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Original Article

Limb-dominance and gender differences in the ground reaction force during single-leg lateral jump-landings

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Abstract. [Purpose] The purpose of this study was to examine limb-dominance and gender differences in the magnitude of the ground reaction force during single-leg lateral jump-landings. We hypothesized that the peak ground reaction force would be larger in the non-dominant leg compared to that in the dominant leg and would be larger in females compared to that in men. [Subjects and Methods] Fifteen females and 15 males performed jump-landings sideways from a height of 20 cm, with a lateral distance of 60 cm. Vertical and medial ground reaction forces were measured, and the elapsed time from the initial contact to the peak ground reaction force was determined. The loading rate was calculated as the peak ground reaction force divided by the elapsed time from the initial contact to the peak ground reaction force. [Results] The vertical and medial peak ground reaction forces during single-leg lateral jump-landings were larger in females compared to that in males. In addition, the medial peak ground reaction force was larger for the non-dominant leg compared to that for the dominant leg. [Conclusion] The results suggest that in rehabilitation and conditioning settings, evaluations and instructions regarding attenuation are especially important for females and the non-dominant leg.

Key words: Side jump-landing impact, Gender differences, Asymmetry

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INTRODUCTION

Non-contact anterior cruciate ligament (ACL) injuries often occur during single-leg jump-landings while participating in basketball, handball, and soccer[1–4)]. The magnitude of the ground reaction force (GRF), which represents the landing impact force, affects the knee valgus moment and the tibial anterior shear force, and might increase mechanical stress on the ACL[5–9)]. A previous prospective study demonstrated that the vertical GRF (VGRF) during anterior jump-landings is 20% higher in female athletes who had sustained ACL injuries than in those who had not[10)]. Theoretically, the vector synthesized by the VGRF and medial GRF (MGRF) passes through the lateral side of the knee joint center, increasing the valgus moment and resulting in a larger ACL strain[8)]. Therefore, the VGRF and MGRF during landings have been identified as biomechanical risk factors for ACL injury[11)].

During anterior drop-landings, female athletes tend to show a larger valgus moment of the knee compared to that in male athletes[12, 13)]. Thus, female athletes display a greater risk for ACL injuries compared to that in male athletes[14)]. Furthermore, female athletes are more likely to injure the ACL in their non-dominant leg (non-DL), whereas male athletes tend to injure their dominant leg (DL) (defined as the preferred leg when kicking a ball)[15–17)]. These discrepancies could result from differences in the impact force and neuromuscular control between the non-DL and DL in males and females during jump-landings[14, 15, 18–22)].

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Many researchers have reported that the peak VGRF (pVGRF) during anterior drop-landings is larger in females compared to that in men[12, 13, 20]. However, others have reported that there is no difference in the pVGRF between males and females[23, 24], or that the pVGRF is larger in males compared to that in females[18]. Thus, gender differences in the GRF during anterior drop-landings remain controversial.

A previous study reported that there is no difference in the pVGRF during single-leg anterior jump-landings between the non-DL and DL[21]. However, basketball and handball competitions require athletes to jump in the air and land with one-leg in the lateral direction, rather than only in the anterior direction. Thus, in addition to anterior jump-landings, maneuvers that involve other jump-landing tasks should be assessed in order to determine the factors involved in injuries of the lower extremities[25, 26]. Furthermore, a significantly higher peak knee valgus angle is observed during side jump-landings compared to that during forward jump-landings[27]. As the kinetics and kinematics of the lower extremity during single-leg lateral jump-landings are different from those during anterior jump-landings[28], the possibility of a difference in the VGRF between the DL and non-DL during lateral jump-landings exists.

The purpose of this study was to examine limb-dominance and gender differences in the magnitude of the GRF during single-leg lateral jump-landings. We hypothesized that the peak GRF (pGRF) would be larger in the non-DL compared to that in the DL and would be larger in females compared to that in men. Improved understanding of the effect of these factors on the GRF might facilitate more effective evaluations or instructions that intend to attenuate the strain from the landing impact on the ACL during single-leg lateral jump-landings.

SUBJECTS AND METHODS

The inclusion criteria were as follows: physically active, at least 18 years of age, and without a history of serious injuries or surgery in the lower extremities or lumbar region. We recruited 15 healthy females and 15 healthy males with the following characteristics: mean age, 22.4 (SD 2.8) years; mean height, 166.1 (SD 9.7) cm; mean weight, 60.6 (SD 9.8) kg; and mean body mass index, 21.9 (SD 2.1) kg/m^2. There were no significant gender differences in age, sports participation time, or Tegner activity scale score. Eighty percent of the subjects participated in jump-landing and cutting sports, such as handball, volleyball, basketball, soccer, badminton, and tennis. The DL of each subject was defined as the leg used to kick a ball to maximal distance[29, 30]. Two of the 30 subjects were left-leg dominant. The Institutional Review Board at our institution approved the study design (approval number, 1885). All participants provided written, informed consent prior to participating in the study. As all subjects were over 16 years of age, had completed middle school, and were sufficiently able to decide whether to participate in the study, parental approval was not required.

All subjects were clothed in identical athletic attire, which comprised spandex shirts, shorts, and shoes with no air cushions. The subjects performed a 5-minute warm-up comprised of stationary bicycling without resistance and light stretches. Thereafter, the subjects were verbally and visually instructed regarding how to perform the jump-landing task. All subjects practiced 3 single-leg lateral jump-landings with the DL and non-DL to become accustomed to the movements before data collection. Subjects stood on a step (RBK-BO001, Reebok, Canton, MA, USA) on a single leg, with the other knee bent at up to 90°, neutral hip rotation, arms crossed, and hands inserted into the opposite axillae to eliminate the effect of arm movement[23, 25]. The subjects were verbally instructed to jump sideways, without any intentional upward action, to land as naturally as possible on the same leg into the center of a force plate (260AA6, Kistler Instrumente AG, Winterthur, Switzerland), and to maintain their balance for 5 seconds. The subjects were also verbally instructed to face forward during the jump-landing task. A step (25-cm high) was placed 60 cm from the center of the force plate. The height of the force plate surface was 5 cm above ground level. The task was repeated 3 times in succession for the DL and non-DL, in random order. A trial was deemed unacceptable if part of the sole of the foot fell outside the force plate at landing, the foot moved or slid after landing, or the sole of the opposite foot touched the force plate or floor. Failed trials were determined visually, and feedback on landing performance was withheld.

The VGRF and MGRF were collected at a sampling rate of 1,000 Hz. The GRFs were filtered using a low-pass Butterworth filter with a cut-off frequency of 50 Hz, and were normalized by body weight (%) using software (IFS-4 J/3 J, DKH, Tokyo, Japan). Extracted data included the time of initial contact (IC), and the pVGRF and peak MGRF (pMGRF) values and times. The time of IC was defined as the moment when the GRF exceed 10 N. The elapsed time from the IC to the pGRF was determined, and the loading rate was calculated as the pGRF divided by the elapsed time from the IC to the pGRF[13, 31]. The MGRF at the instant of the pVGRF (M-pVGRF) and VGRF at the instant of the pMGRF (V-pMGRF) were also extracted.

Reliability for the pVGRF and pMGRF of the DL showed good agreement, with intraclass correlation coefficients (ICC 1, 1) between 0.73 and 0.74 (among all 30 subjects). The intermediate value of the 3 jump-landing trials was analyzed[25]. In 2-way analyses of variance, the GRF measurements were specified as the dependent variable, and gender and leg dominance were specified as factors. For significant interactions, a t-test was used to compare the differences across classes for each of these factors. The significance level was set at 0.05. All data were analyzed using SPSS version 21.0 (IBM, Chicago, IL, USA). Using G*Power software (version 3. 1.9.2), a power analysis using the primary outcome of a limb difference indicated that 34 participants would be necessary to attain an a priori power of 0.80[32].

Table 1. Ground reaction force variables during single-leg lateral jump-landings (N=30)

GRF parameters	Total	Females		Males	
		Non-dominant leg	Dominant leg	Non-dominant leg	Dominant leg
pVGRF (%BW)*	388.1 ± 57.8 (373.2, 403.0)	408.2 ± 48.9 (381.1, 435.3)	411.4 ± 56.9 (379.9, 442.9)	373.2 ± 63.0 (338.3, 408.1)	359.6 ± 48.3 (332.8, 386.3)
pMGRF (%BW)*†	56.9 ± 11.5 (54.0, 59.9)	64.3 ± 11.3 (58.1, 70.6)	60.0 ± 12.6 (53.0, 67.0)	55.0 ± 8.6 (50.3, 59.8)	48.3 ± 6.6 (44.7, 52.0)
Time to pVGRF (ms)	67.9 ± 12.4 (64.6, 71.1)	66.8 ± 9.5 (61.6, 72.0)	64.9 ± 10.1 (59.4, 70.5)	69.7 ± 16.1 (60.8, 78.6)	70.0 ± 13.3 (62.6, 77.4)
Time to pMGRF (ms)	65.5 ± 15.4 (61.5, 69.5)	64.5 ± 10.4 (58.8, 70.3)	61.7 ± 9.9 (56.2, 67.2)	68.8 ± 16.4 (59.8, 77.9)	66.9 ± 22.1 (54.6, 79.2)
V-Loading rate (%BW/ms)	6.0 ± 1.8 (5.5, 6.5)	6.3 ± 1.5 (5.4, 7.1)	6.6 ± 2.2 (5.4, 7.8)	5.7 ± 1.6 (4.8, 6.5)	5.4 ± 1.9 (4.4, 6.5)
M-Loading rate (%BW/ms)	0.9 ± 0.3 (0.8, 1.0)	1.0 ± 0.2 (0.9, 1.1)	1.0 ± 0.4 (0.8, 1.3)	0.8 ± 0.2 (0.7, 1.0)	0.8 ± 0.4 (0.6, 1.0)
V-pMGRF (%BW)*†§	316.8 ± 94.7 (292.3, 341.3)	366.8 ± 74.4 (325.6, 408.0)	365.7 ± 94.9 (313.1, 418.3)	301.4 ± 73.5 (260.7, 342.1)	233.3 ± 69.9 (194.6, 272.0)
M-pVGRF (%BW)*†	52.1 ± 15.4 (48.1, 56.0)	61.2 ± 12.6 (54.2, 68.1)	57.3 ± 14.4 (49.3, 65.3)	50.5 ± 14.9 (42.21, 58.8)	39.2 ± 11.0 (33.1, 45.3)

Data are shown as means ± standard deviation (95% confidence interval). GRF: ground reaction force; BW: body weight; pVGRF: peak vertical ground reaction force; pMGRF: peak medial ground reaction force; Time to pVGRF: time between initial contact and pVGRF; Time to pMGRF: time between initial contact and pMGRF; V-Loading rate: pVGRF/(Time to pVGRF); M-Loading rate: pMGRF/(Time to pMGRF); V-pMGRF: VGRF at pMGRF; M-pVGRF: MGRF at pVGRF.
*Significant effect of gender.
†Significant effect of limb dominance.
§Significant interaction between gender and limb dominance, with a significant simple effect of limb dominance only in males.

RESULTS

Results for the GRF variables during the single-leg lateral jump-landing task are presented in Table 1. In females, the average pVGRF was more than 380% of the body weight (%BW), and the average pMGRF was more than 53%BW for both the DL and non-DL. In both males and females, the average elapsed time from the IC to the pVGRF and pMGRF was in the range of 61.7–70 ms for both the DL and non-DL. In females, the average V- and M-loading rates exceeded 6 and 1.0%BW/ms for the DL and non-DL, respectively. In females, the average V-pMGRF exceeded 365%BW, and the average M-pVGRF exceeded 57% BW for both the DL and non-DL.

A significant effect of gender was demonstrated for the pVGRF, pMGRF, V-pMGRF, and M-pVGRF, with larger values in females compared to those in males (Table 1). For the non-DL, the average pVGRF was 35% greater in females compared to that in men. A significant effect of leg dominance was demonstrated for the pMGRF, V-pMGRF, and M-pVGRF, with larger values in the DL compared to those in the non-DL. In addition, a significant interaction between gender and limb dominance was found for the V-pMGRF, with a simple main effect of leg dominance observed only in men.

DISCUSSION

The present study sought to examine the effect of limb-dominance and gender on GRF assessments during single-leg lateral jump-landings, which is a common maneuver in sports activities associated with ACL injuries, but has not been well-studied. The results showed that the pVGRF and pMGRF during single-leg lateral jump-landings were larger in females compared to that in men. The average pVGRF and pMGRF for the non-DL were approximately 35%BW and 9%BW greater in females compared to that in men, respectively. These findings suggest that the capacity to absorb the vertical and frontal landing impact is less in females compared to that in men.

There are no reports related to gender differences in the GRF during single-leg lateral jump-landings. During a single-leg anterior drop-landing, active healthy females landed with 35% greater pVGRF compared to that in men[20]. Females exhibited 120% greater pVGRF compared to that in men[12]. Gender had a significant effect on the VGRF, with higher pVGRFs in females compared to that in men[13]. A combination of less knee and hip flexion during landing in females relates well to the concept of females adopting a “stiffer” landing mechanism in order to decrease downward momentum[20, 33, 34]. The magnitude of the VGRF during anterior jump-landings is greatest during the landing phase when the knee is between 0° and 25° of flexion, and must resist rapid changes in kinetic energy[35]. Attenuating the impact forces by increasing knee and hip flexion during anterior jump-landings with one leg or both legs reduces both the pVGRF and ACL strain[36–38]. Since the angles of the leg joints were not measured in the current study, the relationship between the joint angles and the demonstrated gender difference in GRF is unknown. However, based on the results of previous studies using anterior jump-landing tasks, we can infer that during lateral jump-landings, the flexion angle of the knee or hip joint in females adopts a smaller angle, resulting in a stiffer landing; therefore, the GRF is larger in females compared to that in men.

The pMGRF in females (43 ± 11%BW) is not significantly different from that in males (37 ± 10%BW) during single-leg anterior drop-landings[12]. In contrast, the current study found that the MGRF was significantly higher in females during single-leg lateral jump-landings. This perhaps indicates that lateral jump-landing tasks are more appropriate than anterior jump-landing tasks for evaluating gender differences in the attenuating capacity of the frontal impact force.

The VGRF is lower in females compared to that in males during forward jump-landings of 30–70 cm from a height of 30–60 cm[18]. The task used in the current study did not have a short distance drop-landing; rather, the subjects performed jump-landings from a height of 20 cm, with a lateral distance of 60 cm. Although the jumping task and direction used by Ali et al. were different from that in the current study, the step height and sagittal distance were similar. Despite this, the VGRF in males and females showed reversed magnitude/size relationships.

The frontal plane knee or leg kinematics during anterior drop-landings has been reported to be different in males and females[19]. In men, the hip flexion angle is significantly smaller during lateral jump-landings compared to that in anterior jump-landings[28]. Thus, the larger VGRF in females in the current study may be due to gender differences in altered neuromuscular control during lateral-jump landings relative to that in anterior jump-landings. No previous reports exist wherein the pVGRF and pMGRF during single-leg lateral jump-landings were larger in females than in men. Thus, the current study provides new data related to gender differences in the GRF during single-leg lateral jump-landings.

The current study also showed that the pMGRF and M-pVGRF were larger for the non-DL compared to that in the DL. The average pMGRF in females and males was 4.3%BW and 6.7%BW greater for the non-DL compared to that for the DL, respectively. In addition, the average M-pVGRF in females and males was 3.9%BW and 11.3%BW greater for the non-DL compared to that for the DL, respectively. These findings suggest that the capacity to absorb the frontal impact force is less in the non-DL compared to that for the DL in both genders, but particularly in men. Moreover, the current study also showed that the V-pMGRF was about 68%BW larger for the non-DL compared to that in the DL in men, whereas there was no significant difference in females. These findings suggest that only males have a lesser capacity to absorb the vertical impact force in the non-DL compared that in the DL. In their study, van der Harst et al. reported that there was no clear difference in the pVGRF during single-leg anterior maximal jump-landings between the DL and non-DL[21]. However, the fact that the hop distance was significantly longer in the DL compared to that in the non-DL indicates that the impact absorption capacity of the non-DL lags behind that of the DL. Thus, a difference occurs in frontal impact attenuation due to this lag in the neuromuscular control of the non-DL relative to that of the DL[39, 40]. No previous reports exist wherein the pMGRF, M-pVGRF, and V-pMGRF during single-leg lateral jump-landings were larger in the non-DL compared to that in the DL. Thus, the current study provides new data related to limb-dominance effects on the GRF during single-leg lateral jump-landings. Although the calculation of excessive anterior translation or internal rotation of the tibia associated with ACL damage requires a model and the use of a 3-dimensional motion capture system, this system is expensive and requires a long time for preparation and measurement, creating a significant burden on the subjects. In contrast, calculating the GRF using a force plate is quick and easy, and the measurements can be taken in a relatively short period of time. Therefore, we can regularly check the GRF asymmetry and transition in athletes and patients at actual sporting fields or in clinical practice. In addition, we consider GRF measurement advantageous in terms of providing movement instructions for impact attenuation, based on the GRF data.

The greatest limitation of the current study is that both males and females landed from a height of 20 cm even though males were, on average, slightly taller (by 15.5 cm). This may have resulted in the task being slightly more difficult for females, thus altering their landing strategy[20]. In addition, a relatively small sample size (N=30) may have hindered our ability to detect GRF differences. The ability to detect the presence of effect sizes less than 0.25 at 80% power would have necessitated 2 additional subjects of each gender. Furthermore, although the DL in the current study was defined as the leg used for kicking, there are various other possible definitions. Although previous studies have similarly defined the DL as the kicking leg[41, 42], other definitions have been used, including the stronger leg[43], the foot used to initiate stair-climbing[44], the leg used to regain balance after an unexpected perturbation[45], and the side with the highest single leg-jump height[40, 44]. The relation between the GRFs for the DL and non-DL might change depending on the definition used[6]. In addition, various authors have previously reported that many subjects do not jump higher with the self-determined DL compared to that with the self-determined non-DL[40, 46]; thus, performance comparisons of the DL to the non-DL may not be useful for detecting differences in neuromuscular capacities. However, the neuromuscular function of the DL is not necessarily higher than that of the non-DL; the relation seems to change based on the specific task[39, 40]. In the current study, to minimize the effect of arm movement on the GRF parameters, subjects were asked to cross their arms and keep their hands under the opposite axillae[23, 25]. Thus, the results of this study may not apply when subjects perform jump landings without crossing their arms. Finally, in order for the gender and limb-dominance effects on the GRF that were obtained in the current study to support the finding that the GRF is a risk factor of ACL injury, it may be necessary to conduct a longitudinal study in which the onset of an ACL injury occurs after the GRF has been analyzed together with the knee joint angles and moment, using a three-dimensional motion capture system.

The significant effects of gender and leg dominance on GRFs should be considered during evaluations and instructions in attenuation, especially for females and the non-DL. Based on a previous study using an anterior jump-landing task to improve the attenuation capacity and to control the mechanical stress on the ACL, instructions and feedback that include increasing the hip and knee flexion, contact using the ball of the foot, imagining a feather dropping, and controlling the foot contact sound should be applied[36]. The only previous study using a lateral jump-landing task suggested controlling the excessive anterior inclination of the pelvis to attenuate the landing impact[25].

Gender differences and asymmetry in neuromuscular control of the lower extremity are commonly evaluated based on the muscle strength. However, it is also important to analyze the kinetics or kinematics using actual sports activities with jump-landings[39]. The kinetics or kinematics of a non-injured or non-operated leg are commonly used as a comparison base in the evaluation of lower extremity function after ACL injury or reconstructive surgery. However, the asymmetry of the impact attenuation before the ACL issue arises must be taken into consideration.

In conclusion, we examined limb-dominance and gender differences in the magnitude of the GRF during single-leg lateral jump-landings. The pVGRF and pMGRF during single-leg lateral jump-landings were larger in females compared to that in men. In addition, the pMGRF and M-pVGRF were larger for the non-DL compared to that for the DL. These findings suggest that the capacity to absorb the vertical and frontal landing impact is affected by gender and limb dominance. The advantage of lateral jump-landings over anterior jump-landings as a measurement task is that the MGRF can be analyzed as a variable with impact attenuation ability. An understanding of the differences in the pMGRF, not just the pVGRF, caused by limb dominance and gender might facilitate more effective evaluations or instructions that intend to attenuate the strain of the landing impact on the ACL during single-leg lateral jump-landings.

Conflict of interest

None.

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