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Soccer-specific video simulation for improving movement assessment

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Abstract
The improvement of ecological validity of laboratory research studies has recently come to the forefront of technology with virtual reality scenarios. The purpose of this study was to assess differences between unanticipated and anticipated lower extremity biomechanics while performing a sidestep cutting task. A visualization software was developed for this purpose, which would recreate a soccer game situation for use in a laboratory setting. Thirteen participants volunteered for this study. Lower extremity biomechanical data were collected with a VICON motion analysis system and two force plates, under anticipated and unanticipated conditions while performing a sidestep cutting task. Paired *t*-tests were conducted to assess possible differences between conditions. Alpha level was set *a priori* at 0.05. We found an increased knee adduction angle (unanticipated: $-7.2 \pm 5.3°$; anticipated: $-4.0 \pm 5.3°$), and knee internal rotation (unanticipated: $8.1 \pm 4.7°$; anticipated: $5.2 \pm 6.5°$) when performing the unanticipated condition ($p < 0.05$). The methodological approaches for studies investigating the factors possibly associated with ACL injury may need to take into account the laboratory environment and how the task(s) are presented to the participants.

Keywords: *software, visualization, anticipated, unanticipated, soccer*

Introduction

Ecological validity of human movement studies is an essential research concept that is often underestimated (Robins, Hunyadi, and Schultz, 2009; Shiffman, Stone, and Hufford, 2008). The generalization of research findings is highly dependent on the design of the study and its applicability to real-life situations outside the study (Robins et al., 2009; Shiffman et al., 2008). Parsons, Silva, Pair, and Rizzo (2008) utilized virtual reality environments to study neurocognitive functions, and concluded that it improved the reliability and (ecological) validity of the study (Parsons et al., 2008). Shiffman et al. (2008) reported that

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utilizing an ecological momentary assessment method allows to minimize the recall bias, and evaluate how behavior changes on real time and, more important, measured within the participants' environment. To our knowledge, few biomechanical studies have attempted to improve their ecological validity, especially those that dealt with anterior cruciate ligament (ACL) in the endeavor of clarifying possible risk factors.

Several risk factors have been hypothesized as the mechanisms of ACL injury (Davis, Ireland, and Hanaki, 2007; Griffin et al., 2000; Griffin et al., 2006). These risk factors have been primarily studied using a drop-box jump, stop-jump, or anticipated cutting tasks (Blackburn and Padua, 2008; Chappell and Limpisvasti, 2008; Colby et al., 2000; Cortes et al., 2007; Houck, 2003; Kernozek, Torry, Van Hoof, Cowley, and Tanner, 2005; Malinzak, Colby, Kirkendall, Yu, and Garrett, 2001; Russell, Palmieri, Zinder, and Ingersoll, 2006; Seegmiller and McCaw, 2003). More recently, few authors have attempted to improve the experiment ecological validity by developing unanticipated tasks through the usage of light stimulus (e.g., green/red light, arrows pointing) (Beaulieu, Lamontagne, and Xu, 2008; Ford, Myer, Toms, and Hewett, 2005; Pollard, Heiderscheit, Davis, and Hamill, 2004; Pollard, Heiderscheit, van Emmerik, and Hamill, 2005). This light stimulus is expected to provide a situation similar to that where the athlete has to react quickly to a given stimuli. However, the light stimulus might not replicate a common game situation (e.g., marker lines, players, grass, and soccer ball). Few studies have examined the effects of anticipation on lower extremity biomechanics (Besier, Lloyd, Ackland, and Cochrane, 2001; Houck, Duncan, and Haven, 2006). Besier et al. (2001) utilized a light stimulus to create the unanticipated effect. The authors found an increased in knee joint loadings during running and cutting maneuvers when performed under unanticipated stimulus. They theorized that the increased loads could potentially increase the risk for injury, and that intervention programs should focus on providing unanticipated cues. However, the light stimulus does not reflect a cue normally received during practice or game. The existing gap between the current laboratory tests and real-life situations have lead some authors to strongly recommend that the methods used in biomechanical studies need to improve their ecological validity and approach real-life situations (Davis et al., 2007).

Therefore, the purposes of this study was to assess differences between unanticipated and anticipated lower extremity biomechanics while performing a sidestep cutting task. A visualization software was developed for this purpose, which would recreate a soccer game situation for use in a laboratory setting.

Methods

Software development

All software was written in object oriented C++, Open GL, GLUT (Open**GL U**tility **T**oolkit) and GLEW (Open**GL E**xtension **W**rangler Library) using Microsoft Visual C++2005 Express Edition. A Sick WL260-S270 Proximity/Reflex infrared sensor detected the participant and sent a signal to the software via a mouse.

A testing scenario consists of a series of random cues: left, right, and stop within a soccer visualization. The researcher can review the scenarios with the participant, or set the quantity of each cue and use a random cue generating algorithm to run a series of tests (Blount, 2007). The soccer scenario displays a soccer ball rolling forward on a soccer field to give the participant the illusion that s/he is pursuing the soccer ball. The motion cue consists of the ball changing direction left or right to simulate the ball being kicked, or other soccer players getting in front of the participant to signal the participant to stop. The researcher can change

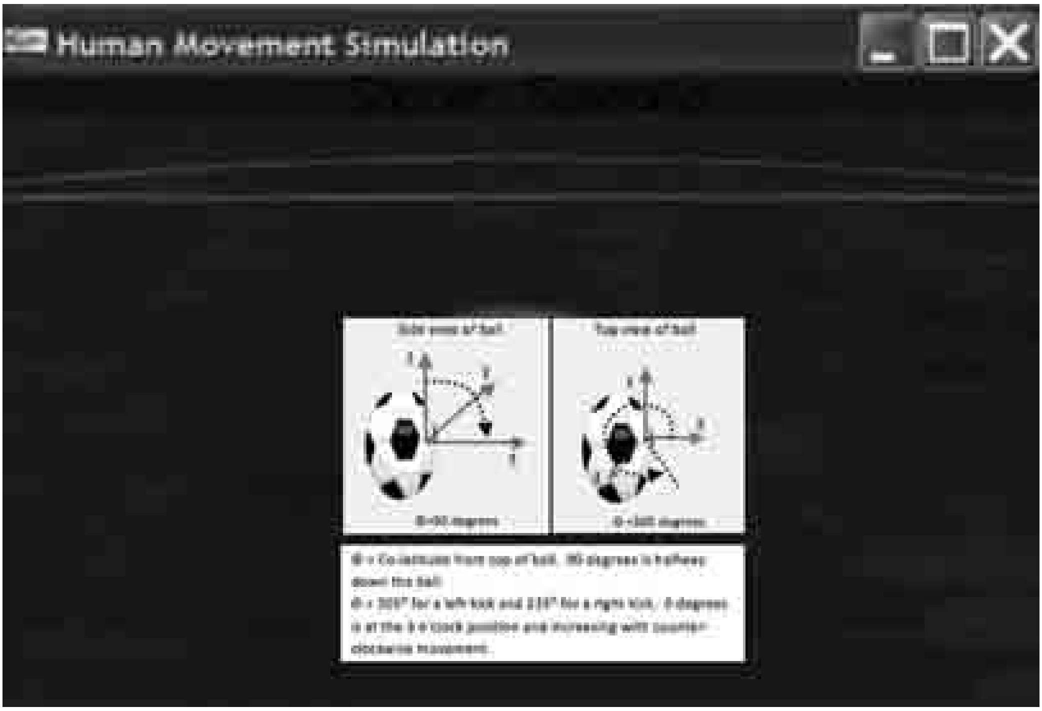

Figure 1. Ball image and calculations for the various parameters for the ball (e.g., rolling speed, contact colatitude, foot velocity).

the ball's velocity to allow for varying speeds at which the athlete runs and adjust the ball movement after the "kick".

Actual measurements were used in the physics calculations for visualization (Figure 2). The vector of movement for the ball was calculated using polar coordinates:

$$X = r \cdot \cos\Theta \cdot \sin\Phi \tag{1}$$

$$Y = r \cdot \sin\Theta \cdot \sin\Phi \tag{2}$$

$$Z = r \cdot \cos\Phi \tag{3}$$

where r is the actual radius of the soccer ball; Θ and Φ are the longitude and co-latitude polar coordinates for calculating the vector of movement for the contact point of the kick. X, Y, and Z were relative to the soccer field for calculating the vector of movement. X was the horizontal axis moving left to right, Y was depth, and Z was the vertical axis. The ball would move straight up if kicked at exactly $\Phi = 180°$. A kick at the 3 o'clock position ($\Theta = 0°$) would send the ball directly left. X, Y, and Z were measured in meters.

The law for conservation of momentum was used to determine the velocity vector of travel:

$$m_{ball} \cdot v_{ball} + m_{foot} \cdot v_{foot} = m_{ball} \cdot u_{ball} + m_{foot} \cdot u_{foot} \tag{4}$$

where m is mass, u is velocity before impact, and v is velocity after impact. To simplify the equation, the ball velocity before the kick (u_{ball}), and the foot velocity after the kick (v_{foot}) were assumed to be zero. After the kick, the altitude of the ball was changed using gravity

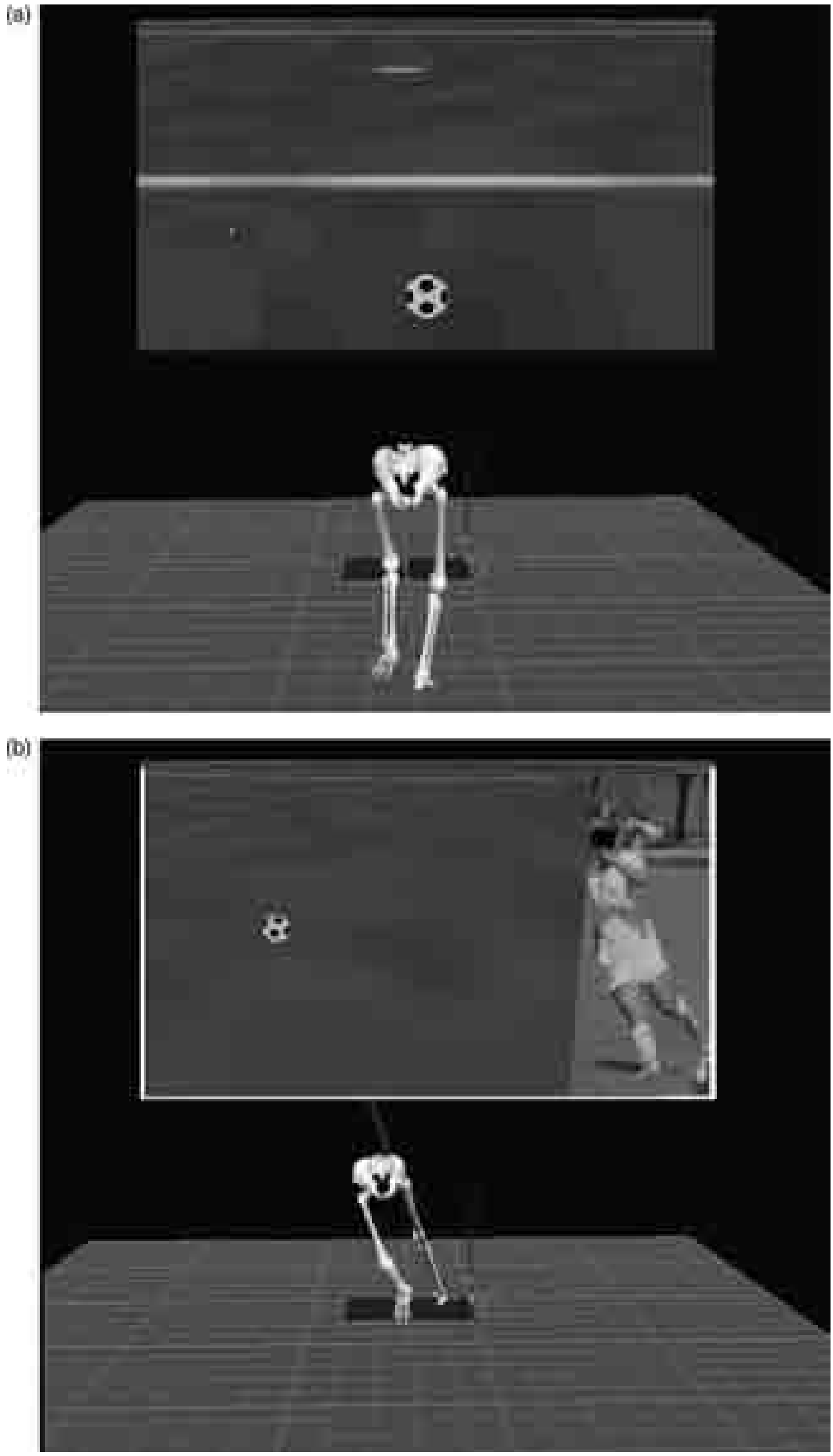

Figure 2. Example of soccer scenario display. (a) Initial visualization of the screen with ball rolling on the soccer field; (b) cue for a sidestep cutting if participant is right side dominant.

($9.81\ m/s^2$). The ball rotated on a vector perpendicular to the trajectory of the ball calculated by adding 90°to Θ. The degrees of rotation were calculated using the distance traveled (d) and ball circumference (C):

$$\theta_{rot} = \frac{d}{C} \tag{5}$$

The calculation of ball movement did not take into account air resistance, the Magnus effect, deflection, or impact with the ground (Wesson, 2002). Motion continued in the X and Y directions, but the Z coordinate was static once the ball impacts the ground. When the ball was "kicked", the trajectory changed using the above equations, and a picture of a soccer player was displayed on the kicking side, signaling the participant to pursue the soccer ball along its new trajectory. Samples of the scene before a movement cue, a cut left cue, and menu options are shown in Figure 3.

Experimental design

Participants. Thirteen Division I female collegiate soccer athletes ($M \pm SD$: age = 19.3 ± 0.9 years; height = 1.68 ± 0.05 m; mass = 61.3 ± 5.6 kg) participated in this study. Criteria for inclusion were that the NCAA Division I female soccer players had no previous history of cardiovascular or respiratory disease, and they also had to be cleared by the team physician for practice and games at the moment of data collection to be included in the study. 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, approval of the research through Institutional Review Board, and written informed consent for all participants was obtained.

Figure 3. Example of sidestep cutting task with the participant approaching the force plate, planting the dominant foot on the plate, and cut to the contra lateral side with the cue being displayed on the wall in front of the participant.

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Experimental procedures. Participants wore spandex shorts, sports bra and used the team running shoes provided at the beginning of the season (Adidas Supernova, AG, Herzogenaurach, Germany). The participants were given a 10-minute warm-up period, consisting of cycling and self-directed stretching. After the warm-up period and stretching, 40 reflective markers were placed on specific body landmarks. The same researcher [NC] placed the markers on all subjects. Pilot test in our laboratory has shown good to excellent reliability in marker placement for knee flexion and abduction, and hip abduction (ICC = 0.620 to 0.889). From those 40, 10 were calibration markers, which included greater trochanters, medial and lateral knee, medial and lateral malleoli. The other 30 markers were tracking markers including posterior superior iliac crest, anterior iliac crest, four maker clusters for the thighs and shanks, and fiver markers on each foot. A standing trial and a dynamic trial to calculate hip joint centers were obtained prior to data collection. After those trials, the calibration markers were removed.

After explanation of the athletic tasks, the participants were given time to practice each one. For the anticipated condition, the participants were instructed to perform five trials of a sidestep cutting task (Figure 4). For the unanticipated condition, a light beam was placed across the platform where the participants were running and 2 m prior to the force plates. When the participants' crossed and interrupted the light beam it triggered a software program on a laptop to randomly generate the athletic task and project it onto a screen in front of the participants. There were two possible cues that the participants could receive; one to perform a sidestep cutting task, and the other to execute a running stop-jump. For the purpose of this study, we only analyzed the sidestep cutting task. A Brower timing system (Brower Timing Systems, Draper, UT, United States) was used to control the approach speed.

The sidestep cutting task consisted of a running approach, step with the dominant foot on the force plate and cut to the contra-lateral side of the dominant foot touching the force plate at an angle of approximately 45°(Colby et al., 2000). The participant then cut at an angle between 35°and 55°to the opposite side of the contact foot. Prior to data collection, the participants had three trials to practice or until they felt comfortable with the task. The participants were required to perform five successful trials. There was a 1-minute rest

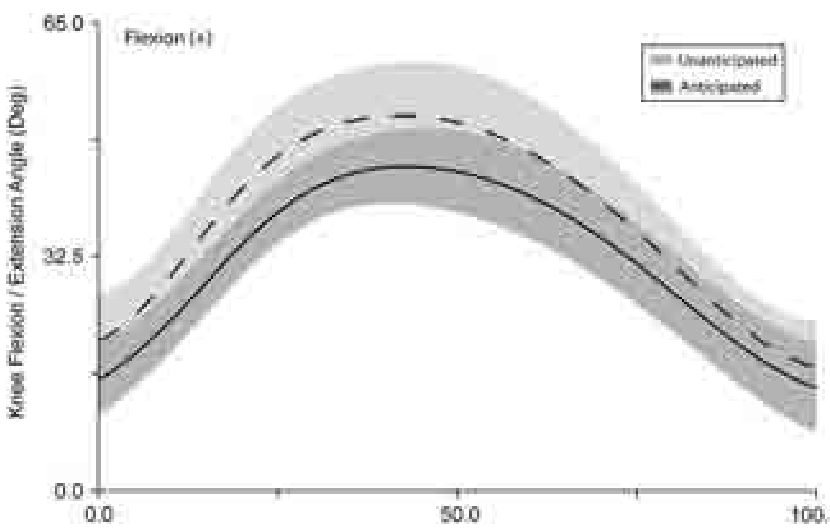

Figure 4. Knee flexion angular displacement throughout the stance phase during the anticipated and unanticipated sidestep cutting a task. Lines represent normative values of the entire sample ± *SD*.

period between trials to minimize fatigue. Participants performed five successful trials of a running stop and of a sidestep cutting. Testing trials were repeated if the participant did not land completely on the force plate, or was unable to execute the trials at a minimum speed of 3.5 m/s. The participants had an approach speed of 3.7 ± 0.2 m/s for unanticipated condition, and 4.4 ± 0.5 m/s for anticipated condition. There was a significant difference between conditions for approaching speeds ($p < 0.001$).

Twelve high-speed video cameras (Vicon Motion Systems Ltd., Oxford, UK) were used to monitor the motion analysis of the lower extremity, with a sampling rate of 270 Hz. Two Bertec Force Plates, Model 4010 (Bertec Corporation, Columbus, OH, United States) with a sampling rate of 1,080 Hz were used to measure ground reaction forces. From the standing (static) trial, a lower extremity kinematic model was created for each participant using Visual 3D (C-Motion, Rockville, MD, United States). The kinematic model was used to quantify the motion at the hip, knee, and ankle joints utilizing standard inverse dynamics (Winter, 2005). The convention used for flexion-extension, abduction-adduction, and internal-external rotation was comparative to a joint coordinate system (Grood and Suntay, 1983). The standing trial with circular motion of the pelvis was used to estimate a functional hip joint center (Begon, Monnet, and Lacouture, 2007; Schwartz and Rozumalski, 2005). Based on a power spectrum analysis, marker trajectory was filtered with a fourth-order Butterworth zero lag filter with a 7 Hz cutoff frequency, whereas ground reaction force data were filtered with a similar filter with a 25 Hz cutoff frequency.

Statistical analysis

Case-wise diagnostic were performed to assess data normalcy based on the Kolmogorov-Smirnov test. Paired *t*-tests were conducted to evaluate differences between unanticipated and anticipated conditions. The dependent variables used in this study included: vertical and posterior ground reaction forces, knee flexion, knee abduction, knee rotation, knee flexion-extension moment, knee abduction-adduction moment, hip flexion, hip abduction, and hip rotation. These variables were measured at different time instants that included: initial contact and peak stance. Initial contact was defined as the time where vertical ground reaction force was higher than 10N. At that time all dependent measures were obtained from each trial separately. Peak stance was defined as the maximum value of any dependent variable between initial contact and 50% of Stance Phase. The peak stance values for each dependent variable were obtained per each trial. Kinematic data were measured in degrees, whereas ground reaction forces were normalized to multiples of bodyweight, and joint moments were normalized to mass * height (Nm/kgm). Data were analyzed between initial contact and maximum knee flexion, which defines the stop-jump phase. All data were reduced using Visual 3D and a custom-made Matlab (The MathWorks, Inc., Natick, MA, United States) program to export into a Microsoft Excel spreadsheet. Each of the five trials were averaged and exported into SPSS version 16.0 (SPSS Inc., Chicago, IL, United States) for data analysis. Alpha level was set *a priori* at 0.05.

Results

Kinematics. Descriptive statistics for kinematic data with means, standard deviations and 95% confidence intervals are presented in Table I. The unanticipated condition had consistently greater kinematic values than the anticipated condition. Specifically, knee flexion at initial contact was significantly higher for unanticipated condition (−20.7 ± 4.7°) than the anticipated condition (−15.4 ± 4.5°) ($p < 0.001$; Figure 5). An identical pattern

Table I. Descriptive analysis (*M*, *SD*, and 95% confidence intervals) of the kinematic variables at initial contact and peak stance during two conditions (unanticipated and anticipated).

	Unanticipated		Anticipated		
	M ± *SD*	95% CI	*M* ± *SD*	95% CI	*p*
Initial contact					
Knee flexion (+) (°)	20.7 ± 4.7	23.5, 17.9	15.4 ± 4.5	18.1, 12.7	<0.001*
Knee adduction (+) / abduction (-) (°)	−1.5 ± 3.9	−3.9, .9	−.8 ± 3.9	−3.2, 1.4	0.039*
Knee internal rotation (+) / external (-) (°)	8.1 ± 4.7	5.3, 10.9	5.2 ± 6.5	1.3, 9.2	0.031*
Hip flexion (+) (°)	36.6 ± 15.0	27.5, 45.7	38.9 ± 16.9	28.7, 49.2	0.251
Hip adduction (+) / abduction (-) (°)	−12.7 ± 4.8	−15.7, −9.8	−8.8 ± 7.6	−13.4, −4.2	0.015*
Hip internal rotation (+) / external (-) (°)	10.9 ± 6.6	6.9, 14.9	10.7 ± 10.3	4.5, 16.9	0.916
Peak stance					
Knee flexion (+) (°)	52.4 ± 5.6	55.8, 48.9	45.2 ± 4.5	47.9, 42.5	<0.001*
Knee adduction (+) / abduction (-) (°)	−7.2 ± 5.3	−10.4, −4.0	−4.0 ± 5.3	−7.2, −.8	<0.001*
Hip flexion (+) (°)	38.7 ± 14.4	29.9, 47.4	40.3 ± 15.9	30.7, 49.9	0.228

*Denotes statistical significance at $p < 0.05$.

was observed for knee abduction with higher angles at unanticipated (−1.5 ± 3.9) than anticipated (−.8 ± 3.9°) ($p = 0.039$). Knee rotation was also higher for the unanticipated condition (8.1 ± 4.7°) when compared to anticipated condition (5.2 ± 6.5°) ($p = 0.031$). There was a significantly higher hip abduction at initial contact during unanticipated condition (−12.7 ± 4.8°) than with the anticipated (−8.8 ± 7.6°) ($p = 0.015$; Figure 6).

Similarly, for peak stance angles, the unanticipated condition had higher angles than the anticipated. For peak knee flexion the unanticipated condition (−52.4 ± 5.6°) was higher than during the anticipated (−45.2 ± 4.5°) ($p < 0.001$). Peak knee abduction was

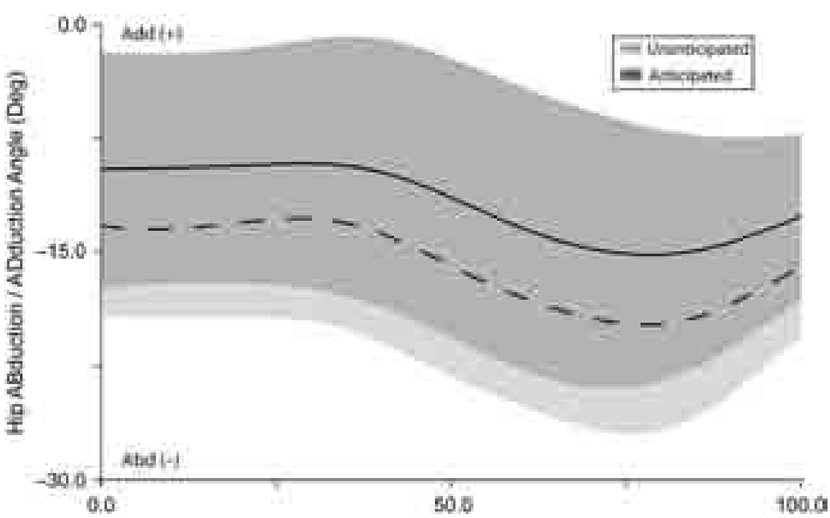

Figure 5. Hip abduction angular displacement throughout the stance phase during the anticipated and unanticipated sidestep cutting a task. Lines represent normative values of the entire sample ±*SD*.

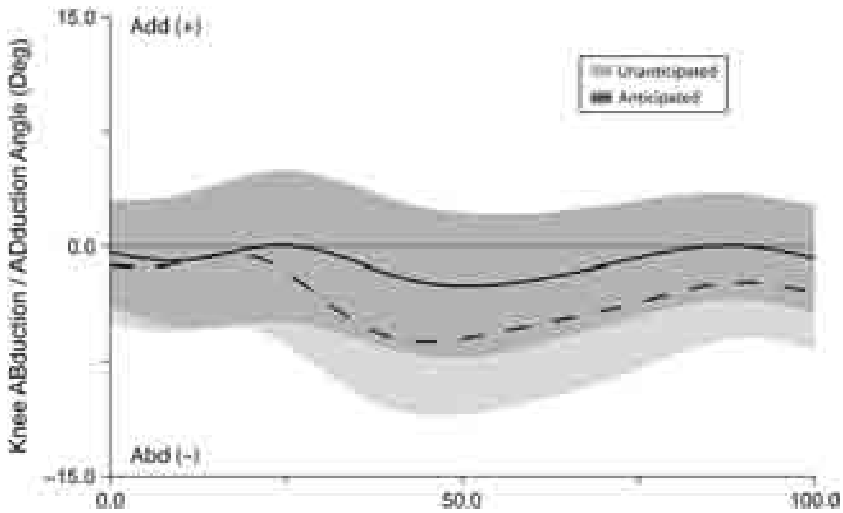

Figure 6. Knee abduction angular displacement throughout the stance phase during the anticipated and unanticipated sidestep cutting a task. Lines represent normative values of the entire sample ± *SD*.

Table II. Descriptive analysis (*M*, *SD*, and 95% confidence intervals) of the kinetic variables at initial contact and peak stance during two conditions (unanticipated and anticipated).

	Unanticipated		Anticipated		
	$M \pm SD$	95% CI	$M \pm SD$	95% CI	p
Initial contact					
Knee flexor/extensor moment (Nm/kgm)	0.014 ± .11	−.05, .08	−0.164 ± .14	−.249, −.081	0.003*
Knee adductor/abductor moment (Nm/kgm)	.038 ± .07	−.005, .08	.05 ± .08	.003, .103	0.251
Peak stance					
Knee adductor/abductor moment (Nm/kgm)	.37 ± .36	.16, .59	.52 ± .4	.28, .76	0.035*
Knee flexor/extensor moment (Nm/kgm)	1.9 ± .2	1.8, 2.1	1.9 ± .19	1.8, 2.0	0.272

*Denotes statistical significance at $p < 0.05$.

significantly higher during the unanticipated condition (−7.2 ± 5.3°) than during the anticipated condition (−4.0 ± 5.3°) ($p < 0.001$; Figure 7).

Kinetics. Descriptive statistics for kinetic data with means, standard deviations and 95% confidence intervals are depicted in Table II. Knee extension moment, at initial contact, was higher during the unanticipated condition (0.014 ± 0.11 Nm/kgm) than the anticipated condition (−0.164 ± 0.14 Nm/kgm) ($p = 0.003$). Contrastingly, peak knee internal adduction moment during the unanticipated condition (0.37 ± 0.36 Nm/kgm) had lower value than during the anticipated condition (0.52 ± 0.4 Nm/kgm) ($p = 0.035$).

Discussion and implications

The present study was designed to evaluate kinematic and kinetic differences between an anticipated and unanticipated sidestep cutting task, based on development of novel visualization software specifically created to mimic conditions occurring in soccer games. One of the main results to emerge from this study is that the unanticipated sidestep cutting task had distinct neuromechanical characteristics than during the anticipated condition. Specifically, the unanticipated condition presented increased knee abduction angles, knee internal rotation, and hip abduction and decreased knee flexion angles. The delineation of the conditions may possibly suggest that there is an increased demand of the neuromechanical system when presented with a decision-making process. Thus, the methodological approaches for studies investigating the factors possibly associated with ACL injury may need to take into account the laboratory environment and how the task(s) are presented to the participants. This does not necessarily mean that only unanticipated conditions should be used, given that baseline evaluation (e.g., anticipated condition) of how the neuromechanical control is performed for the different tasks is necessary. Still, to improve a study's applicability to real-life situations, the development of laboratory scenarios that will improve its ecological validity are necessary (Parsons et al., 2008; Robins et al., 2009; Shiffman et al., 2008). Hence, by using a visualization scenario that is closely related to a soccer situation we theorize that the differences obtained between conditions would be a consequence of the improved ecological validity, and this can augment the generalization of our results.

During the unanticipated condition, the participants had to decide, in a fraction of seconds (e.g., anticipated = 0.5 s, and unanticipated = 0.45 s), which task they would perform based on the visual cue, similarly to a game situation. The complexity of such decision process was in attempts to re-create what the players experience in a game situation, through the innovative aspect of having the athletes immersed in a scenario mimicking a soccer field (e.g., ball, field, and player). By reconstructing a similar game situation, we altered the movement patterns during an unanticipated condition; with increased knee abduction angle and internal rotation that might be related to the increased difficulty of the task and decision process involved. These two factors (e.g., knee abduction and internal rotation) have been previously theorized as possible mechanism of injury. The excessive knee abduction angle has been shown to be related with ligament dominance (Andrews and Axe, 1985). This ligament dominance has been associated with lack of ability to control the knee joint, and increased knee loads (Ford, Myer, and Hewett, 2003). Additionally, knee abduction angle have been related with increased (internal) adduction loading, which seems to be a strong predictor for increased risk of ACL injuries (Hewett et al., 2004; McLean, Huang, Su, and Van Den Bogert, 2004; McLean, Huang, and van den Bogert, 2005). These changes in frontal knee alignment have been shown to be enhanced under the presence of an unanticipated stimulus when compared with anticipated stimulus (Besier et al., 2001; Houck et al., 2006). Furthermore, knee internal rotation has been shown to be directly related to ACL rupture (Markolf et al., 1995). Thus, when our participants faced an unanticipated stimulus it is feasible to assume that they had diminish knee control, observed through increased knee abduction and internal rotation, and that could potentially place them at higher risk for injury occurrence. It seems that our visualization software elicited the demands of a sidestep cutting task that is normally carried out during practice and games.

A possible reason for the differences in kinematic and kinetic parameters, between the two conditions, could be due to the fact that the participants during an anticipated condition can potentially feel more comfortable with the movement rather than during the unanticipated condition, since no decision process was involved. Basically, the task demands were elicited during the unanticipated since the participants had to closely observe the screen where the cue was being displayed to properly react and execute the correct task. This is supported by motor control literature (Hick, 1952; Hyman, 1953). Hick's law states that the time it takes to choose the appropriate action is linearly dependent on the number of possible choices. Hence, by increasing the number of choices during the unanticipated condition, our participants had to slow down, which is evident by the different approaching speeds of approximately 1 m/s, to aptly react to the presented cue, and consequently altering their landing mechanics. Nonetheless, the difference in speeds between conditions is similar to those previously reported (Besier, Lloyd, and Ackland, 2003). We only set a minimum approach speed, which potentially allowed for some of the observable differences. Though, even with slower speeds during the unanticipated condition, participants still altered their mechanics to possible be at higher risk for injury (e.g., lower knee flexion angle, increased knee abduction angles). The unanticipated condition replicates more a game situation as the athletes' constantly have to make decisions throughout games, however, the reduced speed might not be mimicking their naturally speed as it was observed during the anticipated condition. Future studies should evaluate differences between reaction stimuli (i.e., anticipated vs. unanticipated) while performing the tasks at similar speeds or within a set range of speeds.

A number of limitations exist with our study. We did not control for a similar approach speed between conditions. We had a minimum approach speed (3.5 m/s), but did not set a maximum, more specifically a range that would create more consistency between conditions. Even though our visualization scenario is a major development when compared with previous stimulus (e.g., light, arrows), we used motionless pictures instead of an interactive avatar. The sudden appearance of the still picture on the screen did not perfectly mimic a soccer situation, where the participant adapts to the motion of the opponent. We did not compare our data with data from a "real-life" situation (e.g., practice, game). A comparison of both conditions (e.g., unanticipated and anticipated) with data obtained during practice or game situation would be necessary to further conclude about the changes currently enhanced by the visualization software.

Conclusion

Overall, we found differences on lower extremity biomechanics between conditions (e.g., anticipated and unanticipated) when using innovative visualization software. Specifically, the unanticipated condition had increased knee abduction, knee internal rotation, and decreased knee flexion angles. The differences between conditions may suggest that by using a novel visualization software to create an unanticipated event we may be (i) approaching the demands of a practice/game situation to a laboratory environment, and (ii) using a realistic scenario similar to what participants experience in their daily routine when compared to light and arrows stimulus. This promising software and results can improve laboratory research related to ACL risk factors. Further, the flexibility of the software can allow easy modifications for other research venues requiring different scenarios (i.e., military). We acknowledge that further development of the current scenario is needed combined with validation with data collected during real situations (e.g., practice, game); however, methods to (accurately) conduct such data collection are yet to be developed.

References

Andrews, J. R., and Axe, M. J. (1985). The classification of knee ligament instability. *Orthopedic Clinics of North America*, *16*, 69–82.

Beaulieu, M. L., Lamontagne, M., and Xu, L. (2008). Gender differences in time-frequency EMG analysis of unanticipated cutting maneuvers. *Medicine and Science in Sports and Exercise*, *40*, 1795–1804.

Begon, M., Monnet, T., and Lacouture, P. (2007). Effects of movement for estimating the hip joint centre. *Gait Posture*, *25*, 353–359.

Besier, T. F., Lloyd, D. G., and Ackland, T. R. (2003). Muscle activation strategies at the knee during running and cutting maneuvers. *Medicine and Science in Sports and Exercise*, *35*, 119–127.

Besier, T. F., Lloyd, D. G., Ackland, T. R., and Cochrane, J. L. (2001). Anticipatory effects on knee joint loading during running and cutting maneuvers. *Medicine and Science in Sports and Exercise*, *33*, 1176–1181.

Blackburn, J. T., and Padua, D. A. (2008). Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing. *Clinical Biomechanics (Bristol, Avon)*, *23*, 313–319.

Blount, E. (2007). *Generating demographically accurate household information*. Paper presented at the VMASC 2007 Capstone Conference.

Chappell, J. D., and Limpisvasti, O. (2008). Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *American Journal of Sports Medicine*, *36*, 1081–1086.

Colby, S., Francisco, A., Yu, B., Kirkendall, D., Finch, M., and Garrett, W., Jr. (2000). Electromyographic and kinematic analysis of cutting maneuvers. Implications for anterior cruciate ligament injury. *America Journal of Sports Medicine*, *28*, 234–240.

Cortes, N., Onate, J. A., Abrantes, J., Gagen, L., Dowling, E., and Van Lunen, B. (2007). Effects of gender and foot-landing techniques on lower extremity kinematics during drop-jump landings. *Journal of Applied Biomechanics*, *23*, 289–299.

Davis, I., Ireland, M. L., and Hanaki, S. (2007). ACL injuries–the gender bias. *Journal of Orthopaedic and Sports Physical Therapy*, *37*, A2–A7.

Ford, K. R., Myer, G. D., and Hewett, T. E. (2003). Valgus knee motion during landing in high school female and male basketball players. *Medicine and Science in Sports and Exercise*, *35*, 1745–1750.

Ford, K. R., Myer, G. D., Toms, H. E., and Hewett, T. E. (2005). Gender differences in the kinematics of unanticipated cutting in young athletes. *Medicine and Science in Sports and Exercise*, *37*, 124–129.

Griffin, L. Y., Agel, J., Albohm, M. J., Arendt, E. A., Dick, R. W., Garrett, W. E. et al. (2000). Noncontact anterior cruciate ligament injuries: Risk factors and prevention strategies. *Journal of American Academy of Orthopaedic Surgeons*, *8*, 141–150.

Griffin, L. Y., Albohm, M. J., Arendt, E. A., Bahr, R., Beynnon, B. D., Demaio, M. et al. (2006). Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *American Journal of Sports Medicine*, *34*, 1512–1532.

Grood, E. S., and Suntay, W. J. (1983). A joint coordinate system for the clinical description of three-dimensional motions: Application to the knee. *Journal of Biomechanical Engineering*, *105*, 136–144.

Hewett, T. E., Myer, G., Gregory, D., Ford, K. R., Heidt, R. S., Colosimo, A. J. et al. (2004). Neuromuscular control and valgus loading of the knee predict ACL injury risk in female athletes. *Medicine and Science in Sports and Exercise*, *36*, S287.

Hick, W. E. (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology*, *4*, 11–26.

Houck, J. (2003). Muscle activation patterns of selected lower extremity muscles during stepping and cutting tasks. *Journal of Electromyography and Kinesiology*, *13*, 545–554.

Houck, J. R., Duncan, A., and Haven, K. E. (2006). Comparison of frontal plane trunk kinematics and hip and knee moments during anticipated and unanticipated walking and side step cutting tasks. *Gait Posture*, *24*, 314–322.

Hyman, R. (1953). Stimulus information as a determinant of reaction time. *Journal of Experimental Psychology*, *45*, 188–196.

Kernozek, T. W., Torry, M. R., Van Hoof, H., Cowley, H., and Tanner, S. (2005). Gender differences in frontal and sagittal plane biomechanics during drop landings. *Medicine & Science in Sports Exercise*, *37*, 1003–1012, discussion 1013.

Malinzak, R. A., Colby, S. M., Kirkendall, D. T., Yu, B., and Garrett, W. E. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clinical Biomechanics (Bristol, Avon)*, *16*, 438–445.

Markolf, K. L., Burchfield, D. M., Shapiro, M. M., Shepard, M. F., Finerman, G. A., and Slauterbeck, J. L. (1995). Combined knee loading states that generate high anterior cruciate ligament forces. *Journal of Orthopaedic Research*, *13*, 930–935.

McLean, S. G., Huang, X., Su, A., and Van Den Bogert, A. J. (2004). Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. *Clinical Biomechanics (Bristol, Avon)*, *19*, 828–838.

McLean, S. G., Huang, X., and van den Bogert, A. J. (2005). Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: implications for ACL injury. *Clinical Biomechanics (Bristol, Avon)*, *20*, 863–870.

Parsons, T. D., Silva, T. M., Pair, J., and Rizzo, A. A. (2008). Virtual environment for assessment of neurocognitive functioning: virtual reality cognitive performance assessment test. *Studies in Health Technology and Informatics*, *132*, 351–356.

Pollard, C. D., Heiderscheit, B., Davis, I. M., and Hamill, J. (2004). Influence of gender on lower extremity segment and joint coordination during an unanticipated cutting maneuver. *Medicine and Science in Sports and Exercise*, *36*, S8.

Pollard, C. D., Heiderscheit, B. C., van Emmerik, R. E., and Hamill, J. (2005). Gender differences in lower extremity coupling variability during an unanticipated cutting maneuver. *Journal of Applied Biomechanics*, *21*, 143–152.

Queen, R. M., Gross, M. T., and Liu, H. Y. (2006). Repeatability of lower extremity kinetics and kinematics for standardized and self-selected running speeds. *Gait Posture*, *23*, 282–287.

Q3

Robins, D. L., Hunyadi, E., and Schultz, R. T. (2009). Superior temporal activation in response to dynamic audio-visual emotional cues. *Brain and Cognition*, *69*, 269–278.

Russell, K. A., Palmieri, R. M., Zinder, S. M., and Ingersoll, C. D. (2006). Sex differences in valgus knee angle during a single-leg drop jump. *Journal of Athletic Training*, *41*, 166–171.

Schwartz, M. H., and Rozumalski, A. (2005). A new method for estimating joint parameters from motion data. *Journal of Biomechanics*, *38*, 107–116.

Seegmiller, J. G., and McCaw, S. T. (2003). Ground Reaction Forces among Gymnasts and Recreational Athletes in Drop Landings. *Journal of Athletic Training*, *38*, 311–314.

Shiffman, S., Stone, A. A., and Hufford, M. R. (2008). Ecological momentary assessment. *Annual Review of Clinical Psychology*, *4*, 1–32.

Q4 Wesson, J. (2002). *The science of soccer*. Taylor & Francis.

Winter, D. A. (2005). *Biomechanics and motor control of human movement*, 3rd ed. (pp. 75–102). West Sussex: John Wiley.