THE COMPARISON OF KNEE JOINT KINEMATICS BETWEEN TWO TYPES OF STOP JUMP

Josh Walker[1], Sarah B. Clarke[2], and Randall L. Jensen[2]

Institute of Sport, Physical Activity and Leisure, Leeds Beckett University, Leeds, UK[1]
School of Health and Human Performance, Northern Michigan University, Marquette, MI, USA[2]

Sagittal and frontal plane knee kinematics have been linked to anterior cruciate ligament injury risk during several jumping and landing tasks. The purpose of this study was to compare the knee joint kinematics of the dominant and non-dominant leg during two types of stop jump. Eleven recreationally active participants performed a stop jump from an anteroposterior approach and from a mediolateral approach. The study found significant differences in knee flexion for both limbs, and significant between-limb differences in knee flexion for the mediolateral approach and knee varus/valgus for the anteroposterior approach ($p<0.05$). These findings indicate that both types of stop jump may pose a risk of injury, but particularly during the anteroposterior approach for both limbs, and the mediolateral approach for the non-dominant limb only.

KEY WORDS: jumping, knee flexion, knee valgus, anterior cruciate ligament injury.

INTRODUCTION: Sport-specific movements such as vertical jumps and side-cutting tasks are used frequently in biomechanical research to investigate injury risks. The vertical stop jump (SJ) is one of the most frequently used activities due to its similarity with sporting movements associated with injury (Chappell, Creighton, Giuliani, Yu & Garrett, 2007). Ford, Myer and Hewett (2003) discussed the possible mechanisms behind non-contact knee injury, and suggested that females are at an increased risk of Anterior Cruciate Ligament (ACL) injuries for several reasons, including knee valgus. Knee valgus has been shown to be significantly greater in females than their male counterparts in drop landing tasks, which was potentially attributed to reduced dynamic knee joint stability (Ford et al., 2003). The topic of limb dominance has also been related to knee injury risk (Brown, Palmieri-Smith & McLean, 2009; Sugiyama, Kameda, Kageyama, Kanehisa, & Maeda, 2014). Benjanuvatra, Lay, Alderson and Blanksby (2013) reported that there is a between-limb asymmetry in neural drive, but not necessarily strength imbalances. Additionally, Withrow, Huston, Wojtys, & Ashton-Miller (2006) found that ACL strain correlated with quadriceps muscle force as well as knee flexion, indicating that excessive force and knee flexion increased the risk of ACL injury during jumping, however, there may be other mechanisms involved.
The SJ is frequently used in research with a “front-on” approach (e.g. Chappell et al., 2007), which represents a popular sporting movement. However, in many sports such as volleyball and basketball, athletes may often be required to approach a jump from various positions or angles. This alternative approach requires further investigation to establish any kinematic differences that may exist between approaching a SJ from the front, or from a lateral approach position. The aim of this study was to quantify the dominant and non-dominant knee kinematics of a regular SJ and compare them to the same jump from a lateral approach, or a lateral stop jump (LSJ). Due to the LSJ generating lateral momentum, it was hypothesised that more frontal plane knee motion would occur, particularly in the non-dominant leg, thus increasing injury risk. Based on the same principle, it was also hypothesised that the SJ produces a greater magnitude of knee flexion than the LSJ.

METHODS: Eleven participants (Mean±SD; age = 20.4±1.5 years, height = 1.74±0.07 m, body mass = 80.1±12.9 kg) volunteered to act as participants for the current study. This research received university ethical approval and all participants provided informed consent prior to participation. Participants were injury free at the time of testing and for 6 months prior.

Participants were recreationally active in a range of sports, including both individual and team-sports.
All participants carried out a standardised warm-up and were familiarised with the testing protocol prior to data collection. The participants then carried out regular SJ, which involved three steps before landing on both legs prior to a vertical jump; and LSJ, where participants approached from the side by taking three side steps before landing on both legs and executing a vertical jump. Jumps were carried out in a randomised order and were repeated three times each, with a minimum of three minutes of rest between each trial (Baechle & Earle, 2008).
Knee angle in the frontal and sagittal plane was recorded using a ten-camera motion capture system (Qualisys, Sweden) recording at 250 Hz. Retroreflective markers were placed on various pelvic bony landmarks, the left and right greater trochanter, as well as medial and lateral epicondyles and malleoli of both limbs. Cluster markers were placed on the upper and lower segment of the dominant and non-dominant leg. Joint angles were calculated using Visual 3D (v.6, C-Motion, USA) using an inverse dynamics modelling specification including pelvis, upper and lower legs and a static calibration file. Full extension was defined as 180°, while full flexion was 0°. For frontal plane knee angle, 0° was neutral and valgus was defined as an angle less than zero, with knee varus being positive values. The dominant leg was defined as the 'plant leg' used when kicking a ball for distance. Participants were instructed to lead with their dominant leg on their final step prior to the jump. Kinematic data of the jumps were filtered at 10 Hz using a lowpass Butterworth filter (Blackburn & Padua, 2008) and normalised from 0-100%, where 0% was initial contact and 100% was take-off. Initial contact was established using two side-by-side piezoelectric force platforms (Kistler, Switzerland) sampling at 1000Hz.
Statistical Analysis: Statistical analysis was carried out using SPSS (version 24.0). A two-way repeated measures ANOVA (between-limb, between-jump design) was used to determine differences in average knee angle across all trials. Alpha level for this study was set at 0.05. Cohen's *d* effect sizes (ES) were also used to determine magnitude of differences. Interpretation of ES were based on the scale for effect size classification of Hopkins (2000): < 0.04 = trivial, 0.041-0.249 = small, 0.25-0.549 = medium, 0.55-0.799 = large, and >0.8 = very large.

RESULTS: Average knee joint angles in both planes for the jump tasks can be seen in Table 1. There was a significant difference in average knee flexion between SJ and LSJ for both the dominant (p<0.001, ES=1.01 (large)) and non-dominant limbs (p=0.001, ES=0.69 (large)) (Figure 1, Table 1). Average knee Varus/Valgus angle did not significantly differ for either limb between jumping conditions (dominant limb: p=0.401, ES=0.19 (small); non-dominant limb: p=0.753, ES=0.00 (trivial)) (Table 1).

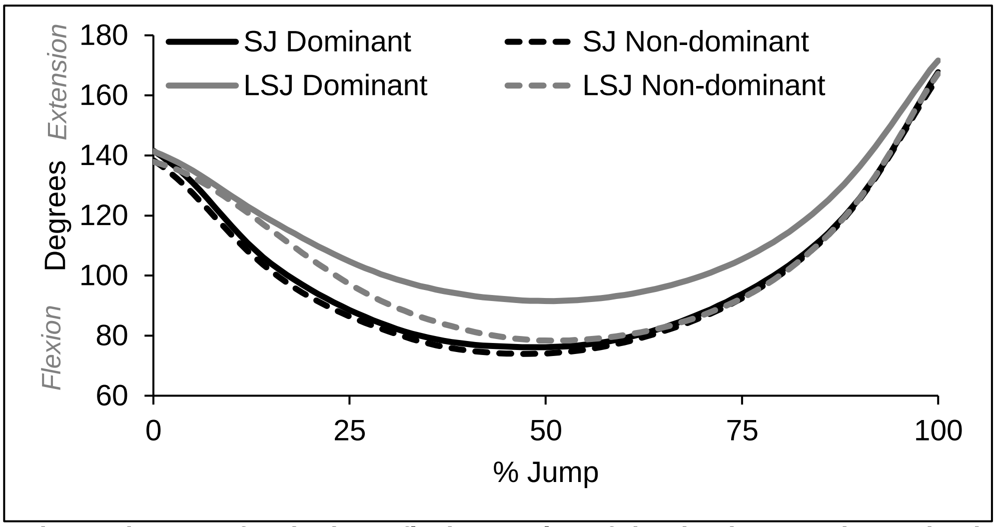

Figure 1: Kinematic curve for the knee flexion angles of the dominant and non-dominant limb for both jumps.

In the LSJ, average knee flexion was significantly greater on the non-dominant limb than the dominant limb (p<0.001, ES=0.94 (very large)), however the same difference was not found for the SJ (p=0.235, ES=0.18 (small)) (Figure 1, Table 1). There was an observed interaction between the type of jump and limb in this study (Figure 1), as type of jump appeared to cause the between-limb differences in knee flexion.

Table 1: Mean ± Standard Deviation of Knee Kinematics in both limbs for both jumps.

Variable (all average values)	SJ	LSJ	p-value
Dominant Knee Flexion (°)	99.79 ± 12.57[a]	112.25 ± 12.04[ab]	<0.001
Non-dominant Knee Flexion (°)	97.96 ± 6.26[a]	102.78 ± 7.61[ab]	0.001
Dominant Knee Varus/Valgus (°)	-4.52 ± 10.81[b]	-2.25 ± 12.90	0.401
Non-dominant Knee Varus/Valgus (°)	1.80 ± 13.36[b]	1.86 ± 13.55	0.753

[a] Significantly different (p<0.05) between jumps
[b] Significantly different (p<0.05) between limbs

There was a significant between-limb difference in varus/valgus for the SJ, with the dominant limb showing more knee valgus than the non-dominant limb (p=0.006, ES=0.52 (medium)) (Table 1). There was no significant difference in knee varus/valgus between limbs for the LSJ (p=0.258, ES=0.31 (medium)).

DISCUSSION: The aim of the present study was to investigate the knee joint kinematics of a stop jump when executed from an anteroposterior run-up (SJ) and a lateral side step (LSJ) approach. As hypothesised, the results of this study showed a significantly (p<0.05) greater average knee flexion during the SJ than the LSJ for both limbs (p≤0.001; Figure 1, Table 1).The differing levels of knee flexion between jumps were expected due to the anteroposterior momentum generated during SJ, which was found for both limbs. Sugiyama et al. (2014) found a significant between-limb difference in knee flexion during single-leg jumps. However, Sugiyama et al. (2014) only found a significant difference in the second half of the jump (from the minimum value of centre of gravity displacement to take-off), whereas the difference in the first half of the jump (touchdown to the minimum value of centre of gravity displacement). This finding was supported by the present study, as Figure 1 shows that the majority of the between-limb differences were seen from 50-100% of the jump. However, similar to the findings of Brown et al. (2009), no differences in knee valgus were found between jumps for either the dominant or non-dominant limb (p>0.05). As the differences in knee flexion were possibly due the anteroposterior momentum, it would therefore be expected that the LSJ would generate more knee valgus, based on the same principle. One possible explanation for this non-significant difference was the large amount of between subject variability for knee varus/valgus (Table 1). Had the values been more consistent between trials, a statistically significant difference may have been found.
The current study also found that the LSJ produced a significantly greater degree of knee flexion in the non-dominant limb than the dominant limb (p<0.001, ES=large; Figure 1, Table 1). This contrasts with previous studies such as Brown et al. (2009), which found no differences in variables such as peak knee moments between limbs for anticipated and unanticipated drop landing tasks. During the landing movement, activation of the knee extensors prevents excessive knee flexion during the landing and downward phase of a jump (Withrow et al., 2006). Therefore, this between-limb difference could indicate a delayed neuromuscular response of the non-dominant limb (Benjavunatra et al., 2013), and therefore an increased risk of ACL injury (Withrow et al., 2006). The between-limb difference in knee flexion was not found in the SJ (p=0.235, ES=small; Figure 1, Table 1), suggesting that the difference is primarily caused by the direction of approach. However, it may be noted that factors such as speed of approach may also impact knee flexion, which was not controlled for in this study.

In the SJ, there was a significant difference in frontal plane knee angle between limbs (p=0.006, ES=medium; Table 1). Interestingly, the dominant limb showed a greater average knee valgus than the non-dominant limb. Although participants were intending to land on the ground bilaterally, the dominant limb was the take-off limb for the final step, and the trailing leg during flight before initial contact. This is a possible explanation for the greater knee valgus shown, as this limb had a shorter period in which to be stabilised. This finding corresponds with the difference found in the LSJ, however this failed to reach statistical significance but did have a medium effect size (p=0.258, ES=0.31), which was most likely due to the high variability between trials and participants.

CONCLUSION: Based on previous research stating that increased levels of knee extension during jumping increase ACL strain and therefore the risk of injury, it was concluded that LSJ poses an increased risk of ACL injury to the non-dominant limb. This is predominantly due the asymmetric between-limb findings. However, it may be noted that SJ was significantly greater in dominant knee valgus. It was therefore concluded that both approaches to a stop-jump pose risks to the ACL, but the lead leg during a lateral approach is subject to the least amount of strain. This should be noted when using jumping tasks during ACL recovery programmes, as the injured leg could perhaps be used as the lead leg in LSJ exercises. Future research should study this asymmetric knee flexion from an electromyographic standpoint, to determine the impact of knee extensor force on ACL strain.

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