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Landing Technique Affects Knee Loading and Position During Athletic Tasks

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Abstract

Anterior cruciate ligament (ACL) injuries have been reported to occur with the ankle in a dorsiflexed position at initial contact. Few studies have attempted to quantify the biomechanical parameters related with such landing patterns during athletic tasks.

Objective—The purpose of this study was to evaluate the effects that two landing techniques have in lower extremity biomechanics while performing two tasks.

Design—Single-group repeated measures design.

Methods—Twenty female soccer athletes from a Division I institution performed two landing techniques (forefoot and rearfoot) during two unanticipated tasks (sidestep cutting and pivot). Repeated measures analyses of variance were conducted to assess differences in the kinematic and kinetic parameters between landing techniques for each task.

Results—The forefoot landing technique had significantly higher internal knee adductor moment than the rearfoot for both the pivot and sidestep cutting task ($p<0.001$ and $p=0.003$, respectively). For the sidestep cutting task, participants had increased knee valgus angle with the rearfoot, whereas for the pivot they had increased knee valgus with the forefoot landing technique ($p<0.05$).

Conclusions—The results of this study highlighted that there are inherent differences in biomechanical outcomes between foot-landing techniques. The forefoot landing technique increasingly affects knee adduction moment loading, which can potentially place a higher strain on the ACL. Essentially, the demands of the landing technique on lower extremity biomechanics (e.g., hip and knee) are task dependent.

Keywords

pivot; sidestep; kinematics; kinetics; landing technique

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INTRODUCTION

Damage to the anterior cruciate ligament (ACL) is a common knee injury, often resulting in potential short and long-term effects for the individual.[1, 2] The ACL rupture is more commonly observed during the deceleration phase of a given action, particularly when the movement also involves a change of direction.[3] Numerous intervention programs specifically tailored to address neuromuscular and biomechanical risk factors for ACL injuries have been implemented;[4, 5] yet the injury ratio has remained steady over the past decade.[6] One of the critical issues that still needs to be addressed is to quantify how different landing techniques influences the neuromechanical risk factors and the potential for non-contact ACL injury.[7]

Recently, researchers have focused on whether ankle position at initial ground contact is a potential biomechanical marker for ACL injury.[7, 8] However, few studies have investigated the contribution of foot landing technique to the neuromuscular and biomechanical aspects during landing.[8, 9] Specifically, Kovacs and colleagues found an increased range of motion for the hip and knee flexion during the heel landing being 1.2 to 2 times greater than the toe landing.[9] It was suggested that the increased range of motion was to accommodate and dissipate the higher ground reaction forces obtained with the heel landing. Cortes et al. also investigated the impact different landing techniques (e.g. rearfoot and forefoot) have on biomechanical factors related to ACL injury.[8] One of the main results to emerge from this study was the notable differences in the risk factors were observed between the two landing techniques. Specifically, all participants adopted a more erect lower extremity position (e.g., decrease knee flexion) when performing the rearfoot landing technique in comparison to the other techniques. These two studies lacked an evaluation of the effects of landing techniques on lower extremity biomechanics while performing athletic tasks, as they focused on a drop-jump task.[8, 9] The contradiction between those two studies warrant further research to understand the effects of landing techniques on lower extremity biomechanics.

Supporting this concept of the influence of landing strategies in knee injury during athletic tasks is the observational study conducted by Boden and Hewett (2009).[7] The authors analyzed videos of non-contact ACL injuries during basketball games. They reported that ACL injuries commonly occurred with the ankle in a dorsi-flexion (heel contact) strategy at initial ground contact. However, to our knowledge no study has quantified the effect of foot landing technique during cutting tasks that are frequently utilized during athletic events (e.g., basketball, soccer).

A commonly observed motion during a soccer game is a cutting motion, which encompasses a change in direction. While such action is essential to either track the ball or evade an opponent, the likelihood of injury increases dramatically during such actions.[3] Researchers have attempted to replicate this motion within a laboratory environment using a sidestep cutting task,[10] and a pivot task with a 180 degrees change in direction.[11] There are some natural differences between these tasks.[11] These inherent differences suggest that the control mechanism and demands between these tasks are different. Thus, the multiple biomechanical risk factors may play a different role depending on the task, as it may require different demands from the motor system.[12] Few studies have attempted to quantify and compare biomechanical parameters among tasks (sidestep, and pivot) and landing techniques (rearfoot, and forefoot).

Therefore, the purpose of this study was to investigate changes in lower limb kinetic and kinematic risk factors while performing two unanticipated tasks (sidestep cutting and pivot) with different landing techniques (rearfoot, forefoot). We hypothesized that the rearfoot landing technique with either task (pivot and sidestep cutting) will produce a significant

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increase in knee abduction angle and moment, vertical ground reaction force, and decreased knee flexion than the forefoot landing technique.

METHODS

Participants

Twenty female collegiate soccer athletes (age = 20 ± 0.9 years old; height = 1.67 ± 0.1 cm; mass = 63.2 ± 10.1 kg) from a Division I institution volunteered to participate in this study. Number of participants was based upon *a priori* power calculations to achieve a 80% statistical power with an alpha level of 0.05 based on previous literature related to foot landing technique and lower extremity biomechanics.[13, 14] Participants were screened to ensure none had any previous ACL injury/surgery, and no hip, low back, knee, or severe ankle injuries within the last six months or surgeries within the last 2 years. The dominant leg, defined as the leg that the participant would use to kick a soccer ball as far as possible, was used for analysis. Prior to data collection, experimental procedures were approved, and complied with University Institutional Review Board guidelines and were consistent with the Declaration of Helsinki; written informed consent for all participants was obtained.

Instrumentation

Kinematic measures of the lower extremity were captured using an eight-camera high-speed motion capture system (Vicon Motion Systems Ltd., Oxford, England) with a sampling rate of 500 Hz. Ground reaction force data were obtained through two force plates (Bertec Corporation, Columbus OH, USA) sampling at 500 Hz. A standing (static) trial with the participants standing on the force plates with shoulders abducted at 90 degrees was obtained. From the standing trial a kinematic model (pelvis, thigh, shank, and foot) was created for each participant using Visual 3D software (C-Motion, Inc, Germantown MD, USA) with a least-squares optimization.[15] This kinematic model was used to quantify the motion at the hip, knee, and ankle joints. Marker trajectories and ground reaction forces were filtered with a 4^{th} order low-pass Butterworth filter with a cutoff frequency of 7Hz and 25Hz, respectively. A standard inverse dynamics analysis, using segment inertial characteristics estimated for each participant as per the methods of Dempster,[16] was employed to the kinematic and ground force data to calculated 3-D joint forces and moments.[17] Intersegmental joint moments are defined as internal moments (e.g., a knee internal extension moment will resist a flexion load applied to the knee).

Experimental Procedure

Participants wore spandex shorts, sports bra and the team running shoes (Adidas Supernova, AG, Herzogenaurach, Germany). Participants completed a 5-minute cycling warm-up and 5-minute self-directed stretching, prior to data collection. General anthropometric measures (height, and weight) were taken for each participant by the same researcher [NC]. After the warm-up, reflective markers were placed on specific body landmarks (anterior and posterior iliac spine, thigh, knee, shank, malleoli, heel, and fifth metatarsal) according to a modified Helen Hayes marker set.[18] Participants were required to partake in two different landing techniques (forefoot and rearfoot) while performing a sidestep task and a pivot task. Participants were permitted three practice trials for each technique. Five successful trials, verified by video, were collected for each task. If participants did not place the dominant foot on the force plate, lost balance, did not execute the task with the appropriate landing technique, or did not perform the appropriate task based on the cue generated by the software the trial was not successful and discarded from analysis. There was a one-minute rest period between trials to minimize fatigue.

A Brower timing system (Brower Timing Systems, Draper UT, USA) was used to control the approach speed. Participants had to attain a minimal speed of 3.5 m/s at time of contact with force plates. An infrared beam was placed across and 2 meters prior to the force plates where the participants were running. A software program on a laptop was triggered when the light beam was crossed and interrupted to randomly generate one of the soccer athletic tasks (e.g., pivot, and sidestep) and project it onto a screen in front of the participants.[19] For the sidestep cutting task, the participants started running, and stepped with the dominant foot on the force plate. At that moment they had to perform a cutting motion to the contra-lateral side of the dominant foot touching the force plate. The running pathway was constrained to 35 to 55 degree angle to provide an optimal cutting angle of 45-degrees.[11] For the pivot task, the participant ran and planted onto the force plate with the dominant foot and pivoted 180 degrees and ran to the starting position.[11, 13] The forefoot landing consisted of initial contact with the toes first on the force plates followed by the rearfoot. For the rearfoot landing, the initial contact was performed with the heels first on the force plates followed by the forefoot.

Data Analysis

All trials were normalized to 100% of stance phase. All data were reduced using MATLAB (The MathWorks, Inc, Natick MA, USA) with the creation of a custom made program to export the dependent measures into a Microsoft Excel spreadsheet. Each of the five trials were averaged and exported into PASW version 18.0 (IBM Corporation, Somers NY, USA) for data analysis. A Bonferroni adjustment for multiple comparisons was used with an adjusted alpha level set *a priori* at 0.025. Separate repeated measures analyses of variance (ANOVA) with landing technique (2 levels; rearfoot and forefoot) as the repeating factors were conducted to evaluate the kinematic and kinetic parameters. These parameters were evaluated at different time instants for each task. Specifically, initial contact included: knee flexion, valgus, hip flexion, knee flexion and abduction moment, and posterior ground reaction force. Peak posterior ground reaction force included: knee flexion and posterior ground reaction force. Peak stance included: knee flexion, valgus angles, hip flexion, and knee flexion and abduction moment. Peak vertical ground reaction force was also measured. The stance phase was defined from initial contact, as the moment where vertical ground reaction force was higher than 10N, until toe-off from the force plate. Peak stance was defined as the maximum value of a dependent measure between initial contact and 50% of stance phase.[20] Ground reaction forces were normalized to bodyweight (bw), while joint moments were normalized to mass and height (Nm/Kgm).

RESULTS

Descriptive statistics with means and standard deviations for the two landing techniques while performing each task are presented in Table 1 and Table 2.

Sidestep cutting task

During the sidestep cutting task, participants presented an erect posture while landing with the rearfoot landing technique. Specifically, at initial foot contact using the rearfoot landing technique they had: decreased knee flexion ($F_{(1,18)}$=22.370, p<0.001), knee internal adductor moment ($F_{(1,18)}$=11.882, p=0.003), and increased knee valgus ($F_{(1,18)}$=5.511, p=0.031), and hip flexion ($F_{(1,18)}$ = 5.302, p=0.033). The rearfoot landing technique also produced a lower peak vertical ground reaction force ($F_{(1,18)}$=7.546, p=0.014), and a decreased posterior ground reaction force at initial contact ($F_{(1,18)}$=68.323, p<0.001). At peak stance, the rearfoot landing technique when compared with forefoot landing technique had significantly higher angles (degrees) for: knee flexion ($F_{(1.18)}$=7.871, p=0.012), and hip flexion ($F_{(1,18)}$=9.598, p=0.006). Figure 1 illustrates the relative changes in knee flexion angle as a function of landing technique and task. No other statistical significant difference was attained ($p>0.05$)

Pivot task

A similar pattern was attained for the pivot task. The rearfoot landing technique had increased angles and forces, with the exception of knee sagittal and frontal plane moments. Specifically, the rearfoot landing technique presented decreased knee valgus angles ($F_{(1,18)}=17.922$ $p<0.001$), knee flexion ($F_{(1,18)}=29.237$, $p<0.001$), knee adductor moment ($F_{(1,18)}=28.951$, $p<0.001$), and posterior ground reaction force ($F_{(1,18)}=18.580$, $p<0.001$), and an increased hip flexion angle ($F_{(1,18)}=26.132$, $p<0.001$) at initial contact. Lastly, at peak stance, the rearfoot had increased hip flexion ($F_{(1,18)}=29.381$, $p<0.001$) and decreased knee valgus ($F_{(1,18)}=25.453$, $p<0.001$) angles over the forefoot landing technique.

DISCUSSION

The present study was designed to evaluate the impact two landing techniques (forefoot and rearfoot) had on lower limb kinematic and kinetics. In line with our initial hypothesis, the rearfoot landing technique performed during the sidestep cutting task exhibited increased knee valgus angles, and a decreased knee flexion angle. However, this pattern was not entirely observed during the pivot task. The only similarity was the decreased knee flexion angle during the rearfoot; whereas there was an increased knee valgus during the forefoot landing technique. Nonetheless, regardless of the landing technique performed participants were always in a knee valgus position, and with a (internal) knee adductor moment. The observed kinematic and kinetic differences seen between different landing techniques for each task suggest that the landing techniques present differentiated characteristics and that the injury mechanism may be dependent on the combination of foot landing technique and task utilized.

One key finding was that all participants adopted a knee valgus position irrespective of the landing technique used. However, while performing the pivot task the forefoot landing technique presented an increased valgus angle. Previous studies have reported through visual observation that participants were in a valgus position at the time of injury, and with a heel contact position (rearfoot) at time of ground contact.[7, 21] The knee valgus position presented by our participants could increase their likelihood of injury as compared to participants that present neutral to varus alignment. However, when comparing with Boden et al. (2009) findings it appears that even during a forefoot landing our participants would be at increased risk for injury as our participants also presented increased knee valgus position during this landing technique. It has previously been found that an increase in valgus angle and (internal) adduction loading is a strong predictor of ACL injuries.[22] Thus, regardless of the landing technique utilized by our participants, they seem to be at an overall increased risk for injury due to this valgus position.

Participants were in a more extended knee position at initial contact while performing the tasks with the rearfoot landing. At peak knee flexion angle they presented similar angles between landing techniques, however, their dominant knee remained in a valgus position during both tasks. Though, the higher knee flexion during the forefoot landing technique may assist in protecting the knee from a valgus collapse. The combination of decreased knee flexion and valgus position with an (internal) adductor moment may increase the stress on the knee structures, particularly the ACL. Hence, developing individualized intervention strategies that focus on minimizing knee valgus position and loading, combined with proper landing technique have been proposed.[22, 23]

The results of the current study demonstrated that no changes were seen for the vertical ground reaction force between landing techniques during the pivot task. This result was somewhat surprising given that previous research reported that the vertical ground reaction force was up to 3.4 times greater during the rearfoot than the forefoot landing technique.[9] One possible explanation is that our participants presented a higher range of motion, between initial contact and peak stance, at the knee and hip flexion, which may have assisted in absorbing the ground reaction force. One possible reason for the discrepancy between the two studies is the different methodological practices. Kovacs and colleagues (1999) utilized a vertical drop from a box, whereas our tasks required mainly horizontal momentum with minimal vertical motion. In the current study, the participants had to make contact with the force plates and perform either a deceleration with rapid acceleration and change of direction (sidestep), or a complete deceleration combined with 180 degrees change of direction followed by an acceleration phase (pivot). The difference in the respective task demands, regardless of the landing technique used, may explain the lack of change in vertical ground reaction force. Several studies and concepts of motor control support the notion that the multiple risk factors can vary with different task constraints.[11, 24]

Of the two landing techniques, the rearfoot landing technique was characterized by increased posterior ground reaction forces, at initial contact, combined with decreased knee flexion when compared to the forefoot landing technique. This result is of some significance given that both these variables have been associated with increased risk of ACL injury. For example, an increased posterior ground reaction force has been theorized to increase the strain on the knee ligamentous structures by enhancing the proximal anterior tibia shear force, which creates an anterior displacement of the tibia, thus increasing the strain on the ACL.[25] Similarly, decreased knee angle has been associated with potentially injurious position at time of initial contact and peak posterior ground reaction force.[25] Together, the low knee flexion angles and the increased force during the pivot task might be augmenting the quadriceps activation.[26] It is worth noting that this became especially relevant when the pivot task was performed with the rearfoot landing technique, where the participants barely achieved 20 degrees of knee flexion. Though, it should be noted that most likely this force is not sufficient to induce a relevant stress in the knee structure even when associated with decreased knee flexion angle. One recent theoretical approach to the injury mechanism is the paradox between hip extension and knee flexion velocities during stiff landings. Specifically, during high impact landings the hip tends to extend, whereas the knee is strained to flex and this combination with other theoretical factors (e.g., slow co-activation of quadriceps and hamstrings, high ground reaction force with knee approximately extended, and shallow tibial plateau and steep posterior tibial slope) for injury can drastically increase the injury occurrence.[27]

Low knee flexion angles during the first 50% of the stance phase have been predicted to raise the likelihood of injury,[28] since the strain placed by the quadriceps on the ACL can potentially cause its rupture at low flexion angles if not counteracted by the hamstrings.[29, 30] The maximum knee flexion across both techniques ended in similar knee flexion angles; however, at the time instants theorized to increase ACL strain (e.g., initial contact, peak posterior and vertical ground reaction forces) our participants had diminished knee flexion angle. The decreased angle may not be sufficiently protective of the knee structures. These results are consistent with previous reports which demonstrated that knee flexion angle was significantly lower at peak vertical ground reaction force for the rearfoot landing technique when compared with the forefoot technique during a drop-jump.[8]

CONCLUSIONS

Overall, the results highlighted that there were inherent differences in biomechanical outcomes between foot-landing techniques. Specifically, the rearfoot landing technique, during the sidestep task, placed the athletes in a more extended and abducted knee position, as well as with an increased peak (internal) knee adductor moment. The decreased knee flexion angle combined with the knee adductor moment, during the rearfoot landing technique in the sidestep task, can potentially be creating higher stress and strain on the ACL. Further, the small knee flexion angle may not allow for proper hamstring activation to protect the tibia from anterior displacement and decrease ACL strain. Increased trunk flexion will facilitate increased hip and knee flexion, which may be a protective mechanism to the ACL.[26] The consideration of landing technique and person interaction is also fairly important in the multifactorial approach to ACL injury prevention since we have shown that different inherent task demands associated with two landing techniques can reflect significant movement differences.

PRACTICAL IMPLICATIONS

- Various landing techniques can alter landing mechanics during unanticipated tasks commonly used in game situation;
- Participants utilizing the forefoot landing technique presented a potentially greater risk for injury, during the pivot task, than the rearfoot;
- Conversely, the rearfoot landing technique, during the sidestep task, created a more extended and abducted position at the knee, as well as with increased peak knee adductor moment;
- Intervention programs should take into account the interaction between landing technique with the tasks on lower extremity mechanics.

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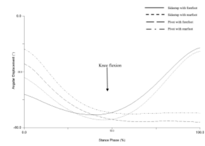

Figure 1.
Changes observed in knee flexion angular displacement (degrees) across the two tasks (sidestep, pivot) and landing techniques (rearfoot, forefoot). Angular displacement curves are shown during the stance phase. Each curve represents the mean normative value of the entire sample.

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Table 1

Descriptive analysis (Means of five trials, and SD) of the kinematic variables at initial contact, peak posterior ground reaction force (PGRF), and peak stance during two athletic tasks using two landing-techniques. All variables measured in degrees.

	Sidestep					Pivot				
	Forefoot		Rearfoot			Forefoot		Rearfoot		
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P
Initial contact										
Knee flexion (−) / extension (+)	−42.0	10.3	−33.1	6	<0.001*	−25.9	7.8	−17.8	5	<0.001*
Knee valgus (−) / varus (+)	−0.7	11.2	−3.1	9	0.031*	−12.8	7.9	−7.4	6.7	<0.001*
Hip flexion	49.5	10.6	55.1	8.3	0.033*	46.5	8	50.7	6.9	<0.001*
PPGRF										
Knee flexion (−) / extension (+)	−50.2	7.8	−48.4	7	>0.05	−41.1	12.3	−30.3	8.7	<0.001*
Peak Stance										
Knee flexion (−) / extension (+)	−53.7	7.1	−56.1	5.4	0.012*	−58.6	9.3	−54.6	8.4	>0.05
Knee valgus (−) / varus (+)	−3.6	11	−4.8	8.6	>0.05	−14.4	8.2	−8.4	7.3	<0.001*
Hip flexion	50	9.8	57.3	7.8	0.006*	58.2	12.4	66.3	10.4	<0.001*

* Denotes statistical difference between landing techniques within each athletic task

Table 2

Descriptive analysis (Means of five trials, and SD) of the kinetic variables at initial contact, peak vertical ground reaction force (PVGRF), peak posterior ground reaction force (PGRF), and peak stance between two landing techniques (rearfoot and forefoot) while performing two tasks. Ground reaction forces measures normalized to body weight; internal moments measures in Nm/Kgm.

	Sidestep					Pivot				
	Forefoot		Rearfoot			Forefoot		Rearfoot		
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P
Initial contact										
Posterior Ground Reaction Force (−)	0.04	0.02	−0.01	0.02	<0.001*	0.02	0.01	−0.001	0.01	<0001*
Knee flexion moment (−) / extension moment (+)	−0.18	0.11	−0.16	0.08	>0.05	−0.22	0.08	−0.14	0.08	0.002*
Knee abduction moment (−) / adduction moment (+)	0.04	0.06	0.01	0.03	0.003*	0.10	0.08	0.011	0.04	<0.001*
PVGRF										
Vertical ground reaction force	1.7	0.4	1.4	0.4	0.014*	1.2	0.7	1.4	0.07	>0.05
PPGRF										
Posterior ground reaction force (−)	0.24	0.12	0.25	0.11	>0.05	0.64	0.42	0.63	0.23	>0.05
Peak Stance										
Knee flexion moment (−) / extension moment (+)	1	0.3	1.1	0.3	>0.05	0.48	0.2	0.46	0.2	>0.05
Knee abduction moment (−) / adduction moment (+)	0.34	0.3	0.41	0.3	>0.05	0.61	0.3	0.62	0.3	>0.05

* Denotes statistical difference between landing techniques within each athletic task