DOES SYMMETRY IN GROUND REACTION FORCE REPRESENT SYMMETRY IN KNEE LOADING PATTERNS DURING LANDING FROM A LATERAL-MOVING JUMP?

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SUMMARY
Asymmetrical lower limb loading during landing may lead to overuse knee injuries if one limb is required to repetitively attenuate greater load. Symmetry of the peak vertical ground reaction force (vGRF) and knee moment generated in the lead and trail lower limbs of healthy female volleyball players during landing from a lateral-moving jump were determined. Each participant performed five jump-landings moving left and moving right onto two force platforms (1500 Hz). Peak vGRF (BW) and peak knee extensor moments (Nm/kg) were obtained and analysed. A symmetry index was used to calculate the functional symmetry of knee loading patterns during landing. No significant between-limb differences in the vGRF or knee moment magnitude were observed. However, functional asymmetry was identified and appeared to be influenced by movement direction. When players moved right, there was an average asymmetry of 18.1% and 16.1% for the vGRF and knee moment, respectively. This suggests that the dominant (lead) limb attenuates more load than the non-dominant (trail) limb. Based on these results we recommend that when investigating the magnitude of the vGRF or knee extensor moment generated during landing, one force platform is sufficient. However, dual force platforms are recommended when conducting injury prevention research.

INTRODUCTION
In landing research, movement symmetry of the experimental landing task is often assumed either due to task or equipment restrictions [1]. This assumption presumes that during landing the participant experiences similar loads on their left and right lower limbs. However, if this assumption is incorrect and more force is attenuated by one limb, this may amplify the risk of sustaining a chronic overuse injury, such as patellar tendinopathy, to that particular limb [2]. Clinically, asymmetrical knee loading patterns of greater than 10% have been defined as being pertinent in terms of increasing the susceptibility for injury [3]. As knee injury is highly prevalent in volleyball players who perform numerous lateral-moving block jumps [4], investigations into this movement and knee loading is warranted. Despite knee extensor moments being related to the ground reaction force (GRF) generated during landing, symmetry in GRF may not represent symmetry in knee extensor moments, although this notion has not been previously investigated. Therefore, the purpose of this study was to determine the symmetry of the knee extensor moments and the peak vertical GRF (vGRF) forces generated during landing from lateral-moving jumps.

METHODS
Ten female volleyball players (23.9 ± 4.1 years; 64.92 ± 6.03 kg; 171.3 ± 5.6 cm) with no existing knee joint injury or disease participated in this study. Limb dominance, as assessed though a questionnaire, was defined as the limb the participant would kick a ball with. Eight out of ten participants indicated their right limb as their dominant limb. Each participant performed 10 trials of a lateral-moving slide step block jump-landing; five moving right and five moving left. A portable volleyball net set at a regulation height of 2.24 m and a block post with a ball placed 5 cm above the net were used to simulate a typical volleyball situation. The lateral-moving block jump was performed while the participant was facing the net using a one-step approach, a two-footed take-off to touch the mounted ball, and a final two-footed landing with each foot contacting a separate force platform. The lead leg was defined as the one the participant initiated the first movement with and the trail leg as the contralateral limb. To prevent targeting of the force platforms during landings, the participants were not made aware of the position or purpose of the force platforms.

Three-dimensional kinematic (250 Hz; VICON; Oxford Metrics Ltd, Oxford, UK) and kinetic (1500 Hz; Kistler force platforms; Model Z12697, Kistler Instrument Corporation, Amherst NY, USA) data were collected throughout all trials. Landing was defined from the instant the vertical GRF (vGRF) exceeded 10 N for each force platform. Kinematic and kinetic data were filtered using a fourth-order zero-lag Butterworth digital low pass filter (fc = 16 Hz). Kinematic data were then combined with the GRF data to calculate internal knee extensor moments using standard inverse dynamics, which were then normalised to each participant’s body weight. The outcome variables for both limbs included peak vGRF and peak knee extensor moment with the average of five trials used in the statistical analyses. A paired t-test was then used to determine whether there were any significant (p ≤ 0.05) differences in knee extensors moment or in the vGRF generated by the lead limb compared to the trial limb.

Functional symmetry identifies the percent difference in force generated by the lead and trial limb [5] with positive values
indicating the lead limb was loaded more than the trail limb. A symmetry index (SI) was used to calculate the functional symmetry of the vGRF and knee extensor moments on landing [6]. SI was determined as:

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SI = \frac{(\text{Lead Limb} - \text{Trail Limb})}{(\text{Lead Limb} + \text{Trail Limb})/2} \times 100\%
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RESULTS AND DISCUSSION
Although there is a trend for the lead limb to generate higher force, no significant differences were observed in the magnitude of the peak vGRF (p = 0.07) or the peak knee extensor moment (p = 0.17) between the lead and trail limb (Figure 1). This result was observed when the participants moved left and right. This suggests that when investigating the magnitude of peak vGRF or knee extensor moments when landing from a lateral-moving jump, using one force platform is appropriate.

![Figure 1: Mean (SD) magnitude of the peak vGRF (BW) and peak knee extensor moments (Nm/kg) for each lower limb when landing from a lateral-moving jump.](image)

However, functional symmetry revealed presence of asymmetrical vGRF in nine out of ten participants when moving right, with an average asymmetry of 18.1%. This suggests that whereas the magnitude of the vGRF was not significantly different between the lower limbs, clinically asymmetry was evident. The results of this study support previous research [5], which found asymmetry in the peak vGRF generated during landing by female gymnasts. These results were supported by the knee moment data whereby eight out of ten participants exhibited asymmetry over 10%, with an average asymmetry of 16.1%, when moving to the right. Interestingly, functional asymmetry was not evident when participants moved left before the jump-landing movement, with average asymmetry values of 8.7% and 9.9% for vGRF and knee extensor moment, respectively, suggesting functional asymmetry is influenced by movement direction, perhaps more so when moving away from the dominant limb. Whilst there was no significant difference found in the magnitude of knee moments between the trail and lead limb, the SI results suggest that many of these participants may be susceptible to developing overuse injuries on the limb that they put more load through. For this reason, when investigating the difference in functional loading patterns at the knee during landing from a lateral-moving jump, one force platform is not sufficient.

When a participant moved right, their right limb was their lead limb, which was also the dominant limb for eight out of ten participants. As the functional asymmetry was only present when moving right, these results suggest that when the participants moved left they put a similar load through their leading compared to their dominant limbs. This further implies that female volleyball players adopt different landing strategies when leading with their dominant limb compared to their non-dominant limb when performing lateral-moving jump-landings.

Comparing bilateral isokinetic leg strength may provide further insight behind the presence of functional asymmetry during landing. Alternatively, if the participants did not jump vertically prior to landing, the trajectory of their centre of mass may help explain the functional asymmetry that was present. Further investigation into the effects of variations in the centre of mass trajectory on landing symmetry is therefore recommended. Further investigation into medio-lateral and antero-posterior GRFs and non-sagittal plane knee moments could also further knowledge on knee joint injuries during landings.

CONCLUSIONS
As no significant difference in magnitude of the vGRF or knee extensor moments were observed in female volleyball players, the outcomes of this study suggest that when investigating the magnitude of vGRF or knee extensor moment during landing from a lateral-moving jump, one force platform is sufficient. However, functional asymmetries in knee loading patterns were present when moving right and leading with the dominant limb. For this reason, a minimum of two force platforms are recommended when conducting injury prevention research as functional asymmetry may be present.

REFERENCES