International Journal of EXERCISE SCIENCE

Original Research

Lower Limb Force Asymmetries During Landing and Jumping Exercises: A Pilot Study

SIMON M. CONE† and SANGWOO LEE‡

Department of Human Performance and Health Education, Western Michigan University, Kalamazoo, MI, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 14(1): 544-551, 2021. Significant asymmetries can exist between the lower limbs' force production during the take-off phase of bilateral jumping exercises. Some studies have indicated that similar asymmetries can also exist during the landing phase. It has not been demonstrated if the magnitude of lower body asymmetry was similar between the landing (L) and take-off (TO) phases of bilateral jumping movements. The main purpose of this study was to compare the asymmetry measured during the L and TO phases of bilateral jumping exercises to determine if there was a difference in asymmetry between the phases. In order to quantify the degree of the asymmetry, the vertical ground reaction force (vGRF) produced by each leg was measured during execution of vertical-jump (VJ) and drop-jump (DJ) exercises. Eleven recreationally trained individuals completed three VJ and DJ trials while two force plates recorded vGRF. A two-way repeated measures ANOVA was used to compare the asymmetry levels with the phase (within- subject: L and TO) and the exercise (within- subject: VJ and DJ) being factors. A significant difference in the asymmetry was found between the L and TO phases ($p < .05$). These findings suggested that there was greater asymmetry in the distribution of vGRF during landing than during take-off.

KEY WORDS: Force plates, plyometrics, landing asymmetry

INTRODUCTION

Lower limb asymmetry occurs when there is a difference in the strength, power, or force between the legs. Significant lower limb asymmetry occurred primarily during bilateral lower body movements (3, 7, 13). Multiple factors such as gender, previous lower body injuries, a difference in leg length, and participation in a sport which emphasizes the use of a dominant limb, have been linked to increased asymmetry (6, 9, 12, 14). The level of asymmetry has previously been analyzed using an index of asymmetry (AI) which calculates the asymmetry as a percentage (3, 12, 17). Previous research has suggested that asymmetry greater than 10-15% may result in additional stress being placed on one leg, ultimately increasing an individual's injury risk and potentially inhibiting their performance (9, 11, 19).

It has been established that 70% of anterior cruciate ligament (ACL) injuries occurring during sports participation happened due to noncontact causes (8, 18). These injuries occurred mostly during eccentric lower body movements such as landing or pivoting maneuvers (8,18). During these movements, eccentric muscle contractions controlled the lower body joints, allowing the kinetic energy of the body to be absorbed (18). A research study that investigated ACL injuries in a group of female athletes found that a higher peak vertical ground reaction force (vGRF) and a shorter stance time during a drop-jump (DJ) test were key indicators of ACL injury throughout a sports season (10). In addition, poor joint stability during landings has repeatedly been shown to be a risk factor of noncontact ACL injuries, especially in female athletes (8, 9, 15). Thus, improved landing and cutting mechanics has been shown to decrease the risk of ACL injury and would also allow for optimal absorption of the forces acting on the knee joint and (8).

Despite the importance of lower body energy absorption during landings, research on lower body asymmetry has primarily focused on the concentric phase of the exercise (2, 3, 17). There has been one research study that examined lower body asymmetries during both the eccentric (i.e. landing) and concentric (i.e. take-off) phases. This study measured peak vGRF during DJ trials in individuals who had undergone an ACL surgery (19). The results showed that a significant level of asymmetry was found between the operated and non-operated legs during both the landing and take-off phases; however, this study did not directly compare the levels of asymmetry between the landing and take-off phases (19).

It is also believed by the present authors that the intensity of a jumping exercise could affect the level of asymmetry. Previous research quantified the intensity of several plyometric exercises by using a force plate to assess kinetic characteristics, such as peak vGRF, rate of force development, and jump height (1). Additional research showed that as the exercise intensity increased when preforming back squats, the level of lower body asymmetry decreased; however, it has not been investigated whether this is true for jumping exercises (13). Therefore, the main purpose of this study was to compare the asymmetries during the L and TO phases of the vertical jump (VJ) and DJ to determine if there was a significant difference in the asymmetry. Additional comparisons were conducted between the exercise conditions to determine if exercise selection had an impact on lower body asymmetry. It was hypothesized that 1) asymmetry levels would be significantly different between the L and TO phases and 2) the asymmetry would significantly differ between the exercise conditions.

METHODS

Participants

After gaining approval from the Institution Review Board, eleven university students (ten males and one female) were recruited to participate in the study (age: 23.4 ± 1.3, height: 177.8 ± 8.3, mass: 80.4 ± 12.2). A sample size of eleven was selected based on previous research studies and the fact that this was a pilot study designed to preliminarily investigate two hypotheses and provide direction for future research studies (12, 13, 17). After the procedures and risks of the study were explained and written consent was obtained, the individuals were allowed to begin participation. Participants were all between the ages of 18-28, had an average body mass index of 25.3±2.8 kg/m². In addition, participants all had participated in at least two years of organized sport experience and had engaged in such athletic activity within the previous two years. Any individual with a lower body injury in the previous six months was excluded from participating. This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (16).

Protocol
Height and body mass were first measured. A demonstration of the exercises was then given to the participant, and a warm-up was performed. For this warm-up, participants pedaled on a Monark cycle ergometer at a self-selected pace for five minutes, and then performed three practice trials of the VJ and DJ. These practice trials served to familiarize the participants with the technique of each exercise. In between the warm-up and data collection trials, the participants were given a five-minute break.

Following the warm-up, participants preformed three trials of each exercise for data collection. Each participant preformed the exercises in a randomized order. For the VJ exercise, the participants were instructed to stand with one foot on each force plate and perform a countermovement jump with maximal effort, landing with one foot on each force plate. For the DJ exercise, the participants stood on a box that was 31 cm tall, stepped off and landed, then immediately preformed a countermovement jump with maximal effort, landing again with one foot on each force plate (21). There were two landings during the DJ, the second was used as the L phase. The leg demonstrating the greater peak vGRF value was considered the dominant leg for data analysis.

Two 1000-Hz force plates (Model Optima; Advanced Mechanical Technology, Inc., Watertown, MA, USA) were used to capture vGRF data independently from each foot. Peak vGRF data from the 3 trials were averaged for statistical analysis (4). The data extractions for the peak vGRF during the L and TO phases were presented in Figure 1.

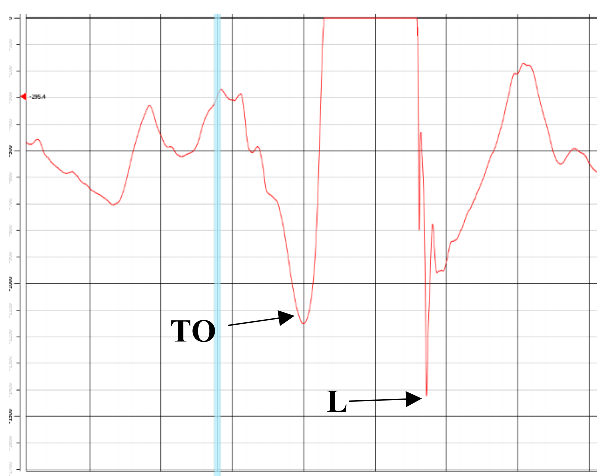

Figure 1. A sample of vGRF extraction for landing (L) and take-off (TO) and phases during vertical jump.

The vGRF data collected was used to calculate an asymmetry index (AI) for each phase of each exercise in order to quantify the asymmetry as a percentage (14). The AI was calculated using the following equation (3, 12, 17).

$$AI\ (\%) = \left(\frac{dominant\ leg - nondominant\ leg}{dominant\ leg}\right) \times 100$$

Statistical Analysis
A two-way repeated measures ANOVA was used to investigate significant differences in the asymmetry with the phase (within- subject: L and TO) and the exercise (within- subject: VJ and DJ) being factors. For any significant effect, post hoc pairwise comparison tests were performed with a paired sample t-test. To explain the AI result, vGRF data were also compared between the L and TO phases using a two-way repeated measures ANOVA. Data was initially analyzed using Microsoft Excel (Microsoft, Redmond, WA). Statistical analysis was conducted using IMB SPSS Statistics version 25 (IBM, New York, USA), and the α level set a priori to 0.05.

RESULTS

The average AI for the experimental conditions were 4.01 ± 3.25% (TO-VJ), 4.43 ± 3.72% (TO-DJ), 12.62 ± 8.36% (L-VJ), and 11.17 ± 7.41% (L-DJ), respectively. The average vGRF in the dominant leg for the experimental conditions were 1047.03 ± 229.53N (TO-VJ), 1008.67 ± 277.66N (TO-DJ), 2335.91 ± 1044.96N (L-VJ), and 2651.48 ± 999.94N (L-DJ), respectively. There was no significant interaction of AI between the phases (TO and L) and exercises (VJ and DJ). However, there was a significant main effect of the phases on AI ($p < 0.05$) indicating that lower body asymmetry was higher during the L phase than the TO phase (Figure 2). The L phase also showed a significantly higher vGRF than the TO phase ($p < 0.05$) (Figure 2).

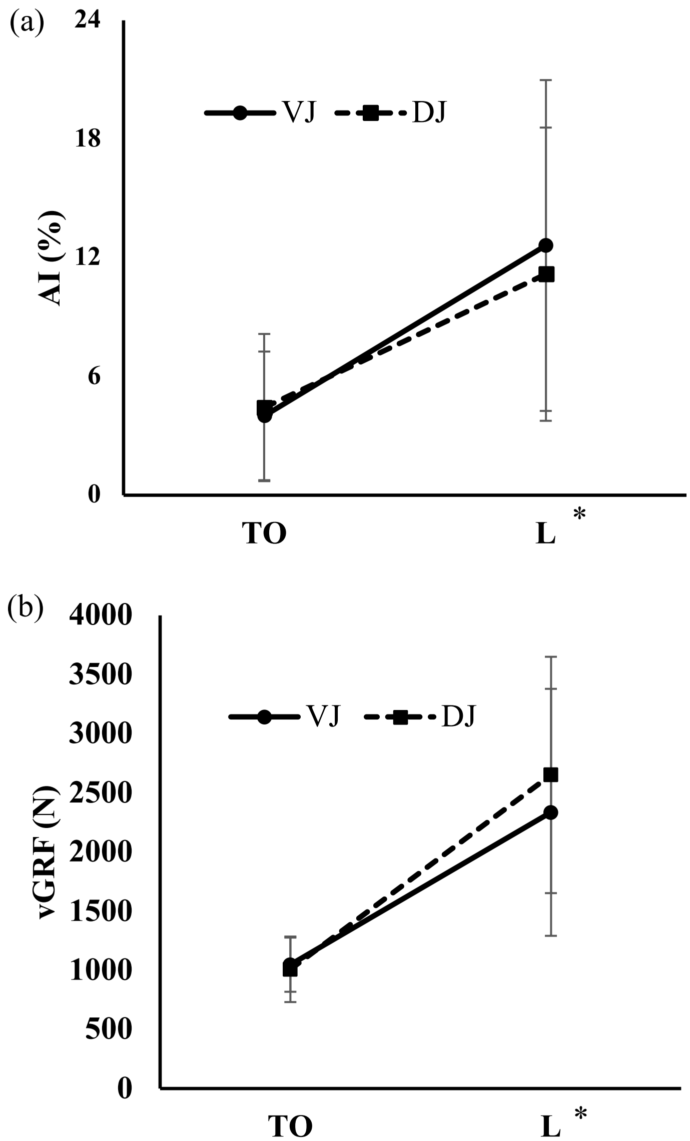

Figure 2. The results of (a) asymmetry index (AI) and (b) peak vertical ground reaction force (vGRF) for the take-off (TO) and landing (L) phases of vertical jump (VJ) and drop jump (DJ). *Represents that the L phase showed significantly greater AI and vGRF than the TO phase.

DISCUSSION

The purpose of this study was to compare the lower body asymmetry present during the TO and L phases of the VJ and DJ exercises. This was the first study to compare the asymmetry measured during the TO and L phases of different jumping exercises. A significant difference in AI was found between the TO and L phases indicating that lower body asymmetry was higher during a phase of force absorption (i.e. L phase) compared to a phase of force production (i.e. TO phase). However, no significant interaction was observed between the phases and the exercises.

The discrepancy in AI between the TO and L phases was likely to be due to a difference in joint stability of the legs between the phases. A previous study reported that the increased movement velocity during eccentric muscle action, such as the L phase, has been shown to produce more strain on the ACL than a maximal voluntary contraction of the quadriceps during concentric muscle action, such as the TO phase (8). This greater strain attributable to the increased velocity during the eccentric phase (i.e. L phase) could contribute to greater knee instability leading to the landing mechanics becoming more difficult to control. Another study also indicated that greater knee instability was often evident during landings in the frontal plane knee valgus (20). Moreover, it was also observed in the current study that the participants tended to land with one foot after another as opposed to the TO phase. As a result, one foot striking the ground before the other could also lead to one leg absorbing a greater portion of the vGRF. Thus, specific exercise programs designed to improve neuromuscular control of the body during landings have been suggested as a method of decreasing the risk of an ACL injury during a landing (9).

Leg asymmetry exceeding 10-15% has been considered to be an injury risk and has also been used as a criterion for return to sport following ACL injuries (19). This threshold was in line with the asymmetry (12.62 ± 8.36 for VJ and 11.17 ± 7.41 for DJ) observed in the current study during the L phase. This study also indicated that a significantly higher mean peak vGRF was observed during the L phase than during the TO phase, which was in agreement with previous research (1). This higher vGRF combined with increased asymmetry during the L phase could be a mechanism explaining the high incidence of ACL injures occurring during landing movements. Due to this, a lower asymmetry threshold of 0-5% for return to sport may be a safer recommendation.

Excessive lower limb asymmetry can increase the likelihood of lower body injuries occurring in both the stronger leg and the weaker leg (4). In a study investigating competitive skiers who had undergone an ACL repair, it was found that the contralateral knee experienced an ACL injury more often than the repaired knee after the repair (19). Thus, following an ACL injury, it is important to address proper landing mechanics during the rehabilitation process because it will facilitate optimal absorption of the forces acting on the joints during a landing and reduce the development of compensatory lower body mechanics.

There were several limitations in this study. A small number of participants were used, and male participants were primarily recruited for this study. The results of this study may be applied with caution to recreationally trained athletes. Since athletes with more years of experience may display lower asymmetry levels due to enhanced neuromuscular movement patterns, the finding of this study needs to be applied to athletes with caution (5).

In conclusion, during jumping exercises, landing showed greater lower body asymmetry and increased vGRF than take-off. Strength coaches and athletes should consider including landing movements, placing an emphasis on proper mechanics, in their workout programs due to their potential to reduce the risk of injury. A landing technique that promotes both decreased asymmetry and vGRF may be optimal for the health of the lower body joints. Future research needs to be carried out in a larger group of both male and female athletes to verify the findings of this research and compare the asymmetry between males and females. Additionally, more research is needed to determine the optimal asymmetry threshold for minimizing the risk of reinjury when returning to sport following ACLR.

REFERENCES

1. Ebben WP, Fauth ML, Garceau LR, Petushek EJ. Kinetic quantification of plyometric exercise intensity. J Strength Cond Res 25(12): 3288-3298, 2011.

2. Flanagan SP, Salem GJ. Bilateral differences in the net joint torques during the squat exercise. J Strength Cond Res 21(4): 1220-1226, 2007.

3. Fort-Vanmeerhaeghe A, Gual G, Romero-Rodriguez D, Unnitha V. Lower limb neuromuscular asymmetry in volleyball and basketball players. J Hum Kinet 50(1): 135-143, 2016.

4. Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. Med Sci Sports Exerc 35(10): 1745-1750, 2003.

5. Fousekis K, Tsepis E, Vagenas G. Lower limb strength in professional soccer players: profile, asymmetry, and training age. J Sport Sci Med 9(3): 364-373, 2010.

6. Friberg O, Kvist M. Factors determining the preference of takeoff leg in jumping. Int J. Sports Med 9(5): 349-352, 1988.

7. Girard O, Brocherie F, Morin JB, Millet GP. Lower limb mechanical asymmetry during repeated treadmill sprints. Hum Movement Sci 52: 203-214, 2017.

8. Griffin LY, Agel J, Albohm MJ, Arendt EA, Dick RW, Garrett WE, Johnson RJ. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. J Am Acad Orthop Surg 8(3): 141-150, 2000.

9. Hewett TE, Ford KR, Hoogenboom BJ, Myer GD. Understanding and preventing acl injuries: current biomechanical and epidemiologic considerations-update 2010. N Am J Sports Phys Ther 5(4): 234-251, 2010.

10. Hewett TE, Myer GD, Ford KR, Heidt Jr RS, Colosimo AJ, McLean SG, Succop P. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. Am J Sport Med 33(4): 492-501, 2005.

11. Hoffman JR, Ratamess NA, Klatt M, Faigenbaum AD, Kang J. Do bilateral power deficits influence direction-specific movement patterns? Res Sports Med 15(2): 125-132, 2007.

12. Jordan MJ, Aagaard P, Herzog W. Lower limb asymmetry in mechanical muscle function: A comparison between ski racers with and without ACL reconstruction. Scand J Med Sci Sports 25(3): 301-309, 2015.

13. Lake JP, Lauder MA, Smith NA. Does side dominance affect the symmetry of barbell end kinematics during lower-body resistance exercise? J Strength Cond Res 25(3): 872-878, 2011.

14. Markou S, Vagenas G. Multivariate isokinetic asymmetry of the knee and shoulder in elite volleyball players. Eur J Sport Sci 6(1): 71-80, 2006.

15. Myer GD, Brent JL, Ford KR, Hewett TE. Real-time assessment and neuromuscular training feedback techniques to prevent ACL injury in female athletes. Strength Cond J 33(3): 21-35, 2011.

16. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

17. Newton RU, Gerber A, Nimphius S, Shim JK, Doan BK, Robertson M, Pearson DR, Craig BW, Kraemer WJ. Determination of functional strength imbalance of the lower extremities. J Strength Cond Res 20(4): 971-977, 2006.

18. Norcross MF, Lewek MD, Padua DA, Shultz SJ, Weinhold PS, Blackburn JT. Lower extremity energy absorption and biomechanics during landing, part I: sagittal-plane energy absorption analyses. J Athl Train 48(6): 748-756, 2013.

19. Paterno MV, Ford KR, Myer GD, Heyl R, Hewett TE. Limb asymmetries in landing and jumping 2 years following anterior cruciate ligament reconstruction. Clin J Sport Med 17(4): 258-262, 2007.

20. Paterno MV, Schmitt LC, Ford KR, Rauh MJ, Myer GD, Huang B, Hewett TE. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. Am J Sport Med 38(10): 1968-1978, 2010.

21. Schmitt LC, Paterno MV, Ford KR, Myer GD, Hewett TE. Strength asymmetry and landing mechanics at return to sport after ACL reconstruction. Med Sci Sports Exerc 47(7): 1426-1434, 2015.