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Pivot task increases knee frontal plane loading compared with sidestep and drop-jump

NELSON CORTES¹, JAMES ONATE², and BONNIE VAN LUNEN³

¹Sports Medicine Assessment, Research & Testing Laboratory, George Mason University, Fairfax, Virginia, USA

²School of Allied Medical Professions, Ohio State University, Columbus, Ohio, USA

³Human Movement Sciences, Old Dominion University, Norfolk, Virginia, USA

Abstract

The purpose of this study was to assess kinematic and kinetic differences between three tasks (drop-jump, sidestep cutting, and pivot tasks) commonly used to evaluate anterior cruciate ligament risk factors. Nineteen female collegiate soccer athletes from a Division I institution participated in this study. Participants performed a drop-jump task, and two unanticipated tasks, sidestep cutting and pivot. Repeated-measures analyses of variance were conducted to assess differences in the kinematic and kinetic parameters between tasks. The pivot task had lower knee flexion ($-41.2 \pm 8.8^\circ$) and a higher valgus angle ($-7.6 \pm 10.1^\circ$) than the sidestep ($-53.9 \pm 9.4^\circ$ and $-2.9 \pm 10.0^\circ$, respectively) at maximum vertical ground reaction force. The pivot task (0.8 ± 0.3 multiples of body weight) had higher peak posterior ground reaction force than the drop-jump (0.3 ± 0.06 multiples of body weight) and sidestep cutting (0.3 ± 0.1 multiples of body weight), as well as higher internal varus moments ($0.72 \pm 0.3 \text{ N} \cdot \text{m/kg} \cdot \text{m}$) than the drop-jump ($0.14 \pm 0.07 \text{ N} \cdot \text{m/kg} \cdot \text{m}$) and sidestep ($0.17 \pm 0.5 \text{ N} \cdot \text{m/kg} \cdot \text{m}$) at peak stance. During the pivot task, the athletes presented a more erect posture and adopted strategies that may place higher loads on the knee joint and increase the strain on the anterior cruciate ligament.

Keywords

Anterior cruciate ligament; biomechanics; knee; hip; ankle

Introduction

Extensive research efforts have been applied to understand the mechanism of anterior cruciate ligament (ACL) injury (McLean, Huang, Su, & Van Den Bogert, 2004a; Yu, Lin, & Garrett, 2006). The devastating consequences of ACL tears (health and monetary) and poor consensus regarding the mechanism of injury have made it a major topic of biomechanical research. Numerous risk factors have been conjectured as possible mechanisms of injury (Davis, Ireland, & Hanaki, 2007; Griffin et al., 2006). These risk factors have received much attention from researchers, with prevention programmes being implemented in attempts to modify them; however, the rate of injury has remained steady over the past decade (Agel, Arendt, & Bershadsky, 2005; Prodromos, Han, Rogowski, Joyce, & Shi, 2007). A multitude of biomechanical risk factors across the lower extremity joints have been hypothesized as

potential markers for injury, including decreased knee flexion angle at initial contact, increased knee valgus angle and loading, high peak vertical ground reaction force, and increased proximal anterior tibia shear force (McLean et al., 2004a; Sell et al., 2006, 2007; Yu et al., 2006). Some authors have supported sagittal plane kinematics and kinetics as the primary risk factor, while others claim that the sagittal plane biomechanics cannot injure the ACL, arguing that knee valgus angle and valgus loading are the primary risk factors for injury (McLean et al., 2004a; Yu & Garrett, 2007; Yu et al., 2006). One consideration that should be noted is the comparison of methodological approaches between these studies. The tasks used to evaluate the relation of risk factors and increased likelihood of injury has differed slightly, yet investigation of the effects of task on movement performance is limited. McLean et al. (2004a) analysed a sidestep cutting task, whereas Yu and colleagues (2006) evaluated a running stop task.

It is noticeable in the literature that different tasks have been used to evaluate biomechanical risk factors for non-contact ACL injury risk, including drop-jump, stop-jump, sidestep cutting, and pivot, yet have been discussed as having similar types of movement demands. The drop-jump task has been commonly used to evaluate participants' landing patterns (Cortes et al., 2007; Kernozek, Torry, Van Hoof, Cowley, & Tanner, 2005). This task permits a controlled environment and is performed in an unanticipated fashion prior to utilizing dynamic/sports-related tasks. The sidestep cutting task (McLean et al., 2004a; Pollard, Sigward, & Powers, 2007; Sigward & Powers, 2006) has been used to mimic a deceleration and cutting motion similar to the hypothesized risk mechanism. It also attempts to replicate a real-life task in a laboratory environment (i.e. cutting in a soccer game) (McLean et al., 2004a; Pollard et al., 2007). Other researchers have focused on a running stop task (Chappell, Yu, Kirkendall, & Garrett, 2002; Yu et al., 2006), which requires a sudden deceleration and a jump straight into the air to reproduce a soccer header. There are some natural differences between these tasks. The drop-jump is a simple step-off from a box with no dynamic motion or decision process involved (anticipated), whereas sidestep cutting and pivoting require a deceleration and acceleration phase while creating a change of direction. The deceleration–acceleration motion coupled with rapid change in direction has been observed during ACL injury events (McLean, Lipfert, & van den Bogert, 2004b). Greig (2009) argued that sidestep cutting does not replicate the demands of a pivot task that normally occurs during a soccer game. A pivot task, with 180° of change in direction, was reported to provide a more realistic representation of a soccer task (Greig, 2009). This manoeuvre requires a complete deceleration with a 180° change in direction followed by acceleration to maximum speed, as opposed to the sidestep cutting, which requires a reduction in velocity while changing direction. These inherent differences suggest that the control mechanism and demands between these tasks are different, and the multiple biomechanical risk factors may have a different role depending on the task (Newell, 1996; Newell & Slifkin, 1998).

The three different types of movement tasks have inherently different directional and functional demands, yet are often grouped together as jumping or cutting tasks to evaluate the movement patterns of tasks typically associated with ACL injury. Few studies have attempted to quantify and compare biomechanical parameters among different types of jumping and cutting tasks. The understanding of how the hypothesized risk factors behave under different task constraints might provide better insight into possible risk motions. The intrinsic difference in the control mechanisms of various tasks and how those tasks are conducted under laboratory experiments has been of recent concern. The purpose of this study was to determine kinematic and kinetic differences between three tasks (drop-jump, sidestep cutting, and pivot tasks) commonly associated with ACL injuries. We hypothesized that drop-jump tasks would present increased knee and hip flexion angles, and decreased

knee valgus angles, knee valgus loading, and decreased vertical and posterior ground reaction forces compared with two unanticipated tasks (pivot and sidestep cutting).

Methods

Participants

An *a priori* power calculation was conducted to estimate the sample needed to establish differences between athletic tasks. Using data from the literature (Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; Ford et al., 2006; Lephart, Ferris, Riemann, Myers, & Fu, 2002), for a power level of 80% and an alpha of 0.05, the necessary sample size ranged from 14 to 20 participants. Nineteen female collegiate soccer players (age = 19.6 ± 0.8 years; height 1.67 ± 0.05 m; mass = 63.7 ± 10.1 kg) from Division I institution were chosen to participate in this study. Before data collection, the research received approval from the Institutional Review Board, and written informed consent was obtained from all participants. Participants were screened to ensure none had any previous hip, low back, knee, or severe ankle injuries within the previous 6 months or surgeries within the last 2 years. Participants had also not participated in an ACL injury prevention programme. The dominant leg, defined as the leg that the participant used to kick a soccer ball as far as possible, was used for analysis.

Experimental procedure

Participants wore spandex shorts, sports bra, and the team running shoes (Adidas Supernova, AG, Herzogenaurach, Germany). Participants completed a 5-min cycling warm-up and 5 min of self-directed stretching. General anthropometric measures were taken for each participant. Reflective markers were placed on specific body landmarks according to a modified Helen Hayes marker set (Kadaba, Ramakrishnan, & Wootten, 1990). A standing (static) trial with the participants standing on the force plates with shoulders abducted at 90° was obtained. The static trial was later used to compute the kinematic model.

Participants were required to conduct three movement tasks: drop-jump, sidestep cutting, and pivoting manoeuvre. The drop-jump was performed upfront with the other two tasks being randomly generated, since it was not possible to create a randomized drop-jump simultaneously with pivot and sidestep cutting. For the drop-jump task, the participants stood on a 30-cm box placed 30 cm from the force plates. They shifted their weight forward to initiate the movement by inclining their trunk, and dropped from the box onto the force plates as vertically as possible. After landing, participants were instructed to immediately jump as high as they could straight up in the air, and land back on the force plates. The initial landing from the box was used for the purpose of analyses with the secondary landing being discarded. Each participant performed a total of three successful trials, with 1 min rest between trials to minimize the effects of fatigue.

A custom-made visualization software was developed to randomly generate the sidestep and pivot tasks by creating an unanticipated event. It allowed the participants to see a soccer field, a soccer ball, and players projected onto a screen (Figure 1). The cues to either perform a sidestep cutting or a pivot task were based on the virtual player position. If a virtual player was shown on the right side of the screen, the participants had to perform a sidestep cutting task. However, if the virtual player was shown in the middle of the screen, the participants had to plant with the dominant foot and pivot 180° . Two metres from the force plates, an infrared beam was placed across the platform where the participants ran. When the participants crossed the infrared beam, it triggered the software program to randomly generate the athletic tasks. The unanticipated factor was expected to mimic as closely as possible soccer match-play, and provide stronger ecological validity to the

experiment. A Brower timing system (Brower Timing Systems, Draper, UT) was used to control the approach speed; a minimum approach speed of $3.5 \text{ m} \cdot \text{s}^{-1}$ was required for a successful trial. For the sidestep cutting task, participants ran and stepped with the dominant foot on the force plate. At that moment, they had to perform a cutting motion to the contralateral side of the dominant foot touching the force plate. The running pathway was constrained to an angle of $35\text{--}55^\circ$ to provide an optimal cutting angle of 45° (Colby et al., 2000). For the pivot task, participants ran and planted onto the force plate with the dominant foot, pivoted 180° , and ran back to the starting position (Greig, 2009). Participants were permitted three practice trials, and then five successful trials were randomly collected for each task. If participants did not plant on the force plate with the dominant foot, lost balance, or did not perform the appropriate task based on the cue generated by the software, the trial was not deemed successful and discarded from analysis. There was a 1-min rest period between trials to minimize fatigue. Participants had an approach speed of $3.7 \pm 0.3 \text{ m} \cdot \text{s}^{-1}$ for the sidestep cutting task, and one of $3.9 \pm 0.5 \text{ m} \cdot \text{s}^{-1}$ for the pivot task.

Instrumentation

Kinematic measures of the various body segments were attained using eight high-speed video cameras (Vicon Motion Systems Ltd., Oxford, UK). Kinetic data relating to the ground reaction forces were acquired from two Bertec force plates (Model 4060-NC, Bertec Corporation, Columbus, OH). The sampling rate for the cameras and force plates was set at 500 Hz (Kernozek & Ragan, 2008; McLean, Myers, Neal, & Walters, 1998). Single-leg analysis was used for kinematic and ground reaction force data. From the standing trial, a lower extremity kinematic model was created for each participant, which included the pelvis, thigh, shank, and foot, using Visual 3D software (C-Motion, Inc., German-town, MD). This kinematic model was used to quantify the motion at the hip, knee, and ankle joints. A Cardan angle sequence was used to calculate joint angles (Grood & Suntay, 1983). An optimal 7-Hz cut-off frequency was determined for raw trajectory marker data and a 25-Hz cut-off frequency for ground reaction force data. A standard inverse dynamics analysis was employed to the trajectory marker data and ground force data to calculate joint moments (Winter, 2005). Segment inertial characteristics were estimated for each participant (Dempster, 1955). Inter-segmental joint moments are defined as internal moments. As an example, a knee internal extension moment will resist a flexion load applied to the knee.

Data analysis

All data were reduced using Matlab 6.1 (The Math Works, Inc., Natick, MA) software with the creation of a custom-made program to export the variables of interest into a Microsoft Excel spreadsheet. The trials were averaged and exported into SPSS version 16.0 (SPSS, Inc., Chicago, IL) for data analysis. The number of successful trials was determined for each task (drop-jump, sidestep, and pivot) based on previous literature (Padua et al., 2009; Pollard, Sigward, Ota, Langford, & Powers, 2006; Pollard et al., 2007). Repeated-measures analyses of variance (ANOVA) were conducted to evaluate the kinematic (hip flexion, knee flexion, knee valgus, and ankle flexion) and kinetic (vertical and posterior ground reaction forces, knee extension–flexion and varus–valgus moments) parameters at different instants (initial contact, peak vertical ground reaction force, and peak stance phase). Initial contact was defined as the instant after ground contact that the vertical ground reaction force was higher than 10 N; peak stance was defined as the maximum value, within the stop-jump phase, for each dependent variable. Foot angle at initial contact was also compared between pivot and sidestep tasks. Alpha was set *a priori* at 0.05.

Results

Kinetics

Descriptive statistics are given in Table I. At initial contact, the drop-jump had a higher posterior ground reaction ($F_{2,36} = 12.864$, $P < 0.001$) than the sidestep and pivot tasks; however, at peak posterior ground reaction force, the pivot had higher posterior ground reaction force ($F_{2,36} = 52.860$, $P < 0.001$) than the drop-jump and sidestep cutting. Participants had greater vertical ground reaction forces ($F_{2,36} = 6.525$, $P < 0.001$) at its peak on the sidestep cutting than on the pivot and drop-jump. For the sidestep cutting task, the peak occurred later during the stance phase ($44.1 \pm 13.3\%$; $F_{2,36} = 37.039$, $P < 0.001$) than for the drop-jump ($18.9 \pm 15.5\%$) and pivot task ($12.2 \pm 10.9\%$). The pivot task presented a lower knee extension–flexion moment ($F_{2,36} = 66.671$, $P < 0.001$) and higher knee varus–valgus moment ($F_{2,36} = 30.667$, $P < 0.001$) than the drop-jump and sidestep tasks at initial contact. Knee extension moment peak stance was higher for the sidestep ($F_{2,36} = 33.245$, $P < 0.001$) than for the drop-jump and pivot, and was higher for the drop-jump than the pivot. Typical patterns of knee varus–valgus moment and posterior ground reaction forces are represented in Figures 2 and 3 respectively. The participants had a higher knee varus–valgus moment ($F_{2,36} = 26.768$, $P < 0.001$) at peak stance for the pivot than the drop-jump and sidestep, and a higher moment with the sidestep than the drop-jump.

Kinematics

Descriptive statistics (means, standard deviations, and 95% confidence intervals) are presented in Table II. While performing the pivot task, participants had lower knee flexion ($F_{2,36} = 43.447$, $P < 0.001$) and higher knee valgus ($F_{2,36} = 34.681$, $P < 0.001$) at initial contact than for the drop-jump and sidestep cutting. Typical patterns of knee flexion and valgus are presented in Figures 4 and 5 respectively. There was no difference among tasks for ankle flexion and hip flexion at initial contact ($P > 0.05$). At peak vertical ground reaction force, the pivot task had lower knee flexion ($F_{2,36} = 21.508$, $P < 0.001$) and a higher valgus angle ($F_{2,36} = 22.175$, $P < 0.001$) than the drop-jump and sidestep. Furthermore, sidestep was also significantly different from the drop-jump, where the participants were in a varus position. Hip flexion ($F_{2,36} = 41.587$, $P < 0.001$) at peak vertical ground reaction was higher for the drop-jump than the sidestep and pivot, and higher for the sidestep than the pivot.

For knee flexion at peak stance, participants went into higher flexion ($F_{2,36} = 235.283$, $P < 0.001$) on the drop-jump than the sidestep and pivot. For knee valgus at peak stance, the pivot task presented higher valgus angles ($F_{2,36} = 9.235$, $P < 0.001$) than the sidestep and drop-jump. Lastly, hip flexion peak stance was lower ($F_{2,36} = 52.770$, $P < 0.001$) in the sidestep than the drop-jump and pivot, and lower in the pivot than in the drop-jump. The pivot task had an increased foot angle ($90 \pm 12.9^\circ$; $F_{1,18} = 318.573$, $P < 0.001$), relative to the antero-posterior direction, than the sidestep cutting task ($38.7 \pm 14.2^\circ$).

Discussion

The present study was designed to evaluate kinematic and kinetic differences among three landing tasks in a female collegiate soccer population using innovative visualization software. One of the main results to emerge from this study is that the three tasks appear to have distinct kinematic and kinetic characteristics; specifically, increased knee valgus position and loading, increased peak posterior ground reaction force, and decreased knee flexion angle for the pivot task compared with the drop-jump and sidestep cutting tasks. The results for each task suggest that they have differentiated characteristics and that the injury

mechanism may be task dependent, possibly requiring individualized prevention programmes and screening processes.

We found that the pivot task presented significantly higher knee valgus angle and loading at initial contact and at peak stance compared with the other two tasks. For the drop-jump task, our results are at odds with those of Blackburn and Padua (2009). They reported a knee valgus angle of 6° , whereas our participants were almost in a neutral alignment (0.8°). This suggests that even with a low knee flexion angle at initial contact, the participants were able to maintain their alignment without displacing the knee into a valgus position, which has been hypothesized as a risk factor (Hewett et al., 2005; McLean, Huang, & van den Bogert, 2005). This difference may be explained by the participants' background. Blackburn and Padua (2009) opted for recreational athletes, whereas our volunteers were Division I collegiate soccer athletes who are trained to perform these tasks on a regular basis. In contrast, for the sidestep and pivot tasks the participants were always in a knee valgus position, which is comparable to the results of Ford and colleagues (Ford, Myer, Toms, & Hewett, 2005). The valgus alignment might increase the load on the ACL, especially in the pivot task where they attained approximately 11° of valgus position. This increase in knee valgus angle might be due to the demands of the task, as well as the foot position at initial contact where the participants were perpendicular with the antero-posterior direction, which could have potentially enhanced the knee valgus position. The participants had to come to a full deceleration and perform a 180° change in direction, which entails a full rotation over the dominant foot. The drop-jump movement, on the other hand, consisted of deceleration followed by a jump into the air without an unanticipated factor. Lastly, the sidestep task has a momentary deceleration and change of direction as opposed to a complete stop of forward momentum, thus lending itself to varying movement pattern results. The biomechanical movement outcomes of multiple jump-landing tasks (e.g. drop-jump, sidestep) need to be taken into consideration when comparing studies focusing on biomechanical risk factors for ACL injury.

We hypothesized that a dynamic task (sidestep and pivot) would increase the knee internal varus moment when compared with the drop-jump. This was supported by our results, showing a large increase in the pivot task over the other two tasks for knee internal varus moment. Multi-directional jump-landing tasks more closely replicate field conditions, thus indicating a greater risk for injury due to the increased frontal plane demands compared with the uni-directional drop-jump task. Researchers have promoted that dynamic valgus load may be the primary risk factor for the rupture of the ACL (Ford, Myer, & Hewett, 2003; McLean et al., 2004a). This valgus position combined with an increased internal varus moment has been shown to increase the load placed at the ligament (Bendjaballah, Shirazi-Adl, & Zukor, 1997). A prospective study by Hewett and colleagues (2005) found that knee valgus angles and loading were strong predictors for athletes that injured their ACL (Hewett et al., 2005). The authors theorized that if a valgus angle and loading are present during a landing, it could place excessive strain on the ACL and rupture it. We have observed that the pivot task presented higher knee valgus angle and loading, which may represent an increased strain on the ACL during the execution of this common task in soccer. However, this pattern was not fully observed for the other tasks. This might suggest that the pivot task augments the load on the ligament and increases the likelihood for injury. When comparing our sidestep results to those of McLean et al. (2005), it is interesting to observe that the knee varus moments of our female participants ($0.49 \text{ N} \cdot \text{m/kg} \cdot \text{m}$) are similar to those of McLean and colleagues' male athletes ($0.45 \text{ N} \cdot \text{m/kg} \cdot \text{m}$) (McLean et al., 2005). Yet, this similarity may be due in part to the anthropometric height differences of Division I female soccer versus Division I male basketball players. The females were approximately 15 cm shorter, thus their lower centre of gravity may have created a biomechanical advantage to aid them in performing the movement tasks similar to taller trained males, versus potential muscular

strength differences. The lack of significant valgus loading demands during the sidestep pivoting task indicates that this type of motion may not impose a strenuous load on lower extremity movement patterns in healthy, trained Division I female soccer athletes. Lastly, while performing the drop-jump task, the participants were always in a varus position with minimal knee varus loading. This could potentially indicate that the drop-jump does not elicit similar factors for knee loading and likelihood of injury as the pivot and sidestep tasks.

A second result to emerge from our results is the decreased knee flexion angle at initial contact and peak stance for the pivot task compared with the drop-jump. A decreased knee flexion angle at initial contact has been proposed as a risk mechanism for ACL tear (Wojtys, Ashton-Miller, & Huston, 2002). With low knee angles (0–30°), the quadriceps muscles can place enough strain on the ACL to rupture it (Nisell, 1985). In our study, the athletes presented decreased knee flexion while performing a pivot task (24°). The low knee flexion angle presented at initial contact might place the participants at higher ACL strain due to the combination of an erect posture with a probable increase in quadriceps activation (Blackburn & Padua, 2009). At peak stance, the participants were in slightly lower knee flexion angle for the pivot and sidestep cutting tasks than the drop-jump. We found that peak posterior ground reaction force was higher in the pivot task than the other two tasks. The increased posterior ground reaction force can also be a consequence of the foot placement at initial contact. During the pivot task, the foot was parallel with the antero-posterior direction, potentially producing an increased posterior force, whereas during the sidestep, the foot was approximately parallel with the same direction. Researchers have shown a high correlation between posterior ground reaction force and proximal anterior tibia shear force (Sell et al., 2007; Yu et al., 2006). Proximal anterior tibia shear force is thought to create an anterior displacement of the tibia, thus increasing the strain on the ACL (Sell et al., 2007; Yu et al., 2006). When this force is too high, it is speculated it can lead to ACL rupture. Consequently, a high posterior ground reaction force for the pivot task may suggest that there is an increased load on the ACL. It is our belief that the association of two theoretical risk factors, low knee flexion and increased posterior ground reaction force, most likely increases the knee loading and the demands in the knee ligamentous structures during the pivot task. It is worth noting that the participants experienced approximately one time their body weight for posterior ground reaction force during this task. However, caution is required when speculating about the link of a single variable to potential ACL tear, since none of the participants actually injured their ACL during testing.

An interesting result to note is the decreased hip flexion range of motion during the sidestep and pivot tasks. The hip flexion range of motion, similar to knee flexion, was significantly higher in the drop-jump than in the sidestep and pivot. The augmented knee and hip range of motion for the drop-jump makes it plausible that the athletes assumed a more protective landing mechanic towards the ACL during the drop-jump task than for the sidestep and pivot. However, this fact is possibly due to the nature of the tasks. The drop-jump motion can be observed while landing from a basketball rebound or landing from a soccer header, whereas the athlete has to quickly react and adjust to stimuli for the sidestep and pivot cutting motions (i.e. players, ball). Further investigation on the amount of hip and trunk strength and its role in controlling multi-directional rotational movement tasks (e.g. pivot) should be conducted to help elucidate training factors that can potentially aid in the reduction of lower extremity injuries. Lastly, the drop-jump is performed in an anticipated fashion. These factors may suggest that the drop-jump task, in a controlled laboratory environment, might not induce sufficient risk/strain to the ACL to allow a clear understanding of the injury mechanism.

Conclusions

Overall, we found that there were differences in kinematic and kinetic variables between the three landing tasks. In particular, the pivot task exhibited an increased knee valgus position and internal varus moment at initial contact and peak stance compared with the sidestep cutting and drop-jump tasks. The pivot also had lower knee flexion at initial contact and peak stance and higher peak posterior ground reaction force than the other two tasks. When combining all the factors, it appears that the athletes presented a more erect posture during the pivot task, and adopted strategies that may place higher loads on the knee joint, and increase the strain on the ACL. Studying the female population in isolation may provide detailed insight into their landing patterns. However, to fully understand the underlying mechanisms responsible for the disparity in injury rates between the sexes, future studies should include male counterparts, as well as athletes screened and classified at high and low risk for injury. Future studies should focus on the influence of foot-landing strategies on the proximal structures of the lower extremity and differentiate how the movement task (e.g. vertical vs. horizontal) influences the jump-landing movement strategy. The influence of instruction on jump-landing patterns should be further evaluated for various motor tasks to provide evidence-based instructional approaches for injury prevention and investigate how these changes affect performance outcomes. Various approaches (e.g. sagittal vs. frontal plane) to identify the primary risk factor for ACL injuries have been proposed and debated in the literature, yet the failure to take into account the task $\times$ person $\times$ environment trichotomy leads to silo viewpoints that do not account for all the possible reasons for ACL injury. Future assessments should be conducted utilizing a dynamical holistic approach to movement tasks to better account for all factors that can influence movement patterns and thus act as potential risk factors for injury. Movement pattern assessment must take into consideration the type of functional and directional movement task applied per individual to create a personalized approach to lower extremity risk assessment with the ultimate goal of reducing risk for future injury occurrence or re-occurrence.

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Figure 1.
Example of the unanticipated scenario projected onto a screen to mimic a soccer game situation.

Figure 2. Knee varus–valgus moment during the stance phase of three tasks: drop-jump, sidestep, and pivot tasks.

Figure 3. Posterior ground reaction force during the three landing tasks measured in multiples of body weight while performing three tasks: drop-jump, sidestep, and pivot.

Figure 4. Knee flexion angle during the stance phase of three tasks: drop-jump, sidestep, and pivot tasks.

Figure 5. Knee valgus angle during the stance phase of three tasks: drop-jump, sidestep, and pivot tasks.

Table 1

Descriptive analysis (means, standard deviations, and 95% confidence intervals) of the kinematic variables at initial contact, peak stance, and peak vertical ground reaction force (PVGRF) during three athletic tasks.

	Drop-jump				Sidestep cutting				Pivot			
	Mean	s	95% CI-LB	95% CI-UB	Mean	s	95% CI-LB	95% CI-UB	Mean	s	95% CI-LB	95% CI-UB
Initial contact												
Knee flexion (°)	-30.3	5.2	-32.8	-27.8	-38.8	8.4	-42.9	-34.8	-24.3	5.7	-27.1	-21.5
Knee valgus (°)	0.8	4.7	-1.4	3.1	-1.4	9.3	-5.9	3.1	-11.6	6.7	-14.9	-8.4
Hip flexion (°)	53.5	8.3	49.5	57.5	48.6	13.5	42.1	55.1	48.3	8.4	44.3	52.4
Ankle flexion (°)	-6.7	7.4	-10.1	-2.9	-0.8	11.7	-6.4	4.8	2.5	36.4	-15.1	20.0
Peak stance												
Knee flexion (°)	-108.8	13.1	-115.2	-102.5	-56.5	7.2	-59.9	-53.0	-57.6	7.9	-61.4	-53.8
Knee valgus (°)	-3.9	8.0	-7.8	-0.8	-3.8	10.0	-8.6	1.0	-12.2	7.0	-15.5	-8.8
Hip flexion (°)	95.0	14.7	87.9	102.1	49.1	13.7	42.5	55.7	64.9	13.4	71.3	58.4
PVGRF												
Knee flexion (°)	-73.2	2.7	-85.6	-60.8	-53.9	9.4	-58.4	-49.3	-41.2	8.8	-45.7	-37.0
Knee valgus (°)	3.7	6.4	0.6	6.7	-2.9	10.0	-7.8	1.8	-7.6	10.1	-12.5	-2.8
Hip flexion (°)	75.7	15.6	68.1	83.2	37.0	13.1	30.7	43.3	52.7	11.6	47.1	58.4

Table II

Descriptive analysis (means, standard deviations, and 95% confidence intervals) of the kinetic variables at initial contact and peak stance during three athletic tasks.

	Drop-jump			Sidestep cutting			Pivot					
	Mean	s	95% CI-LB	95% -UB	Mean	s	95% CI-LB	95% -UB	Mean	s	95% CI-LB	95% -UB
Initial contact												
Extension moment	-0.055	0.048	-0.078	-0.031	-0.225	0.066	-0.257	-0.194	-0.266	0.093	-0.311	-0.222
Varus–valgus moment	0.029	0.027	0.016	0.042	0.261	0.044	0.005	0.047	0.128	0.075	0.091	0.164
PGRF	0.068	0.013	0.061	0.074	0.224	0.034	0.006	0.039	0.024	0.386	0.005	0.042
Peak stance												
Extension moment	0.789	0.208	0.689	0.890	1.131	0.289	1.271	1.150	0.523	0.245	0.405	0.641
Varus–valgus moment	0.140	0.069	0.107	0.173	0.487	0.326	0.330	0.644	0.719	0.300	0.575	0.864
VGRF	1.16	0.16	1.09	1.24	1.64	0.41	1.44	1.84	1.51	0.47	1.28	1.73
PGRF	0.264	0.063	0.233	0.294	0.280	0.121	0.221	0.338	0.801	0.289	0.662	0.941

Note: VGRF = vertical ground reaction force, PGRF = peak ground reaction force.