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Single-Leg Squat Performance and Reported Pain within Youth Softball Players

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Abstract: The purpose of this study was to assess single-leg squat (SLS) performance on reported pain. Forty-two youth softball athletes (13.0 ± 2.0 years; 162.19 ± 9.75 cm; 60.80 ± 14.28 kg) completed a bilateral SLS and a health history questionnaire in which they indicated if they were currently experiencing any pain/discomfort. Due to the clinical significance of the current study, $p < 0.10$ was classified as nearing significance. A point-biserial correlation was run between the groups (pain and no pain) and all kinematic variables (maximal knee flexion, knee valgus/varus, vertical sacrum displacement, anterior pelvic tilt, and pelvic lateral tilt) at each event (45° descent, maximal knee flexion, and 45° ascent), across each phase (descent, ascent), and between legs. Increased vertical sacrum displacement was correlated with pain at 45° ascent and at maximal knee flexion in the right SLS. Knee valgus at maximal knee flexion, 45° ascent, and in the decent phase of the left SLS was significant. Anterior pelvic tilt in the decent phase of the left SLS and knee valgus and pelvic lateral tilt in the decent phase of the right SLS were found to be significantly correlated with pain. Poor SLS performance was correlated with reported pain.

Keywords: injury-prevention screening; lumbopelvic stability; overhead throwing

1. Introduction

Baseball and softball combined is the fourth most played high school sport in the United States [1]. Along with the sport's popularity comes the prevalence of and susceptibility to injury. Contrary to the lack of injury-prevention research in softball compared to baseball, softball injury rates have been found to be at least comparable to, if not higher than, those of baseball [2,3]. Additionally, injury patterns have been shown to vary between the sports [2–4]. While the majority of injuries in softball and baseball are to the upper extremity, softball players reportedly experience proportionally higher rates of injury to the lower extremity than baseball players [5]. Moreover, a greater proportion of softball injuries have been classified as a major injury or season-ending injury, compared with baseball and other female sports [5], thus suggesting injury susceptibility in the sport of softball could be greater than that reported in baseball. Likewise, softball athletes have been observed to suffer a greater proportion of sprains and dislocations than baseball athletes [5]. Such overuse injuries like sprains have been commonplace in youth athletics, as overuse injuries account for at least 50% of all youth sport-related injuries [6]. Injury severity and incidence data in youth softball suggest that most injuries are related to chronic mechanical deficiencies rather than acute trauma. With the high prevalence of severe and overuse injury in youth softball, injury prevention should be of high concern for sports medicine personnel; parents; and coaches.

Youth softball athletes are required to complete numerous near maximal effort overhead throws during practice and games. Such high repetition of a singular movement pattern may lead to overuse injury. Throwing is a complex dynamic movement that requires efficient use of the kinetic chain [7,8]. For the body to function as a kinetic chain, interdependent segments must work synchronously in a proximal to distal fashion. Specifically, force is generated in the proximal lower extremity and then transferred thorough the lumbopelvic-hip complex (LPHC), to the distal upper extremity, and on to the ball at release. Trunk musculature contributes to LPHC stability during the overhead throwing motion is important not only for postural control but to also generate and transfer force from the lower extremity to the upper extremity [8]. Due to the unilateral nature of the overhead throw, structural and mechanical asymmetries develop in overhead throwing athletes; meanwhile, such asymmetries may place athletes at a greater risk of injury. When considering the overhead throwing motion as a total body dynamic activity, awareness of segmental asymmetries that could result in kinetic chain alterations is needed. As any alteration in the kinetic chain could result in compensations and ultimately injury to the more distal segments in the chain [8].

One of the most documented segmental compensations within the kinetic chain is LPHC instability [8–12]. The LPHC serves as the connection between the lower and upper body and is a key component of energy transfer through the body, meaning pathomechanics at the LPHC may be a shared risk factor for upper and lower extremity injuries. Trunk and lower extremity pain have been correlated with upper extremity pain in youth baseball, softball, handball, tennis, badminton, and volleyball athletes [13], suggesting that the lower and upper extremities share injury risk factors. Due to the impact of the LPHC on not only the efficiency of the kinetic chain but also in pain and injury susceptibility, assessment of LPHC stability could prove valuable in injury-prevention strategies for throwing athletes.

Clinically, LPHC stability has been assessed and validated through the use of a single-leg squat (SLS) [7,14]. When considering the ability of the LPHC to stabilize both the lower extremity and trunk, clinicians commonly rely on the assessment of the SLS [15,16]. It has been found that the SLS squat test is a reliable assessment of LPHC strength and stability [11,16], plane specific knee mechanics, sport performance [9,14,17], and lower extremity pain [18]. Based on the dynamic nature of the overhead throwing motion and the need for proximal stability of the lower extremity and LPHC, utilization of the SLS as a mechanism of screening for injury susceptibility though the examination of pain prevalence could prove beneficial [8,10,11,14]. The SLS has been previously examined in various manners. Due to the highly dynamic tasks associated with sport, use of the SLS as a diagnostic tool must include dynamic motion. Therefore, it was the purpose of this study to investigate the associations between bilateral SLS performance and reported pain in youth softball athletes. We hypothesized that poor SLS performance will be positively associated with reported incidence of pain in youth softball athletes. Poor SLS performance was defined as increased anterior pelvic tilt, lateral pelvic tilt, and knee valgus angles, and decreased maximal knee flexion and vertical sacrum displacement.

2. Materials and Methods

Forty-two youth softball athletes (13.0 ± 2.0 years; 162.2 ± 9.7 cm; 60.8 ± 14.3 kg; 5.4 ± 0.5 years of experience) from the South East United States volunteered to participate. Participants were active softball players with a minimum of two years playing at a competitive level and all were right-handed. All participants considered softball as their primary sport and had no injuries or surgery within the past six months. Institutional Review Board of the University approved all testing protocols. Testing procedures were verbally outlined and explained, and informed written consent and assent were obtained from each participant and parent/guardian prior to any data collection.

Kinematic data were collected at 100 Hz using an electromagnetic tracking system (trackSTAR^{TM}, Ascension Technologies, Inc., Burlington, VT, USA) synced with The MotionMonitor (Innovative Sports Training, Chicago, IL, USA). Thirteen sensors were attached to the following landmarks: (1) posterior aspect of the torso at the first thoracic vertebrae (T1) spinous process; (2) posterior aspect of the pelvis at the first sacral vertebrae (S1); (3–4) flat, broad portion of the acromion on the bilateral scapula; (5–6) lateral aspect of bilateral upper arm at the deltoid tuberosity; (7–8) posterior aspect of bilateral distal forearm, centered between the radial and ulnar styloid processes; (9–10) lateral aspect of bilateral upper leg, centered between the greater trochanter and the lateral condyle of the knee; (10–11) lateral aspect of bilateral lower leg, centered between the head of the fibula and lateral malleolus; (12) posterior aspect of the dominate hand below the second phalanx; and (13) superior aspect of the foot, midway between the metatarsophalangeal and talocalcaneonavicular joint [9,10,14]. A fourteenth, moveable sensor was attached to a plastic stylus and used for the digitization of bony landmarks. Using the digitized joint centers for ankle, knee, hip, shoulder, T12-L1, and C7-T1, a link segment model was developed. Joint centers were determined by digitizing the medial and lateral aspect of a joint then calculating the midpoint between those two points [19]. The ankle and knee joints were defined as the midpoint between the digitized medial and lateral malleoli and medial and lateral femoral condyles, respectively, whereas the spinal column was defined as the digitized space between C7-T1 and T12-L1. A rotation method, validated as capable of providing accurate positional data, was utilized to estimate the hip joint centers [20]. Hip joint centers were calculated from the rotation of the femur relative to the pelvis. Raw data regarding sensor position and orientation were transformed to locally based coordinate systems. For the world axis, the Y-axis represented 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 X and Y was the positive Z-axis.

After sensor attachment and digitization, an investigator verbally explained the SLS and instructed the participant to "squat down as far as you can and stand back up." The investigator then demonstrated an acceptable and unacceptable trial for each participant. A trial was deemed acceptable if the participant squatted down as far as possible and then rose to their initial position without the raised leg contacting the ground or stance leg [9,10,14]. Prior to testing, participants were allowed to practice the SLS. Following practice, participants performed the SLS once on each leg. Following completion, the SLS participants completed a health history questionnaire and were asked "Do you currently have any pain/discomfort?" to which they answered either "yes" (n = 13; 13.5 ± 2.2 years; 163.0 ± 11.7 cm; 62.5 ± 17.3 kg; 5.6 ± 2.2 years of experience) or "no" (n = 29; 12.8 ± 1.9 years; 161.8 ± 8.7 cm; 60.0 ± 12.6 kg; 5.3 ± 1.4 years of experience).

The SLS was defined by three events: (1) 45-degree knee flexion during the descent (45° descent), (2) maximal knee flexion, (3) 45-degree knee flexion during the ascent (45° ascent), and two phases: the descent phase (between 45° descent and maximal knee flexion) and the ascent phase (between maximal knee flexion and 45° ascent). All kinematic data (maximal knee flexion, knee valgus, vertical sacrum displacement, anterior/posterior pelvic flexion, and pelvic lateral flexion) were compared bilaterally, at each event, and in each phase. All angular kinematic variables (anterior/posterior pelvic flexion, pelvic lateral flexion, and maximal knee flexion) were defined as orthopedic angles, using predesigned algorithms within The MotionMonitor. Knee valgus and vertical sacrum displacement were defined as the excursion from the neutral stance.

All data were processed using a customized MATLAB (MATLAB R2018a, MathWorks, Natick, MA, USA) script. Statistical analyses were performed using IBM SPSS Statistics 25 software (IBM Corp., Armonk, NY, USA) for data with an alpha level set at *a piori* at 0.05. Values of $p < 0.05$ were classified as significant, and values of $p < 0.10$ were classified as nearing significance to account for broad clinical significance within the current data set. Due to a non-normal distribution in the kinematic data, all data were transformed to Z scores [21]. Participants were divided into two categories based on their responses: those who said "yes" to experiencing pain and discomfort and those who said "no". A point-biserial correlation was run between these groups (pain and no pain) and all kinematic variables (maximal knee flexion, knee valgus/varus, vertical sacrum displacement, anterior pelvic tilt, and pelvic lateral tilt) at each event (45° descent, maximal knee flexion, and 45° ascent), and across each phase (descent, ascent) and between legs.

3. Results

Mean and standard deviation of each variable at each even and phase can be found in Table 1. Correlations between reported pain and kinematics at each event and phase can be found in Tables 2 and 3, respectively. A significant correlation between the bilateral differences of knee valgus and pain were observed at maximal knee flexion (r_{pb} = 0.392, p = 0.010). Maximal knee flexion was the only kinematic variable that did not display a significant or near significant correlation with pain.

Table 1. Means and Standard Deviations of Single-leg squat Kinematics at Each Event and across Each Phase.

Kinematic Variable	Left SLS	Right SLS	Bilateral Asymmetry
Maximal Knee Flexion	77.2 ± 14.9°	79.8 ± 13.5°	10.2 ± 8.0°
Knee Valgus/Varus			
45° Descent	−1.4 ± 6.6°	0 ± 6.3°	6.9 ± 6.0°
Maximal Knee Flexion	−7.9 ± 9.6°	5.4 ± 9.1°	16.4 ± 10.4°
45° Ascent	−1.7 ± 7.2°	0.1 ± 6.7°	7.4 ± 6.1°
Descent Phase	7.1 ± 4.9°	6.4 ± 3.8°	-
Ascent Phase	6.6 ± 4.4°	6.2 ± 4.4°	-
Sacrum Displacement			
45° Descent	5.2 ± 2.6 cm	4.5 ± 2.0 cm	12.4 ± 5.7 cm
Maximal Knee Flexion	17.6 ± 4.9 cm	17.9 ± 5.5 cm	12.2 ± 5.6 cm
45° Ascent	5.3 ± 2.9 cm	4.4 ± 2.4 cm	2.1 ± 2.0 cm
Descent Phase	12.4 ± 5.7 cm	13.4 ± 5.7 cm	-
Ascent Phase	12.2 ± 5.6 cm	13.5 ± 5.9 cm	-
Anterior/Posterior Pelvic Tilt			
45° Descent	6.6 ± 9.0°	7.6 ± 8.2°	4.5 ± 3.0°
Maximal Knee Flexion	19.6 ± 10.5°	20.2 ± 10.5°	4.6 ± 3.5°
45° Ascent	14.8 ± 8.8°	14.9 ± 8.2°	4.1 ± 2.9°
Descent Phase	13.0 ± 7.9°	12.5 ± 8.2°	-
Ascent Phase	4.8 ± 4.9°	5.3 ± 5.6°	-
Lateral Pelvic Tilt			
45° Descent	−2.5 ± 6.0°	2.5 ± 5.1°	7.3 ± 4.6°
Maximal Knee Flexion	4.3 ± 8.1°	−4.5 ± 8.7°	11.7 ± 8.3°
45° Ascent	1.5 ± 7.1°	−0.4 ± 6.9°	6.5 ± 5.7°
Descent Phase	6.9 ± 4.9°	7.0 ± 5.4°	-
Ascent Phase	2.9 ± 3.8°	4.1 ± 4.3°	-

Table 2. Pearson Point Biserial Correlations between Pain and *Z*-scores of Kinematic Data at Each Single-Leg Squat (SLS) Event.

Kinematic Variable		Pain	
	Left SLS	Right SLS	Bilateral Asymmetry
Maximal Knee Flexion	0.030 (0.849)	−0.030 (0.850)	−0.112 (0.480)
Knee Valgus/Varus			
45° Descent	0.253 (0.106)	0.246 (0.116)	0.180 (0.255)
Maximal Knee Flexion	0.276 (0.077) ^	0.195 (0.215)	0.392 (0.010) *
45° Ascent	0.301 (0.053) ^	0.115 (0.468)	0.281 (0.071) ^
Sacrum Displacement			
45° Descent	0.096 (0.544)	0.279 (0.074) ^	−0.128 (0.420)
Maximal Knee Flexion	0.200 (0.205)	0.263 (0.093) ^	−0.101 (0.526)
45° Ascent	0.148 (0.350)	0.255 (0.103)	0.177 (0.263)
Anterior/Posterior Pelvic Tilt			
45° Descent	−0.244 (0.120)	0.009 (0.956)	−0.027 (0.864)
Maximal Knee Flexion	−0.015 (0.926)	0.130 (0.413)	−0.096 (0.544)
45° Ascent	−0.044 (0.780)	0.097 (0.540)	0.123 (0.439)
Lateral Pelvic Tilt			
45° Descent	−0.138 (0.384)	−0.141 (0.372)	−0.231 (0.141)
Maximal Knee Flexion	−0.030 (0.851)	−0.248 (0.113)	0.162 (0.304)
45° Ascent	0.023 (0.883)	−0.196 (0.214)	0.101 (0.524)

* denotes a significant correlation $p < 0.05$; ^ denotes a near significant correlation $p < 0.10$; p-values are located in parenthesis.

Table 3. Pearson Point Biserial Correlations between Pain and *Z*-scores of Kinematic Data across Each Phase.

Kinematic Variable	Pain	
	Left SLS	**Right SLS**
Knee Valgus/Varus		
Descent Phase	0.270 (0.083) ^	0.292 (0.060) ^
Ascent Phase	0.152 (0.336)	0.214 (0.173)
Sacrum Displacement		
Descent Phase	0.128 (0.420)	0.160 (0.311)
Ascent Phase	−0.101 (0.526)	−0.145 (0.360)
Anterior/Posterior Pelvic Tilt		
Descent Phase	−0.259 (0.097) ^	−0.157 (0.322)
Ascent Phase	0.048 (0.762)	0.101 (0.525)
Lateral Pelvic Tilt		
Descent Phase	−0.120 (0.451)	0.267 (0.088) ^
Ascent Phase	−0.106 (0.502)	−0.190 (0.229)

* denotes a significant correlation $p < 0.05$; ^ denotes a near significant correlation $p < 0.10$; *p*-values are located in parenthesis.

4. Discussion

Based on the fact that the SLS is a reliable assessment of LPHC strength and stability, sport performance, and lower extremity pain [9,11,14,16–18], the purpose of this study to investigate the associations between bilateral SLS performance and reported pain in youth softball athletes. A positive correlation was found between bilateral differences of knee valgus at maximal knee flexion and pain. Contrary to our hypothesis, greater anterior pelvic tilt, greater ipsilateral pelvic tilt, greater knee valgus, and less sacrum displacement were not correlated with reported pain. However, these variables did have a near significant correlation with reported pain and should be discussed due to possible clinical significance.

The present study found no significant relationships between pain and SLS pelvic kinematics in the descent phase of each leg. Both greater dynamic anterior pelvic tilt during the left SLS descent phase and greater ipsilateral pelvic tilt during the right SLS descent neared a significant correlation with reported pain. These results are supported by previous findings indicating relationships between SLS, LPHC kinematics, and pain [22,23]. Specifically, it has been found that those with patellofemoral pain had increased ipsilateral trunk lean, contralateral pelvic drop, and hip adduction [22,23], and found females with pain had greater hip internal rotation [22]. Additionally, it has been found that female patients with lower extremity injury displayed greater internal hip rotation, less knee flexion, and more trunk flexion on their injured compared to their noninjured leg [23]. Although the present study did not include trunk or hip kinematics, the increase in pelvic lateral tilt in the right SLS among those with pain is a strong indicator of increased internal hip rotation, while the increase in anterior pelvic tilt in the left SLS is a strong indicator of trunk flexion. The present study also found a near significant correlation between greater degrees of knee valgus and reported pain at maximal knee flexion, 45° ascent (left SLS), and during the descent phase (left SLS and right SLS). These findings are also supported by previous reports of increased knee valgus while performing the SLS in patients with patellofemoral pain [22,24]. Additionally, increased knee valgus during the SLS has been classified as 'poor performance' and a risk for injury [25].

The near significant correlations between vertical sacrum displacement and pain in the right SLS at maximal knee flexion and 45° ascent disagree with our hypothesis. Those participants who squatted down further, as measured by their vertical sacrum displacement from a neutral stance, were more likely to experience pain. It is possible that athletes who achieved greater sacrum displacement did so due to lack of eccentric control during the decent phase, meaning these participants may not have the strength and control needed to act against gravity and stop downward motion in a controlled manner. Such lack of musculoskeletal control would aid in explaining the slight correlation between pain and sacrum displacement in the current study [22,26–28]. In addition to sacrum displacement, maximal knee flexion was used to determine SLS depth. The lack of correlations between knee flexion and pain suggests that squat depth is not the most effective diagnostic variable when attempting to identify current and possible future pain. However, the current data agrees with previous clinical evaluations of the SLS that classify "poor" performers as displaying greater hip flexion, hip adduction, medial hip rotation, and knee valgus, suggesting that there is justification in using the SLS as a diagnostic tool in youth softball [25].

The findings of the current study support the analysis of both SLS events (45° descent, maximal knee flexion, and 45° ascent) and descent and ascent phases when using the SLS as a diagnostic tool. Further evaluation of SLS phases is needed, and it is authors' recommendation that future analysis be conducted on the entire descent and ascent phases, starting from full knee extension, rather than 45° of knee flexion. It is also worth noting that the vast majority of youth softball athletes are female, and previous comparison of males and females in the single-leg squat assessment has shown females to exhibit more injury-prone mechanical patterns in all phases of the single-leg squat [22,29]. Females exhibit less trunk flexion, greater medial trunk rotation, greater knee abduction, and greater hip adduction during the SLS decent [29,30]. Females also produce significantly lower torques at the knee, hip, and trunk in multiple planes of motion [16,30]. Muscle activation in females is generally shown to be weaker than their male counterparts, although Nakagawa et al. found females to exhibit greater gluteus medius and gluteus maximus activation [22]. Due to the predisposition of females to exhibit injury prone lower extremity mechanics, the validity of clinical mechanical evaluations of the SLS, and the similarity of the above-mentioned mechanics to those observed in correlation with pain in the present study, it is reasonable to conclude that the SLS diagnostic tool may play a role in the prescreening of youth softball players in order to prevent future injury.

Correlations between SLS performance and reported pain are present in youth softball athletes. Because of the simplicity of performance and assessment of the SLS, there is merit in its use as an injury-prevention screening tool in youth softball. Limitations of this study include a small sample size (n = 42). Using G*Power 3.1.9.2 for a postcollection sample size analysis with power set at 0.8, *a priori* alpha set at 0.1, and a moderate effect size of 0.3 determined that a sample size of 47 participants was needed. The sample population was also taken from a convenient sample. Location of pain was not reported by all athletes who indicated current pain and was therefore not included in the current analysis. Delimitations include the standardized testing location and procedure, in addition to the participant exclusion criteria.

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