus	–2.95 ± 0.96[b]	–3.7 ± 0.93[b]
Trunk rotation	9.04 ± 5.73	10.54 ± 5.77
Trunk lateral flexion	2.16 ± 1.25[b,c]	–21.87 ± 1.48[c]
Trunk flexion	–22.15 ± 1.45[c]	2.32 ± 1.56[b,c]

[a]Data are presented as mean ± SD.
[b]Statistically significant difference between sides ($P < .05$).
[c]Statistically significant difference between phases ($P < .05$).

Examination of phase differences by side revealed statistically significant differences by phases for both the drive and stride legs. During the descent of the SLS, knee valgus ($P = .028$; $\eta^2 = 0.188$) and trunk lateral flexion ($P < .001$; $\eta^2 = 0.188$) differed between sides. The stride leg had greater knee valgus (mean difference; 3.56°) and trunk lateral flexion (mean difference, 4.87°) than the drive leg during the SLS descent. During the ascent of the SLS, knee valgus ($P = .028$; $\eta^2 = 0.132$) and trunk flexion ($P = .006$; $\eta^2 = 0.132$) differed between sides. The stride leg had greater knee valgus (mean difference, 3.29°) and trunk flexion (mean difference, 5.36°) than the drive leg during ascent of the SLS.

When examining side differences within each phase, significant effects were found related to trunk lateral flexion and trunk flexion. Trunk lateral flexion differed between SLS phases for both the stride ($P < .001$; $\eta^2 = 0.710$) and drive ($P < .001$; $\eta^2 = 0.632$) legs. Similarly, trunk flexion differed between SLS phases for both the stride ($P < .001$; $\eta^2 = 0.710$)) and drive ($P < .001$; $\eta^2 = 0.632$) legs. During the drive-leg SLS, the ascent portion of the SLS produced more trunk lateral flexion toward the nondominant side than during the descent phase (mean difference, 19.03°). For the stride leg, the ascent portion of the SLS produced more trunk lateral flexion toward the nondominant side than during the descent phase (mean difference, 24.04°). The descent phase of SLS of the drive leg produced more trunk flexion than the ascent phase (mean difference, 18.84°). The descent phase of the stride leg produced more trunk flexion than the ascent phase (mean difference, 24.47°).

TABLE 2
Peak Values of Kinematic Variables Between Phases of the SLS Averaged Across Both Stride Leg and Drive Leg[a]

Dependent Variable	Descent	Ascent
Knee valgus[b]	–4.73 ± 1.16	–5.35 ± 1.16
Trunk rotation	10.19 ± 5.7	10.42 ± 6.14
Trunk lateral flexion[b]	–0.28 ± 1.25	–21.8 ± 1.48
Trunk flexion[b]	–22.01 ± 1.45	–0.36 ± 1.5

[a]Data are presented as mean ± SD.
[b]Statistically significant main effect of phase ($P < .05$).

There was a significant main effect of phase ($\Lambda = 0.283$; $F[4, 70] = 44.311$; $P < .001$) (Table 2). It was found that 3 of the 4 dependent variables varied between SLS phases (ascent and descent) (Table 2). Specifically, knee valgus ($F = 5.285$; $P = .024$; $\eta^2 = 0.717$), trunk flexion ($F = 147.735$; $P < .001$; $\eta^2 = 0.717$), and trunk lateral flexion ($F = 177.518$; $P < .001$; $\eta^2 = 0.717$) significantly differed between phases. There was more knee valgus (mean difference, 0.61°) and trunk lateral flexion (mean difference, 21.53°) and less trunk flexion (mean difference, 21.66°) during the descent phase than the ascent phase in the SLS.

DISCUSSION

The most important finding of this study was that pitchers with upper extremity pain had similar LPHC instability to pitchers without pain, as results identified similar knee valgus, trunk rotation, trunk lateral flexion, and trunk flexion mechanics during bilateral SLS. Secondary findings showed that all pitchers, regardless of pain status, showed significant movement deviations between phases of the SLS. Interestingly, drive-leg mechanics during the SLS showed more stability than stride-leg mechanics. Pitchers had slightly few movement deviations of knee valgus on their drive versus stride leg, and minimally fewer movement deviations, based on mean difference values, of trunk flexion and lateral flexion on their stride leg.

There are several reasons as to why both groups may have similar LPHC stability. Pain is multifactorial, with LPHC stability only accounting for one potential factor. Pinpointing the cause of pain can be important, as it is can be considered a future indicator of injury,[7] and there is a lack of scientific evidence regarding upper extremity injury risk factors in collegiate pitchers. In research examining pain and injury in pitchers, shoulder passive range of motion and pitch count throughout the season have been noted as important factors to consider. Prior research examining pain and injury in pitchers has noted large mean deficits in shoulder internal rotation range of motion and horizontal adduction range of motion between injured and noninjured pitchers.[13,24] Beyond range of motion deficits, workload is another important consideration since pitchers are often prone to overuse injuries from pitching multiple games in a row, over consecutive days.[25] Pitchers who suffered from injuries were shown to pitch more innings than their noninjured counterparts.[2] This is exhibited in a study conducted by Shanley and colleagues,[23] who reported that injured athletes pitched 55% more than noninjured pitchers during their season, highlighting the impact of high repetition and overuse on pain and injury development. These aforementioned studies provide evidence of the many factors that can cause upper extremity pain. However, the current study only looked at current pain, and perhaps altered mechanics will develop pain over time. Thus, the current study may have identified altered mechanics secondary to pain.

Regardless of the lack of significant differences between pain groups, there were differences noted between pitchers' drive- and stride-leg SLS kinematics, and between the descent and ascent phases of the SLS. These findings suggest there are asymmetries between pitchers' drive- and stride-leg stability as well as differences in stability between descent and ascent movements. The asymmetry in stability may not be surprising considering that the drive leg serves an important role in propelling the pitcher toward home plate.[20] Prior softball pitching research determined that drive hip external rotation isometric strength is positively related to energy flowing out of the distal trunk and humerus on the pitching arm side. It was suggested that drive hip strength influences energy flow through the kinetic chain and may contribute to enhancing performance.[20] In addition, certain kinematics observed during the SLS in the current study have been recently considered compensatory given that they are associated with weak musculature surrounding the LPHC.[4,21,27,30] Instability of the LPHC can manifest in greater deviations of knee valgus, trunk flexion, trunk lateral flexion, and trunk rotation during a dynamic movement.[5] Therefore, the current study's findings noting differences in kinematics between both sides and SLS phase were worth exploring.

During the descent of the SLS, pitchers exhibited more knee valgus and trunk lateral flexion, and less trunk flexion, than during the ascent of the SLS. Greater movement deviations observed during the downward portion of the SLS suggest that pitchers can control upward motion better than downward motion. While the softball pitch requires pitchers to maintain a single-leg stance by either their drive or their stride leg throughout the pitching motion, there could be similarities in style and performance between the SLS and pitch. Research has noted the compensation present in both the SLS and the pitch,[7] theoretically because of the single-leg nature of both motions. As a result, it might be suggested that pitchers are better apt to control their bodies during the propulsion of the pitch (ascent) than during the landing, when the body is descending upon foot contact. Therefore, injury preventative efforts should additionally examine the landing phase of the motion where the pitcher completes descent.

The current results also indicated there were bilateral differences between SLSs occurring on the drive and stride legs. The stride leg regains contact with the ground at foot contact of the pitch and is emphasized during the later portion of the pitch; meanwhile, the drive leg is largely involved with the propulsion of the pitch. The results indicate that the stride leg accrued more knee valgus and trunk lateral flexion during the descent of the SLS, and more knee valgus and trunk flexion during the ascent of the SLS, than the drive leg. This again might point to the stride leg being less competent in terms of controlling LPHC stability than the drive leg. The study conducted by Friesen and colleagues[5] in 2021 showed increased knee valgus at stride foot contact. Because of the nature of the pitch, athletes may have developed asymmetries in knee mechanics between their stride and drive legs over their years of pitching. Overall, the drive leg seems to exhibit more control than the stride leg when looking at phase by side. Given the importance of the drive leg to powerfully push the pitcher toward home plate, it is plausible that the drive leg may be stronger and have better musculature development. If so, this could explain why the stride leg exhibits greater compensations during the SLS than the drive leg. Gluteal and hip strength were not tested in the current study; therefore, future studies should consider hip strength and stability when examining injury risk factors to the upper extremity. Lack of hip strength and hip muscle activation in female athletes has been shown to correlate with greater lumbopelvic instability and increased knee valgus in single-leg tasks.[8,22]

This current study also revealed that the drive leg had more trunk lateral flexion and less trunk flexion during ascent of the SLS compared with the descent. Similarly, the stride leg had more trunk lateral flexion and less trunk flexion during the ascent compared with during the descent. In counteracting gravity to regain a standing tall position, these pitchers tended to lean laterally more so than on their descent or lowering phase of the SLS. Coincidentally, they also tended to perform more trunk flexion in the sagittal plane while lowering versus rising. Therefore, the authors concluded that pitchers in the current study adopt an anterior/posterior sway while descending and a lateral sway while ascending.

Limitations

There are some limitations to this study. Since prior SLS training experience was not required for participation, some participants may not have been familiar with the SLS movement. This may have contributed to poor mechanics rather than poor LPHC or trunk stability; however, pitchers were given the option to perform practice trials of the SLS before testing to account for the potential unfamiliarity with the test but were not coached to promote a natural movement pattern. Subsequently, a small number of participants reporting pain compared with those reporting no pain could also lead to nonsignificant relationship between pain and lower extremity and trunk kinematics during an SLS. The current study utilized the measure of current self-reported pain and did not track pitchers' upper extremity injuries over time. While self-reported pain can be a limitation, the authors believe that an athlete's perception of pain holds weight, as it can lead to compensatory mechanics in pitching. We recommend that this study be followed by a longitudinal study measuring LPHC stability before the season and comparing those who become injured with those that do not. Longitudinal tracking of injuries will help determine how LPHC instability can contribute to the development of pain or injury. Future research should aim to characterize the risk of poor LPHC and trunk stability on upper extremity injury. Other potential contributing factors should also be considered, such as muscular performance impairments, range of motion deficits at the shoulder, and pitch volume per season, to enable a comprehensive characterization of injury risk in collegiate softball pitchers.

CONCLUSION

Pain is multifactorial, and it has been suggested that lumbopelvic-hip instability may be a contributing factor. However, the current study reported that SLS mechanics do not differ between collegiate softball pitchers with and without reported upper extremity pain. The findings suggest that other factors may be contributing more to the presence of upper extremity pain. Regardless of pain status, drive-leg mechanics showed more stability than stride-leg mechanics.

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