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original article

Kinetic asymmetries between forward and drop jump landing tasks

Assimetrias cinéticas entre saltos para frente e saltos de queda

Morgana Alves de Britto[1,2]
Pedro Silvelo Franco[1,2]
Evangelos Pappas[3,4,5]
Felipe Pivetta Carpes[1,2]

Abstract – Landing asymmetry is a risk factor for knee anterior cruciate ligament injury. The aim of this study was to identify kinetic asymmetries in healthy recreational athletes performing different jump-landing techniques. Twelve recreational athletes engaged in regular training underwent kinetic evaluation using two 3D force plates and were analyzed for: (a) three-dimensional peak forces, (b) time to peak vertical force, and (c) initial phase asymmetries. All data were collected during performance of unilateral and bilateral trials of forward and drop jump tasks. Forward jump-landing tasks elicited greater kinetic asymmetry than drop-landing tasks. Regardless of jump-landing technique, the preferred leg experienced higher forces than the non-preferred leg. The initial landing phase showed more kinetic asymmetries than the later phase when peak vertical forces occur. It was concluded that when screening athletes for kinetic asymmetries that may predispose them to injury, forward jump-landing tasks and the early landing phase might show more kinetic asymmetries than drop jump-landing tasks and the late landing phase, respectively.

Key words: Anterior cruciate ligament; Athletic injuries; Knee injuries; Sports medicine.

Resumo – *Assimetrias durante a aterrissagem de tarefas de salto são um fator de risco para lesão de ligamento cruzado anterior do joelho. O objetivo deste estudo foi identificar assimetrias cinéticas em atletas recreacionais saudáveis, enquanto realizavam diferentes tarefas de salto e aterrissagem. Doze atletas recreacionais que treinavam regularmente realizaram uma avaliação cinética, em que foram avaliadas as seguintes variáveis: (a) pico das forças de reação do solo (nas três componentes), (b) tempo para o pico de força vertical, e (c) assimetrias na fase inicial da aterrissagem. Os dados foram coletados durante a execução de saltos unilaterais e bilaterais, assim como de saltos para frente e saltos de queda. Saltos para frente demonstraram maiores assimetrias cinéticas comparados com os saltos de queda. Independente do tipo de salto, a perna preferida recebeu maiores cargas se comparada com a perna não preferida. A fase inicial da aterrissagem foi mais sensível na detecção de assimetrias cinéticas do que a fase mais tardia da aterrissagem, quando ocorrem os picos de força. Pode-se concluir que as avaliações para detectar assimetrias cinéticas em atletas, saltos para frente e a fase inicial da aterrissagem parecem ser mais sensíveis para a detecção dessas assimetrias.*

Palavras-chave: *Ligamento cruzado anterior; Medicina esportiva; Traumatismos do joelho; Traumatismos em atletas.*

1 Federal University of Pampa. Applied Neuromechanics Research Group. Laboratory of Neuromechanics. Uruguaiana, RS. Brazil.

2 Federal University of Santa Maria. Laboratory of Biomechanics. Santa Maria, RS. Brazil.

3 University of Sydney. Faculty of Health Sciences. Lidcombe, NSW. Australia.

4 Long Island University-Brooklyn Campus. Department of Physical Therapy. Brooklyn, NY. USA.

5 Orthopaedic Sports Medicine Center of Ioannina. Department of Orthopaedic Surgery. School of Medicine. Ioannina. Greece.

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INTRODUCTION

ACL injuries usually occur through a non-contact mechanism, frequent during jump-landing tasks[1-5]. These injuries are very common in the physically active population, and most ACL injuries require surgical treatment[6,7]. Athletes predisposed to knee ACL injury may exhibit one or more faulty neuromuscular strategies: a) they land with excessive knee valgus, which requires higher stress on their ligaments, b) they recruit quadriceps more than hamstrings, c) they present trunk control deficits such as reduced trunk proprioception[8], and d) they exhibit kinetic and kinematic leg asymmetries, for example, imbalance in joint angles or forces between lower extremities. Several studies have focused on the first three strategies[9-13], but there is limited information on the last neuromuscular strategy referred as to "leg dominance" theory[14]. The leg dominance theory refers to the side-to-side symmetry between the lower extremities and how some athletes tend to use more one of the legs during the landing phase of jumps[14]. ACL injury explained by the leg dominance theory may rely on leg asymmetries. However, such asymmetries related to leg preference, which means the preferential use of a given leg rather than the contralateral use of legs, are still debatable.

Two prospective studies have demonstrated that athletes who exhibit leg asymmetries are predisposed to ACL injury. Hewett et al.[15] have shown that knee valgus moment asymmetry predicts future ACL injury in female athletes. Furthermore, in a cohort of athletes recovering from ACL reconstruction, Paterno et al.[16] identified larger asymmetries for knee moments at frontal plane among athletes who suffered a second ACL injury compared to athletes recovering from ACL reconstruction. Two additional biomechanical studies have investigated leg asymmetries between female (higher risk for ACL injury) and male athletes[17,18]. However, both studies analyzed only kinematic variables and, thus, calculating forces in the lower extremity was not possible.

It has been recently demonstrated that the preferred leg was, in general, submitted to greater ground reaction forces (GRF) compared to the non-preferred leg during landing after jump tasks[19-21]. Direct evidence about the link between GRF and ACL injury risk comes from a prospective biomechanical-epidemiological study that found that female athletes at higher risk for ACL injury had 20% higher GRF and higher frontal plane knee kinematic asymmetry[15]. However, there is lack of knowledge regarding asymmetries in GRF during jump-landing tasks among physically active individuals (recreational participants). It is still unclear if leg preference might influence asymmetry assessment during jump tasks, and if different jump-landing tasks may differently be related to asymmetric performance concerning GRF.

This is the first study to assess kinetic asymmetries between different types of unilateral and bilateral jumps and may provide information on the development of optimal screening tools to assess GRF asymmetry, which is a predictor of sports injury during landing in jump tasks. In addition, screening using ground reaction force data can be used to recommend an inverse dynamics approach, which will provide full information for analysis of the risk of injuries.

To achieve this purpose, the aim of this study was to analyze: (a) peak forces for each GRF component, (b) time to peak vertical force, and (c) initial phase asymmetries while athletes performed bilateral and unilateral (forward and drop) landing tasks. We hypothesize that asymmetries can be observed as resultant of higher force on the preferred leg.

METHODOLOGICAL PROCEDURES

Participants

Twelve recreational athletes engaged in regular training (at least 3 training sessions per week for at least 45 minutes each) volunteered and were included in this study. The sample was composed of 11 male and 1 female athletes (9 volleyball players and 3 runners) [mean (SD) age: 22 (3) years, height: 180 (10) cm, body mass: 76.4 (12) kg] without history of lower extremity injury. Participants with previous participation in injury prevention programs, gymnastics or dance were excluded. Leg preference was assessed using the inventory of Waterloo[22]. All participants were required to read and sign the informed consent form approved by the Ethic Research Committee from Federal University of Pampa (protocol number 010108/2013).

Procedures

Participants visited the laboratory on one day to perform the jump-landing trials. After basic anthropometric measurements, participants were instructed to perform each jump-landing task with one foot on each force plate. Jump-landing tasks were:

- Unilateral forward landing: participants performed three maximum height unilateral forward jump-landings on each leg taking off from one force plate to another and landing on one leg.
- Bilateral forward landing: participants performed three maximal height forward jump-landings taking off with both legs and landing with each leg on a separate force plate.
- Bilateral drop landing: participants landed with each leg on a separate force plate from a 32 cm box, which height is similar to that used in previous studies[15,23,24].

All participants performed two practice jumps before each task to familiarize with exercises. For the drop landing, participants were instructed to drop directly down off the box and land with one foot on each force plate. For the forward landing, they were instructed to jump as high as possible and land with one foot in each force plate in the bilateral technique, and to land in one force plate in the unilateral technique. Participants did not receive any other instructions on the landing technique to avoid a coaching effect. Any effect of the arms movement was minimized by asking the participants to keep their arms crossed against their chest during jumps[20,23]. Trials were randomly distributed and repeated when judged as non-acceptable (such as when participants lost their balance or part of the foot landed outside the force plate).

Data analysis

The 3D components of the GRF were measured using two force plates (OR6-2000 AMTI Inc., Watertown, MA) embedded flush with the laboratory floor and calibrated according to manufacturer's recommendations. GRF was sampled at 2000 Hz using an anti-aliasing 1000 Hz low pass 2-pole filter using specialized software and hardware (NetForce, Advanced Mechanical Technology, Inc., Watertown, MA). Data were post-processed in custom-written mathematics routines (MATLAB 7.0, Mathworks Inc., Novi, MI). Ground contact (beginning of the landing cycle) was determined as an increase in the resultant GRF in one of the force plates higher than 7 N while signals were continuously recorded.

Kinetic data processing for each objective was performed as follows: a) peak force values of each GRF component observed for landing were calculated, b) time to peak was computed as the time between toe-on or initial foot contact and the peak vertical GRF, and c) initial asymmetry phase was computed as the absolute difference between preferred and non-preferred leg for each data frame and averaged across 40 ms after landing, for each GRF component, as described elsewhere[9], which are the outcome measures. The first 40 ms after landing were chosen as it has been demonstrated that this is the landing phase when ACL injuries are most likely to occur [25]. All values were averaged for the three trials.

Data normality was verified using the Shapiro-Wilk test. Each pair of data (i.e. preferred vs non-preferred leg; forward *vs* drop landing and so on) was compared using Cohen's effect sizes (ES)[26]and repeated measures analysis of variance with jump tasks and leg as factors for peak forces and time to peak force comparisons by applying Bonferroni corrections for multiple comparisons. When significant effects or interactions were observed, GRF data were compared between legs and tasks by using t-test for paired samples (to compare legs) or one-way ANOVA with post-hoc Bonferroni (to compare jump-landing tasks). The level of significance was set *a priori* at 0.05 for all comparisons.

RESULTS

Peak forces

For unilateral forward landings (Figure 1), no statistical difference was found between legs for peak vertical [$t_{(11)}$=0.672; P=0.516; ES= 0.076; r= 0.038], anteroposterior [$t_{(11)}$=-0.251; P=0.806; ES= 0.065], medial [$t_{(11)}$=0.349; P=0.734; ES= 0.041] and lateral [$t_{(11)}$=-0.50; P=0.961; ES= 0.006] GRF force components.

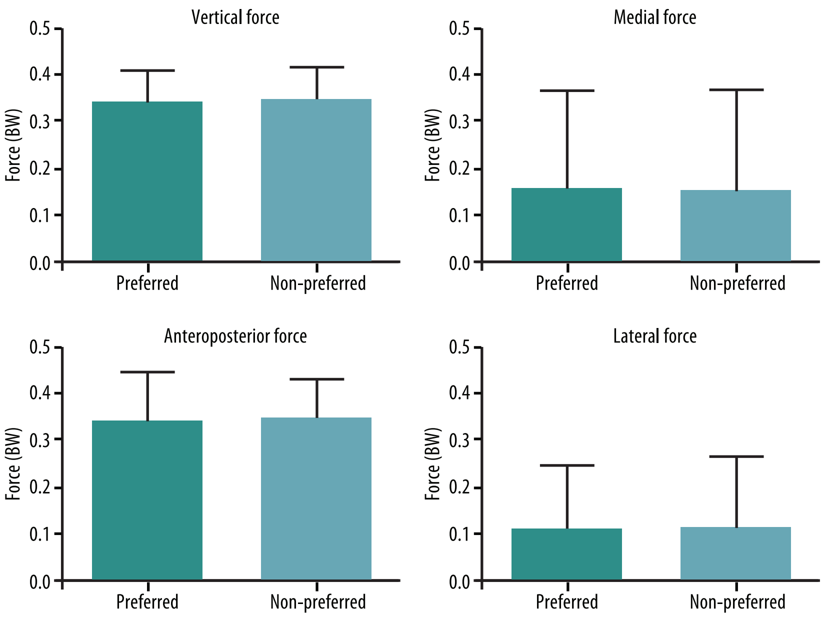

Figure 1. Peak forces (mean and standard-deviation) obtained for unilateral landing kinetics in forward jumps. There were no statistical significant differences between preferred and non-preferred leg for any force component. Peak force was normalized to body weight (BW).

For bilateral landings, it was observed that both tasks (forward and drop landing) elicited statistically significant leg asymmetries for peak forces, but asymmetries did not occur in the same GRF components (Figure 2). A leg effect was observed for vertical GRF component [$F_{(1,11)}$=9.849; P=0.009], with higher peak force in the preferred leg compared to the non-preferred during drop landing [$t_{(11)}$=2.639; P=0.023; ES= 0.544], but not forward landing [$t_{(11)}$=1.132; P=0.282; ES= 0.148]. For the anteroposterior GRF component, there was a leg effect for peak force [$F_{(1,11)}$=7.055; P=0.022] with preferred leg experiencing higher forces during both forward [$t_{(11)}$=2.540; P=0.028; ES= 0.510] and drop landing [$t_{(11)}$=2.222; P=0.048; ES= 0.471]. For the medial component, there was no task [$F_{(1,11)}$=0.362; P=0.559] or leg effect [$F_{(1.11)}$=0.390; P=0.545], as well as any interaction between them [$F_{(1,11)}$=0.856; P=0.375]. For the lateral component, there was a leg effect [$F_{(1,11)}$=10.298; P=0.008] with preferred leg experiencing higher forces during forward [$t_{(11)}$=3,867; P=0.003; ES= 0.120] but not during drop landing [$t_{(11)}$=1,865; P=0.089; ES= 0.138].

Time to peak

The time to peak vertical force in unilateral forward landing was similar [$t_{(1,11)}$=0.532; P=0.605; ES= 0.165] between preferred (0.736±0.224s) and non-preferred leg (0.703±0.171s). Regarding the time to peak vertical force in bilateral landing, there was an interaction effect between task and leg [$F_{(1,11)}$=5.493; P=0.039]. Peak vertical GRF occurred earlier for the preferred leg (0.598±0.362s) compared to the non-preferred leg (0.832±0.431s) during forward landing [$t_{(11)}$=-3.061; P=0.011; ES= 0.606] but not during drop landing [$t_{(11)}$=-0.576; P=0.576; ES= 0.297]. Additionally, the time to peak was shorter during forward landing (compared to drop landing) for the preferred leg [$t_{(11)}$=-2.570; P=0.026; ES= 0.704], but not for the non-preferred leg [$t_{(11)}$=-1.108; P=0.291; ES= 0.300].

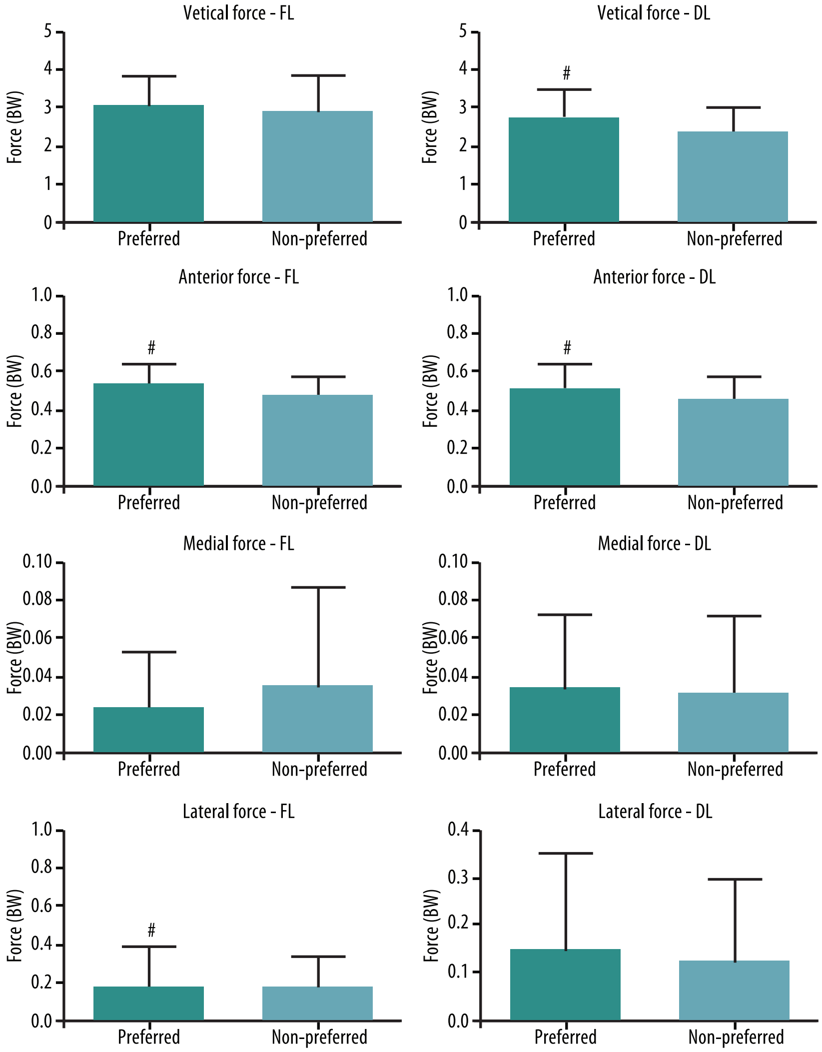

Figure 2. Peak forces (mean and standard-deviation) obtained for forward landing (FL) and drop (DL) landing jumps. # indicates statistical significant asymmetry between preferred and non-preferred leg (P<0.05). There were no statistical significant differences between tasks. Peak force was normalized to individual body weight (BW).

Time 4 of contact and initial phase of kinetic asymmetries

In forward landings, the preferred leg (0.602±0.763s) touched down earlier than the non-preferred leg (0.623±0.751s) [$t_{(11)}$=-4.914; P<0.01; ES = 0.027]. Similarly, in drop landings, the preferred leg (0.415±0.440s) touched down earlier than the non-preferred leg (0.433±0.428s) [$t_{(11)}$=-2.828; P=0.016; ES = 0.041].

Kinetic asymmetries were also calculated for the initial phase of landing (first 40 ms) after touchdown as this has been shown to be the most dangerous phase of landing for ACL injuries[15]. Considering the initial phase of landing, there were statistically significant differences between tasks in the mediolateral [$F_{(2,11)}$=3.911; P=0.003] and vertical GRF components [$F_{(2,11)}$=5.525; P=0.009] but not in the anteroposterior GRF component

[$F_{(2,11)}$=0.680; P=0.934] (Figure 3). For the mediolateral component, asymmetry was higher in forward unilateral landing compared to forward bilateral landing [$t_{(11)}$=-5.01; P<0.001] and drop landing [$t_{(11)}$=2.74; P=0.019]. Considering the vertical component, asymmetry was higher in the bilateral forward landing task compared to drop [$t_{(11)}$=2.48; P=0.03] and forward unilateral landing tasks [$t_{(11)}$=5.34; P<0.001].].

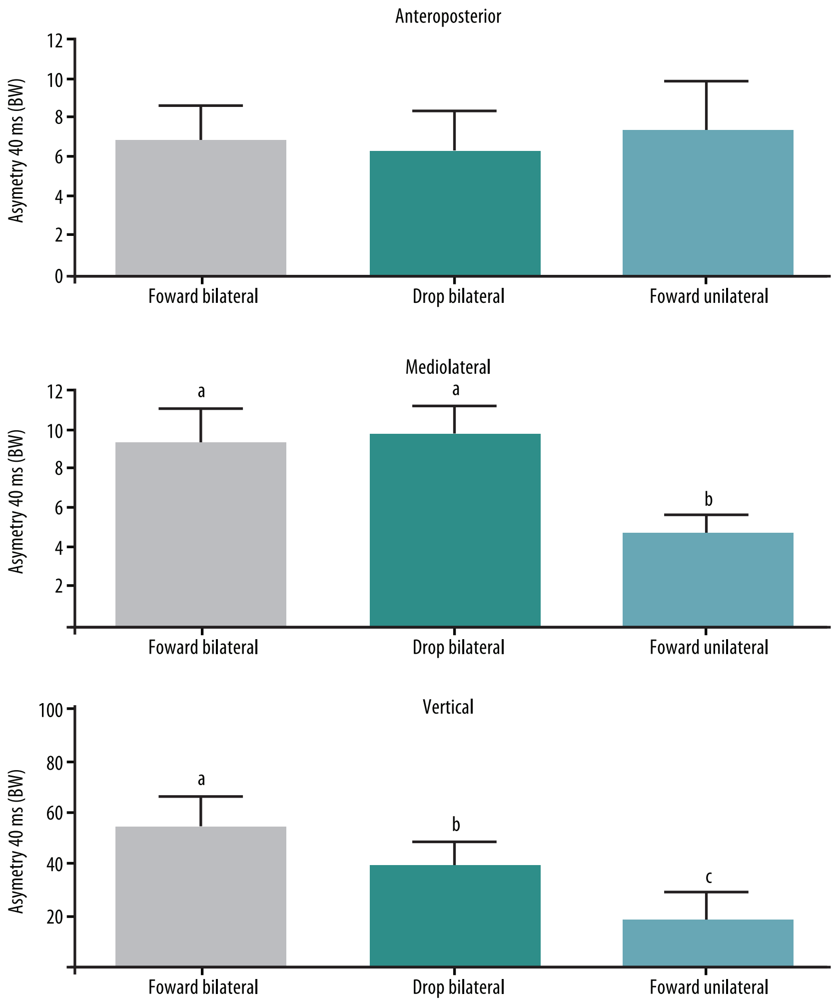

Figure 3. Initial phase of asymmetry was analyzed in the 40 ms after landing. Data of peak force for anteroposterior (AP), mediolateral (ML) and vertical (VERT) GRF components are presented (mean and standard-deviation). Different letters indicates statistical significant difference between jump-landing tasks (P<0.05). Peak force was normalized to individual body weight (BW).

DISCUSSION

It has been recently shown that forward landing elicits greater hip adduction and knee valgus asymmetries than drop landing[18]. Here, GRF asymmetries were quantified during the landing phase of unilateral and bilateral jump tasks performed by healthy recreational athletes. Our main purpose was to assess kinetic asymmetries between different jump-landing techniques. Three main findings were obtained: a) when significant asymmetry was observed, the preferred leg experienced higher loads with shorter time to peak compared to the non-preferred leg, b) the initial landing phase showed more asymmetries compared to the later landing phase, and c) the bilateral forward landing task showed more asymmetries compared to the other jump-landing tasks. According to our findings, when assessing the risk of injuries, coaches should consider the forward jump-landing task instead of the drop landing task. Additionally, our results may suggest that an inverse dynamics approach considering both lower limbs would be useful to identify joint loading and more properly address the the risk of injuries in the different landing tasks analyzed.

The higher loading on the preferred leg may suggest that the preferred leg will be more exposed to impact regardless of jump-landing technique. Athletes probably use the preferred leg more or earlier than the non-preferred leg to absorb the landing impact as it is commonly stronger and may provide more confidence. This information can have implications for injury prevention training by emphasizing simultaneous temporal contact between both legs when landing from a jump. There are currently low cost solutions that allow assessing the time of initial contact that can be widely implemented to identify athletes that exhibit asynchronous contact between the two lower extremities.

Patellar tendinopathy[27] and ACL injury15 are among unilateral injuries that may be associated with asymmetries . Although there is no current consensus, epidemiological studies have suggested that the preferred leg is more susceptible to ACL injuries[28]. The type of primary sport that athletes are involved in plays a major role in the development of asymmetries and possibly influences the effect of leg preference on motion patterns and subsequently risk of ACL injuries [29].

Previous studies have suggested no kinetic differences between legs during a horizontal hop[30] when peak values were compared as in the first objective of our study. However, when a novel symmetry comparison method was used for the initial asymmetry phase during bilateral landing tasks, our data showed more kinetic asymmetries in the early phase than in the later phase when peak vertical forces occur. This suggests that athletes have the ability to correct the kinetic asymmetry in the later part of the landing cycle after landing asymmetrically. Therefore, the initial asymmetry phase can be pertinent to evaluating the risk of ACL injuries [25]. As vertical peak GRF did not differ between legs in the forward landing, the movement asymmetry phase analysis suggests that peak GRF alone may not provide adequate information when screening for asymmetry in jump-landing tasks.

Our third main finding is that the bilateral forward landing task showed more kinetic asymmetries than the other landing tasks. It has been reported that forward landings also elicit greater kinematic differences than drop landings [17,27], possibly making it a preferable task for screening athletes for potential injury due to asymmetry when time limitations allow only one task to be performed. As athletes are more familiar with forward jump-landing tasks, the associated motor patterns that are already in place may have made it a more realistic task, allowing neuromuscular deficits to appear. On the other hand, drop landings are a less familiar task and, therefore, athletes may have been more cautious when performing it, possibly masking asymmetry that may be present in real athletic situations.

Among study limitations, the low sample size prevents generalizing findings to athletes who participate in other sports. It is currently unclear how large temporal and kinetic differences need to be in order to predict lower extremity injury. Finally, we did not investigate kinematics that could have been used to calculate joint moments and forces in combination with kinetic data , as well to determine jump height during the forward jump technique. Calculation of joint data using inverse dynamics is an important further step towards the identification of high-risk landing techniques. However, a recent article investigating if GRF asymmetry can predict knee moment asymmetry concluded that "vertical GRF asymmetries may be a viable surrogate for knee kinetic asymmetries" as vertical GRF asymmetry predicted knee moments[19].

CONCLUSION

When significant asymmetries were observed, the preferred leg experienced higher loading or touched down first. The initial landing phase showed more kinetic asymmetries (compared to peak values that occur later in the landing cycle). Finally, the bilateral forward landing task showed, in general, more asymmetries than the other landing tasks. According to our findings, when considering the assessment of GRF asymmetries in landing tasks, coaches should consider the forward jump-landing task instead of the drop landing task.

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Corresponding author

Felipe P Carpes.
Federal University of Pampa -
Laboratory of Neuromechanics.
BR 472 km 592 - Po box 118 –
ZIP 97500-970, Uruguaiana, RS. Brazil
E-mail: carpes@unipampa.edu.br