LEG DOMINANCE EFFECTS ON KNEE KINEMATICS IN UNILATERAL AND BILATERAL SQUATS

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Squatting movements are often used to assess known risk factors of injury such as knee valgus angle. This study aims to investigate the knee kinematics during unilateral and bilateral squats in relation to the dominant and non-dominant leg. Five uninjured participants completed three squats in three conditions; dominant unilateral, non-dominant unilateral and bilateral. Knee extension and valgus angles were calculated. Maximum knee valgus angle was higher in the non-dominant unilateral trial than the same leg during the bilateral squat (unilateral = 10.6°, bilateral = 8.4°; $p < 0.05$). Knee extension angles were significantly lower during bilateral squats (unilateral = 111.9° & 109.2°, bilateral = 97.5° & 98.2°; $p < 0.05$). Limb dominance effects knee valgus during squatting, and should therefore be taken into account during injury risk assessments.

KEY WORDS: knee valgus, injury, anterior cruciate ligament, risk assessment.

INTRODUCTION: During squatting tasks, knee biomechanics have been used to identify links between movement patterns and injury (Donohue et al., 2015; Ugalde, Brockman, Bailowitz, & Pollard, 2015). Within the case of anterior cruciate ligament (ACL) injuries, kinematic differences in single leg squat performance have been demonstrated between injured and uninjured participants (Yamazaki, Muneta, Ju, & Sekiya, 2010). Research has demonstrated knee valgus contributes to ACL strain (Kiapour et al., 2015) and identified knee valgus angle during movements to be a risk factor of ACL injuries (Hewett, et al., 2005). Asymmetry between the involved and uninvolved leg within athletes who have undergone ACL reconstruction has been well studied (Jordan, Aagaard, & Herzog, 2015; Rohman, Steubs, & Tompkins, 2015). Asymmetry between the dominant and non-dominant leg during movement tasks has also been investigated (Sadeghi, Allard, Prince, & Labelle, 2000) and although its role in injury risk is uncertain (Harris, Driban, Sitler, Cattano, & Hootman, 2015) kinematic differences between limbs during movement tasks used for injury screening and assessment merit investigation. Due to the use of single squats as both a predictor of ACL injury (Munro, Herrington, & Carolan, 2012) and an evaluation method after treatment (Hall, Paik, Ware, Mohr, & Limpisvasti, 2015) the exploration of knee kinematics during squatting tasks is warranted. Therefore this study aims to evaluate differences in knee kinematics between unilateral and bilateral squats with relation to the dominant and non-dominant leg.

METHODS: Five (Mean±SD; age: 26.0±1.6 yrs; height: 1.72±0.07 m; mass: 75.6±12.0 kg) participants took part in this study. All participants were screened for inclusion (18-45 years old) and exclusion (knee ligament rupture; multi-ligament instability including medial or lateral collateral ligament injury; other lower limb surgery <3 months, or; current significant acute injury affecting other lower-extremity joints, or other relevant neurological or musculo-skeletal pathology) criteria and provided written informed consent. To determine leg dominance participants were asked which leg they would feel most comfortable kicking a ball with. Twenty 9.5 mm spherical reflective markers were adhered to the skin superficial to anatomical landmarks to track the movement of the foot, shank and thigh segment for both legs (Figure 1). A 30 second standing trial was collected to provide neutral joint angles. Participants completed bilateral, and dominant and non-dominant unilateral squat trials in a randomized order. Each trial consisted of three consecutive squats to a self-selected depth. Kinematic data were collected using a four camera motion capture system (Raptor-4; Motion Analysis Corporation, Santa Rosa, USA; 150 Hz). Data were analyzed using a custom written MATLAB code (MATLAB R2015a, The MathWorks, Inc.). The inflection point of knee extension velocity was used to identify the start and return to start of each squat. Knee valgus angle was calculated as the sum of the shank angle (ankle joint center – knee joint center) and thigh angle (knee joint center – thigh marker) in the frontal plane. Mean thigh angle from the balance trial was subtracted to offset knee valgus angle to standing. Positive knee valgus angle represents knee valgus and negative knee varus. Maximum ($Valgus_{max}$) and minimum knee valgus angle ($Valgus_{min}$) and, maximum ($Extension_{max}$) and minimum knee extension angles ($Extension_{min}$) were calculated for each trial, and averaged for each participant. Data were normally distributed (Shapiro-Wilks $p > 0.05$) and compared using paired samples t-test at a statistical significance level of 0.05.

Figure 1: Marker placements

RESULTS: Mean maximum knee valgus angles were significantly higher in the unilateral squat than the bilateral squat for the non-dominant leg (∆2.2°, p=0.01) and not significantly different in the dominant leg (∆4.6°, p=0.15). Minimum extension angle was significantly lower in the bilateral squats compared to the unilateral condition (Table I). During the unilateral squats, knee valgus angle increased as the extension angle decreased (Figure 2a & 2b). During bilateral squats, knee valgus decreased as knee extension increased in the data for participants one, two and four. Figures 2c and 2d also show that participant one demonstrates smaller knee valgus angle at a higher knee flexion angle (108°) in the non-dominant (valgus angle= -13.2°, extension angle = -108.0°) compared to the dominant leg (valgus angle = -8.1°, extension angle = -101.5°) during a bilateral squat.

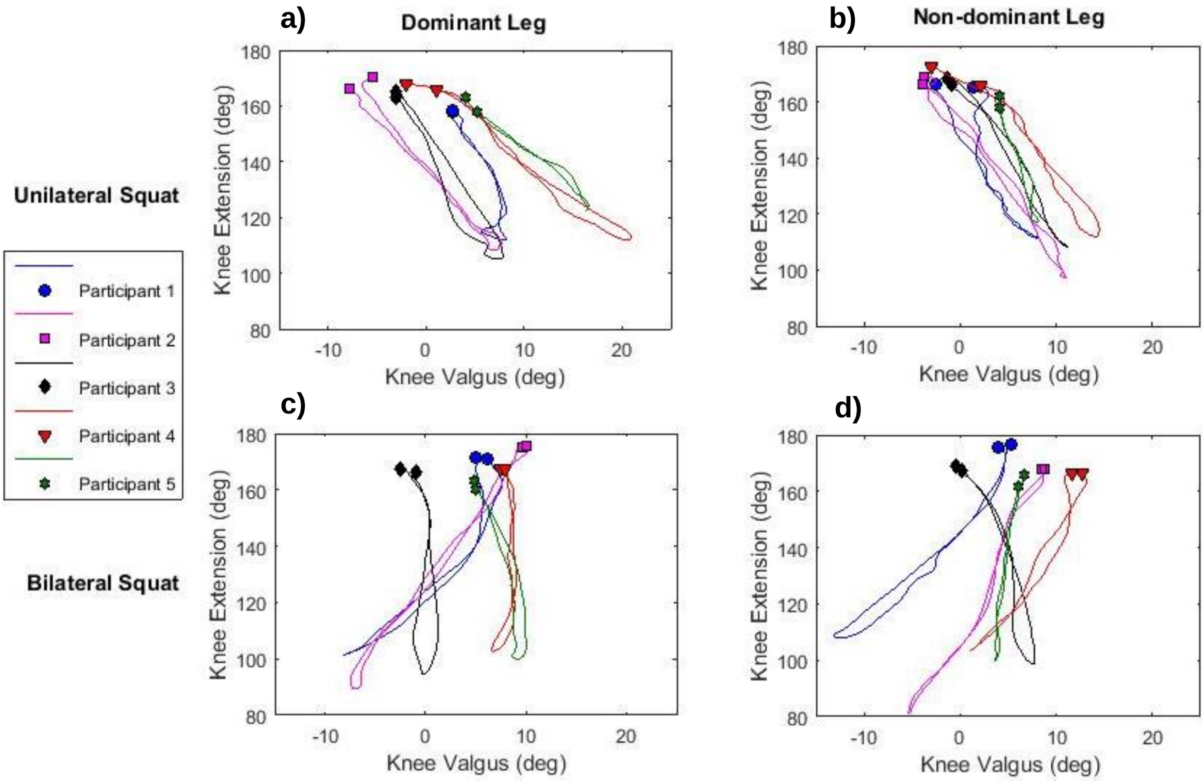

Figure 2: Knee extension and valgus angle-angle plots for individual participants in each squat condition.

Table I
Mean (SD) values for unilateral and bilateral squats for the dominant and non-dominant leg

	Unilateral Squat		**Bilateral Squat**	
	Dominant	Non-dominant	Dominant	Non-dominant
$Valgus_{max}$ (°)	12.3 (6.1)	10.6 (2.6)*	7.7 (3.8)	8.4 (3.0)*
$Valgus_{min}$ (°)	-1.3 (4.7)	-1.5 (3.0)	-1.3 (6.8)	-2.9 (3.0)
$Extension_{max}$ (°)	164.9 (4.6)	167.7 (3.9)	169.3 (4.5)	169.2 (4.4)
$Extension_{min}$ (°)	111.9 (6.5)*	109.2 (7.4)*	97.5 (5.6)*	98.2 (10.3)*

**denotes statistical significance for comparison of unilateral and bilateral squats for each leg (p<0.05)*

DISCUSSION: The data presented shows that maximum knee valgus angle was significantly higher in a unilateral squat when performed by the non-dominant leg. During unilateral squatting the strain placed on the muscular system is increased and this could be an explanation as to the increase in the maximum knee valgus angle. Bell, Padua, and Clark (2008) found participants who demonstrated knee valgus during squatting had decreased strength and range of motion in the ankle joint, however only the dominant leg was tested. This paper is unable to identify specific strength deficits. One theory for a significant difference found only in the non-dominant leg is strength asymmetry. This theory is strengthened by previous findings that show asymmetry is present between the dominant and non-dominant legs (Lanshammar & Ribom, 2011). A second theory which may explain this result is the greater spread of the maximum knee valgus data for the dominant unilateral squat as demonstrated by a larger standard deviation (Table I). This increased spread, as seen in figure 2a, can be attributed to participants four and five. This suggests that leg dominance based asymmetry may be variable between participants and individual analysis may be required to identify the true role of leg dominance on unilateral squat performance. During the bilateral squats smaller minimum knee extension values were seen, showing an increase in squat depth. This is most likely due to the greater stability and combined strength of both legs when performing a bilateral squat. This increase in squat depth may mean that bilateral squats offer a greater capacity to explore knee kinematics at greater squat depths. However the reduced strain placed on the lower limbs may result in these movements being unsuitable for the detection of strength weaknesses. Differences between dominant and non-dominant legs during a bilateral squat are still present. Participant three showed a larger knee valgus angle in the non-dominant leg at minimum knee extension (Figure 2d), which suggests limb asymmetries are still present during the more stable bilateral squat movement.

Knee valgus has previously been suggested as a risk factor for ACL injury (Dai, Mao, Garrett, & Yu, 2014; Hewett et al., 2005). The results of this study show that knee valgus is present during unilateral squatting. As a result of this, the use of unilateral squats in pre-screening protocols for the identification of ACL injury risk factors are warranted. The angle-angle plots shown in Figure 2 demonstrate the change in knee valgus angle throughout the squat. It is known that the strain placed on the ACL changes throughout knee extension during squatting (Beynnon et al., 1997). Strain is higher at larger knee extension angles and therefore the timing of when knee valgus occurs may be of interest. The presented results show that unilateral squats often begin with negative knee valgus angle (knee varus) with the angle increasing as knee extension angle decreases.

CONCLUSION: The findings of this study demonstrate the use of unilateral squats for assessing knee valgus angle and its potential risk to injury. Knee valgus angle in the non-dominant leg during a unilateral squat was found to be significantly larger to when a bilateral squat was performed. This may highlight dominance related asymmetries which may increase the risk of injury in the non-dominant side and therefore may mean unilateral squats are a useful tool in assessing asymmetry and injury risk.

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