LOWER EXTREMITY FLEXION ANGLES AND VERTICAL GROUND REACTION FORCE DURING LANDING IN MULTIDIRECTIONS: A PILOT STUDY IN FEMALE ATHLETES

Komsak Sinsurin[1], Sarun Srisangboriboon[1], Roongtiwa Vachalathiti[1], Sopinya Pluemjai[1]
Faculty of Physical Therapy, Mahidol University, Nakhon Pathom, Thailand[1]

Single-leg jump landing is a complex task. This study investigated lower extremity motion and vertical ground reaction force (GRF) during jump landing between dominant (DL) and non-dominant (NDL) limbs. Five female athletes performed the single leg jump-landing test from a 30 cm height platform in four directions; forward (0°), 30° diagonal, 60° diagonal, and lateral (90°) directions. The findings showed that jump-landing direction significantly influenced hip and knee flexion angles at initial contact phase, hip flexion and ankle dorsiflexion angles, at peak vertical GRF phase, and the peak value of vertical GRF. Female athletes exhibited a trend of using an ankle strategy in multidirections of landing that is similar to stiff landing. An increase of hip and knee flexion should be suggested during landing to increase a soft landing.

KEY WORDS: joint angle, ground reaction force, jump landing, multidirection.

INTRODUCTION: Single-leg landing is a complex task that occurs frequently in sport activities (Tillman, Hass, Brunt, & Bennett, 2004). Variations of jump-landing directions, termed multidirectional landing, occurs in sport activities such as volleyball and basketball. Differences in lower extremity biomechanics in male athletes during multidirectional jump landing have been found (Sinsurin et al. 2013). They reported that an ankle flexion strategy was preferred during multidirectional jump landing. Increased lower extremity flexion during landing absorbs the impact loading (S. N. Zhang, Bates, & Dufek, 2000). Poor lower extremity biomechanics and high ground reaction forces (GRFs) during landing could lead to conditions such as ACL injury (Hewett, Paterno, & Myer, 2002; Louw, Grimmer, & Vaughan, 2006). Higher rates of ACL injury in female athletes have been reported compared to male athletes (Fagenbaum & Darling, 2003).
Differences in lower extremity biomechanics during landing have been found between men and women (Salci, Kentel, Heycan, Akin, & Korkusuz, 2004; Schmitz, Kulas, Perrin, Riemann, & Shultz, 2007). With our procedure to assess lower limb control during landing in multidirections, we were interested in studying female athletes. Side-to-side lower extremity differences in strength, structure, and gait pattern may influence the side of lower limb injury (S. Zhang, Derrick, Evans, & Yu, 2008). Little research has reported the side-to-side difference in functional movements (Soderman, Alfredson, Pietila, & Werner, 2001; Wikstrom, Tillman, Kline, & Borsa, 2006). Therefore, we studied the lower extremity biomechanics between limbs in multi-directional jump landings. The first purpose was to compare lower extremity joint flexion between jump-landing directions. The second purpose was to determine side difference on lower extremity joint flexion. We hypothesized that different flexion patterns would be observed in the various directions. We expected that joint flexion responses during peak impact force would show differences between sides.

METHODS: Five female volleyball athletes who were members of organized university teams participated in this pilot study. . The age range was 18 - 25 years and BMI 19.0 - 24.0 kg/m^2. Participants had no reported musculoskeletal problems on either leg in the prior 3 months. Subjects were excluded if they had a serious injury or operation of lower extremities, such as ankle sprain, ACL injury, fracture, patellar dislocation. Each participant read and signed an informed consent, which was approved by the Committee on Human Rights Related to Human Experimentation of Mahidol University. All data were collected with a Vicon™ Nexus system (Oxford Metrics, Oxford, UK). The GRFs and kinematics data were collected with a AMTI forceplate (1,000 Hz) and video cameras (100 Hz).

Thirty-five reflective markers based on full body model of Plug in Gait were placed bilaterally on the subject's bony prominences including 4 markers of head, 7th cervical spinous process, jugular notch, xiphoid process, right scapular, 10th thoracic spinous process, acromio-clavicular joint, lateral epicondyle of humerus, wrist bar thumb side, wrist bar pinkie side, 2nd metacarpal, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), thigh, lateral condyles of femur, shank, lateral malleolus, heel, and 2nd metatarsals.

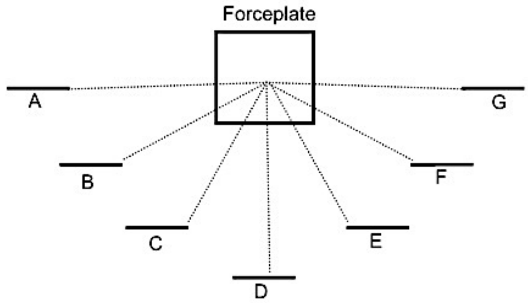

Figure 1: The figure illustrates starting point and research setting in the laboratory.
A - Lateral (90°) jump landing for right lower limb
B - 60° diagonal jump landing for right lower limb
C - 30° diagonal jump landing for right lower limb
D - Forward (0°) jump landing for right and left lower limbs
E - 30° diagonal jump landing for left lower limb
F - 60° diagonal jump landing for left lower limb
G - Lateral (90°) jump landing for left lower limb

Participants were allowed to practice 3 - 5 times of jump landing in each direction to become accustomed with the testing procedure. Both dominant (DL) and non-dominant (NDL) limbs were assessed. Subjects performed single-leg jump landing in four directions for each limb; forward (0°), 30° diagonal, 60° diagonal, and lateral (90°) (Figure 1). The order of limb and jump direction was selected randomly. A 30 cm height wooden platform was placed 70 cm from the center of forceplate. The participants stood on the platform on the leg to be tested and flexed the other knee approximately 90° with a neutral hip rotation. The subject placed both hands on their waist to eliminate variability in jumping mechanics due to arm-swing. Each subject was instructed to carefully jump-off the wooden platform without an upward jump action. Subjects jumped and landed with the tested leg while always facing and looking forward during jump-landing tests. If the subject did not land on the center of forceplate, maintain unilateral balance, or maintain hands on the waist, it was considered as an unsuccessful trial and reperformed. Participants were allowed to rest five minutes between directional sessions and at least thirty seconds between jumping trials. The thirty-five marker coordinates and GRFs were filtered by a fourth order zero-lag Butterworth digital filter at a cut-off frequency of 6 Hz and 40 Hz, respectively. The cut-off frequency was determined by the residual analysis technique (Winter, 2005). A three dimensional model was constructed by Plug in Gait software.
The average of three successful trials in each direction was analyzed. The average angle of lower extremity joints and peak vertical GRF was reported and compared between jump-landing directions and also between limb differences. Two-way repeated measures ANOVA with post-hoc comparison were performed to analyze the data. The statistical comparisons were performed with SPSS 17. The level of significance was set at p-value less than 0.05.

RESULTS and DISCUSSION: The findings of this pilot study found that at initial contact (Table 1), hip and knee flexion angles significantly varied by the jump-landing direction. Hip, knee, or ankle angles did not vary between sides or the jump-landing direction. The lack of sufficient lower extremity joint flexion at initial contact could lead to increased risk of knee injury due to high GRF (Dufek & Bates, 1990). Greater knee flexion was suggested as a crucial movement to reduce joint loading (Devita & Skelly, 1992). We found that male athletes contacted the ground with greater knee flexion than female athletes. These angles were 15.5°, 17.1°, 17.3°, 19.8° in forward, 30° diagonal, 60° diagonal and lateral directions, respectively (Sinsurin, Vachalathiti, Jalayondeja, & Limroongreungrat, 2013). This finding could be a possible reason supporting previous studies (Fagenbaum & Darling, 2003; Schmitz et al., 2007) regarding why females have a higher risk of knee injuries. Interesting, both male and female athletes increased knee flexion from forward to lateral directions.

Table 1
Average lower extremity angle at initial contact phase (mean (SD))

Direction	Average angle of non-dominant limb (degree)			Average angle of dominant limb (degree)		
	Hip flexion	Knee flexion	Ankle plantarflexion	Hip flexion	Knee flexion	Ankle plantarflexion
Forward (0°)	31.2 (2.7)	9.5 (6.7)	21.6 (7.8)	30.7 (4.8)	9.1 (7.1)	24.6 (15.5)
30° diagonal	32.3 (3.4)	10.6 (7.4)	23.06 (7.9)	31.2 (6.2)	8.62 (6.2)	27.0 (13.9)
60° diagonal	31.7 (5.1)	11.0 (7.7)	23.58 (8.1)	31.0 (5.4)	10.0 (6.9)	25.1 (14.0)
Lateral (90°)	27.3 (4.6)	12.9 (8.6)	22.14 (8.7)	29.1 (4.5)	11.8 (7.9)	23.4 (14.3)

Table2
Average lower extremity angle at peak vertical GRF and peak vertical GRF phase (mean (SD))

Direction	Average angle of non-dominant limb (degree)			Average angle of dominant limb (degree)			Peak vertical GRF during landing (N/kg)	
	Hip flexion	Knee flexion	Ankle dorsiflexion	Hip flexion	Knee flexion	Ankle dorsiflexion	Non-dominant	Dominant
Forward (0°)	38.0 (2.0)	24.6 (9.3)	0.8 (3.5)	36.1 (5.2)	22.8 (10.4)	0.9 (3.0)	38.88 (5.70)	40.15 (4.00)
30° diagonal	37.8 (3.6)	24.9 (9.8)	2.56 (4.2)	36.4 (5.8)	23.3 (11.1)	2.6 (3.4)	42.44 (3.32)	42.28 (3.72)
60° diagonal	37.3 (3.7)	26.1 (9.6)	6.58 (3.8)	36.2 (5.7)	23.8 (14.0)	6.5 (2.6)	42.11 (5.48)	42.50 (5.03)
Lateral (90°)	34.9 (4.1)	27.4 (10.9)	14.12 (4.6)	34.6 (5.6)	23.9 (14.2)	15.0 (4.5)	40.31 (5.92)	41.93 (5.57)

An increasing trend of ankle dorsiflexion angle was observed from forward to lateral direction in both the DL and NDL. Increased ankle dorsiflexion may be the strategy for response during peak vertical GRF in different direction of jump landing. An increase of peak plantarflexor moment and ankle dorsiflexion were exhibited during jump landing from forward to lateral direction in male athletes (Sinsurin et al., 2013). Forward landing in both limbs resulted in less peak vertical GRF. Hip flexion and ankle dorsiflexion angles were significantly different at peak vertical GRF in the varied directions of jump-landing (Table 2).
Landing with an ankle dominant strategy was defined as stiff landing (S. N. Zhang et al., 2000). Increased hip and knee flexion during landing, a soft landing, has been suggested to reduce impact loading (Yu, Lin, & Garrett, 2006). In order to prevent knee injuries, increasing hip and knee flexion should be suggested for landing in multidirections rather than using just an ankle strategy. An increasing trend and higher angle at the ankle of the NDL was observed in all directions of landing compared to the DL. The possible reason could be that the NDL might be more accustomed to the landing or weight acceptance movement and, then, increased knee flexion angles from forward to lateral landings to protect joint structures.
Previous studies have investigated the frequency of unilateral landing in volleyball games and reported that landing on the NDL was more common 35% compared to landing on the DL 10%, (Tillman et al., 2004). All participants in the pilot study had right hand dominance. During hitting a ball with the right hand, the body's center of mass shifts to the left due to left lateral trunk flexion. This movement could result in landing on the left lower limb. It might be thought that the NDL frequently is preferred as the landing limb. Strength differences between DL and NDL have been reported. Stronger knee flexors were noted in the NDL meanwhile knee extensors were stronger in DL in females (Lanshammar & Ribom, 2011). Higher 10% - 15% imbalance of lower limbs could lead to increased risk of lower extremity injury. However, the main effect of side-to-side difference was not significant to any parameter. These participants will be included in the larger study. Moreover, other biomechanical parameters will be studied such as frontal angles, joint coordination, and joint moments.

CONCLUSION: Jump-landing direction significantly influenced hip and knee flexion angles at initial contact phase and to hip flexion angle, ankle dorsiflexion angles, and peak value of vertical GRF at peak vertical GRF. These female athletes exhibited a trend of using an ankle strategy in multidirections of landing that is similar to stiff landing. For injury prevention of lower extremity, an increase of hip and knee flexion should be suggested during landing as soft landing.

REFERENCES:

Devita, P., & Skelly, W. A. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and science in sports and exercise, 24*, 108-115.
Dufek, J. S., & Bates, B. T. (1990). The evaluation and prediction of impact forces during landings. *Medicine and science in sports and exercise, 22*, 370-377.
Fagenbaum, R., & Darling, W. G. (2003). Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injury. *The American journal of sports medicine, 31*, 233-240.
Hewett, T. E., Paterno, M. V., & Myer, G. D. (2002). Strategies for enhancing proprioception and neuromuscular control of the knee. *Clinical orthopaedics and related research,* (402), 76-94.
Lanshammar, K., & Ribom, E. L. (2011). Differences in muscle strength in dominant and non-dominant leg in females aged 20-39 years a population-based study. *Physical therapy in sport, 12*, 76-79.
Louw, Q., Grimmer, K., & Vaughan, C. (2006). Knee movement patterns of injured and uninjured adolescent basketball players when landing from a jump: a case-control study. *BMC musculoskeletal disorders, 7*, 22.
Salci, Y., Kentel, B. B., Heycan, C., Akin, S., & Korkusuz, F. (2004). Comparison of landing maneuvers between male and female college volleyball players. *Clinical biomechanics, 19*, 622-628.
Schmitz, R. J., Kulas, A. S., Perrin, D. H., Riemann, B. L., & Shultz, S. J. (2007). Sex differences in lower extremity biomechanics during single leg landings. *Clinical biomechanics, 22*, 681-688.
Sinsurin, K., Vachalathiti, R., Jalayondeja, W., & Limroongreungrat, W. (2013). Different Sagittal Angles and Moments of Lower Extremity Joints during Single-leg Jump Landing among Various Directions in Basketball and Volleyball Athletes. *Journal of physical therapy science, 25*, 1109-1113.
Soderman, K., Alfredson, H., Pietila, T., & Werner, S. (2001). Risk factors for leg injuries in female soccer players: a prospective investigation during one out-door season. *Knee surgery, sports traumatology, arthroscopy, 9*, 313-321.
Tillman, M. D., Hass, C. J., Brunt, D., & Bennett, G. R. (2004). Jumping and Landing Techniques in Elite Women's Volleyball. *Journal of sports science & medicine, 3*, 30-36.
Wikstrom, E. A., Tillman, M. D., Kline, K. J., & Borsa, P. A. (2006). Gender and limb differences in dynamic postural stability during landing. *Clinical journal of sport medicine, 16*, 311-315.
Winter, David A. (2005). *Biomechanics and motor control of human movement* (Third edition ed.). Waterloo: John Wiley & Sons, Inc.
Yu, B., Lin, C. F., & Garrett, W. E. (2006). Lower extremity biomechanics during the landing of a stop-jump task. *Clinical biomechanics, 21*, 297-305.
Zhang, S., Derrick, T. R., Evans, W., & Yu, Y. J. (2008). Shock and impact reduction in moderate and strenuous landing activities. *Sports biomechanics, 7*, 296-309.
Zhang, S. N., Bates, B. T., & Dufek, J. S. (2000). Contributions of lower extremity joints to energy dissipation during landings. *Medicine and science in sports and exercise, 32*, 812-819.

Acknowledgement

The authors would like to thanks all athletes for participation in this study and also Associate Professor Dr. Patricia E. Sullivan. This research was supported by the young investigator funding, Mahidol University.