Influence of gender on hip and knee mechanics during a randomly cued cutting maneuver

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Abstract

Objective. To investigate gender differences in three-dimensional hip and knee joint mechanics in collegiate athletes during a randomly cued cutting maneuver.

Design. Three-dimensional kinematics and kinetics were collected on 24 collegiate soccer players (12 females and 12 males) while each performed the cutting maneuver. In order to create a randomly cued condition, subjects were signaled by a lighted target board that directed them to perform one of three tasks. Hip and knee joint mechanics were compared between genders using one-tailed *t*-tests.

Background. Female athletes have an anterior cruciate ligament injury rate that is larger than their male counterparts. Gender differences in hip and knee joint mechanics during a randomly cued cutting maneuver have not been previously reported.

Methods. Five randomly cued cutting trials were included in the analysis. Selected peak hip and knee joint angles and moments were measured during the first 40° of knee flexion across the stance phase.

Results. Females demonstrated significantly less peak hip abduction than did males. Otherwise, there were no gender differences in selected peak hip and knee joint kinematics and moments.

Conclusions. Male and female collegiate soccer players demonstrate similar hip and knee joint mechanics while performing a randomly cued cutting maneuver.

Relevance

Because it is known that females incur a greater number of anterior cruciate ligament injuries than males, it is of interest to identify gender differences in lower extremity mechanics when performing sport specific tasks. Understanding of these differences will contribute to the development of prevention training programs.
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1. Introduction

Every year, more young women compete in intercollegiate sports and more women of all ages partici-pate in recreational sports. It has been reported that female athletes who participate in jumping and cutting sports are 4–6 times more likely to sustain a serious knee injury than male athletes participating in the same sports (Griffin et al., 2000; Hewett et al., 1999; Hutchinson et al., 1995; Ireland, 1999). Arendt and Dick (1995) analyzed NCAA basketball athletic injury rates over a 5-year period and reported that women have an anterior cruciate ligament (ACL) injury rate

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that is 4 times greater than their male counterparts. The majority of ACL injuries are non-contact in which there is no direct blow to the lower extremity when the injury occurs.

Based on this disproportionate incidence of injury, the current literature has investigated what has been referred to as the "gender bias" in ACL injury and has focused on a variety of potential mechanisms (Ekstrand and Gillquist, 1993; Ireland et al., 2001; Rozzi et al., 1999). These mechanisms include gender differences in structure and hormones as well as neuromuscular and biomechanical differences. Although there is an abundance of research investigating isolated structural and neuromuscular differences, there is limited research that has focused on dynamic biomechanical differences between genders. It is known that non-contact ACL injury often occurs during the deceleration of a lower extremity dynamic task, and this task is frequently some form of cutting maneuver (Boden et al., 2000). However, there has been limited investigation of lower extremity mechanics during this type of task.

To date, the biomechanical literature has included a large number of in vitro knee investigations that have addressed the loading characteristics of the ACL (Markolf et al., 1981; Markolf et al., 1995). From these in vitro investigations, a loading pattern, often referred to as the "high-risk pattern," that places the greatest load on the ACL has been identified. Markolf et al. (1995) reported that this pattern consisted of an internal rotation tibial torque and valgus moment placed on the knee flexed between 0° and 40°.

Although this high-risk pattern has been identified under in vitro conditions, there have been limited three dimensional (3D) kinematic and kinetic investigations that have attempted to address the motions and loads applied to the knee during a dynamic task such as the cutting maneuver. Recent investigation has reported that increases in hip adduction, hip internal rotation and knee abduction are present among females during tasks such as landing and running (Ferber et al., 2003; Ford et al., 2003). However, there has been little investigation of kinematic and kinetic differences at the hip and knee between genders in performing a cutting maneuver. While two investigations have revealed gender differences in knee joint kinematics during a preplanned cutting maneuver, these researchers did not investigate gender differences in hip joint kinematics or hip and knee joint moments (Malinzak et al., 2001; McLean et al., 1999). In addition, these studies were limited to a preplanned cutting maneuver in which the subjects had prior knowledge of the cutting task. In an attempt to better reflect an ecological environment, Besier et al. (2001) utilized an unanticipated cutting maneuver which resulted in knee moments up to twice the magnitude as compared to those under a preplanned condition. However, this study was limited to a male sample population.

While the in vitro literature has suggested that a high-risk pattern may put the ACL at risk of injury, it is unclear if female collegiate athletes demonstrate greater high-risk patterns at the knee during a dynamic task such as the cutting maneuver. In addition, it is unknown if females demonstrate differences in hip mechanics as compared to males during the cutting maneuver which may result in increased loading of the knee. If this were the case, it may suggest that females are predisposed to non-contact ACL injury due to these greater high-risk patterns.

Therefore, the purpose of this study was to investigate 3D kinematics and joint moments at the hip and knee of female and male collegiate soccer athletes during a randomly cued cutting maneuver. It was hypothesized that females would exhibit greater maximum hip adduction, hip internal rotation, knee abduction and knee internal rotation angles during the first 40° of knee flexion of a randomly cued cutting maneuver as compared to males. In addition, it was hypothesized that females would exhibit greater hip abduction, hip external rotation, knee adduction and knee external rotation moments during the first 40° of knee flexion of a randomly cued cutting maneuver as compared to males.

2. Methods

2.1. Subjects

Using data from the literature (Besier et al., 2001; Malinzak et al., 2001; McLean et al., 1999), sample size was estimated for a minimal statistical power of 80% ($P = 0.05$). All sample size and power calculations were completed using G* Power Software (Erdfelder et al., 1996). Given the variation of the dependent measures that were included in this study, 12 subjects per group were deemed adequate.

Subjects consisted of 12 female (height: 1.66 m (SD, 0.05 m); mass: 62.5 kg (SD, 6.9 kg)) and 12 male (height: 1.80 m (SD, 0.07 m); mass: 76.1 kg (SD, 5.9 kg)) collegiate soccer players between the ages of 18 and 21 years old (female: 19.3 years (SD, 1.1 years); male: 19.7 years (SD, 1.5 years)). Both the female and male subjects had at least 12 years of experience in their sport (females: 12.3 years (SD, 2.2 years); males: 13.7 years (SD, 1.8 years)). All subjects were in season during data collection. Approval for the participation of human subjects in this investigation was obtained from the University of Massachusetts Institutional Review Board. Subjects had no history of significant lower extremity injury and were injury-free at the time of data collection (determined by verbal questioning from a licensed physical therapist). In addition, subjects were free of potential health risks related to physical activity.

2.2. Experimental set-up

Kinematic data were collected using a Qualisys, seven-camera, 3D motion analysis system (Qualisys, Inc., Gothenburg, Sweden) at a sampling frequency of 240 Hz. The cameras were interfaced to a microcomputer and placed around a force platform imbedded within the floor (Advanced Mechanical Technologies, Inc., Newton, MA, USA). The force platform (1920 Hz) was interfaced to the same microcomputer that was used for kinematic data collection via an analog to digital converter. This interface allowed for synchronization of kinematic and kinetic data.

The cameras were positioned so that each marker was visible in multiple cameras throughout the stance phase (heel strike to toe off). A right-handed lab coordinate system was defined using a rigid L-frame containing four markers of known locations. A two-marker wand of known length was used within the calibration frame to scale the individual camera views of the measurement volume.

A series of photoelectric timing devices was used to monitor the running velocity just prior and just following the cutting maneuver. Running velocities on approach to and exiting the force platform were monitored with four photocells that were set at a height of 1.06 m and located along the runway. To measure approach velocity, two photocells were aligned parallel to the approach runway with one photocell located 1 m from the force platform and the other 3 m away. To measure exit velocity, two photocells were aligned parallel to the exit pathway with one photocell located 1 m from the force platform and the other 3 m away. To be consistent with two investigations reported in the literature (Malinzak et al., 2001; McLean et al., 1999), approach locomotor speed was required to fall between 5.5 and 6.5 m/s for both genders. In addition, exit locomotor speed was required to fall between 4.5 and 5.5 m/s. The area on the runway to the left of the force platform was outlined with tape to designate the path at which the subject had to proceed (45°) (Fig. 1). In addition, six cones were placed (3 on each side) to create a pathway that the subject had to remain within to successfully perform the cut.

2.3. Protocol

Prior to the kinematic and kinetic data collection, each subject completed an informed consent form. In addition, each subject completed a physical activity readiness questionnaire in order to screen for potential risks (i.e. history of cardiovascular disease) related to physical activity. Subjects were also required to complete questioning by a licensed physical therapist regarding injury history and years of cutting experience. Years of cutting experience were defined as the number of
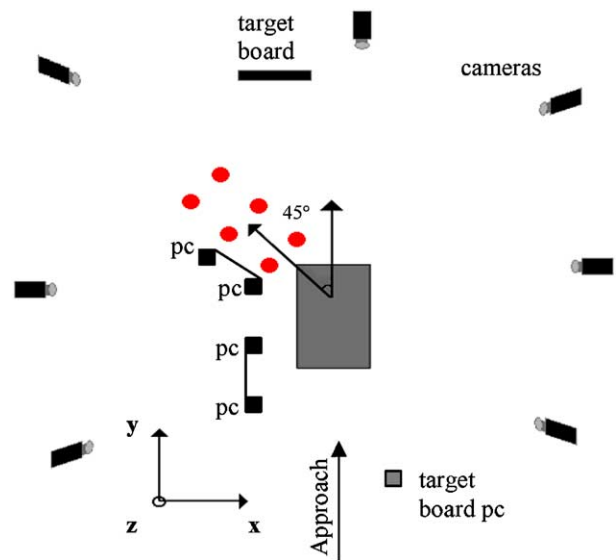

Fig. 1. Runway, cutting and camera set-up (pc = photocell).

years that the subject had participated on a formal soccer team. In addition, height and mass were measured. Following these measurements, each subject completed a practice session which included several preplanned and several randomly cued trials of each of the three tasks (see below for description of tasks).

Following the practice trials, a set of rigid reflective tracking markers was securely placed on the lateral surface of the subject's right thigh, leg and calcaneus. Further, three tracking markers were placed on the anterior superior iliac spine, iliac crest and L_5/S_1 joint line to define the right pelvis. In addition to the tracking markers, calibration markers were placed on bilateral greater trochanters, medial and lateral femoral epicondyles, medial and lateral malleoli, and first and fifth metatarsal heads in order to locate the segment origins. The same individual placed the markers for all subjects. Once the markers were placed, a standing trial was captured. After the standing trial, the calibration markers were removed. The tracking markers remained on the subject throughout the entire data collection session.

All subjects wore spandex shorts and court shoes during the data collection. Each subject completed one data collection that included 21–24 trials. Each subject was given approximately 1.0–1.5 min between trials to reduce the potential effects of fatigue. The subjects performed three tasks that consisted of a 45° cutting maneuver, a straight ahead run, and a jump stop. The run and jump stop were used as a catch tasks in order to present the subject with three options (cut, run, jump stop). Between seven and eight trials of each task were randomly performed. An illuminated target board was used to randomly signal subjects to perform the appropriate task. The target board was triggered by a photocell located 1.5 m prior to the force platform and signaled the subject

to perform the appropriate task. The subject was instructed that a yellow light would indicate a 45° cut, a green light would indicate a straight ahead run, and a red light would indicate a jump stop.

A cutting trial was deemed successful if the right foot came into contact with the force platform and the initial left foot contact following the cutting action was near the designated 45° angle line and the subject remained within the pathway designated by the cones. A straight ahead trial was deemed successful if the right foot came into contact with the force platform and the subject continued along the straight ahead path. A jump stop was deemed successful if the right foot came into contact with the force plate and the subject proceeded forward to land with two feet just after the force platform.

2.4. Data reduction

The following data reduction procedures were performed on data from all collection sessions. Q-Trac software (Qualisys, Inc., Gothenburg, Sweden) was used to digitize the kinematic data. A nonlinear transformation technique was used to transform the two dimensional (2D) coordinates from the seven cameras to 3D coordinates. Visual 3D™ software (C-Motion, Inc., Rockville, MD, USA) was used to quantify hip and knee motion in the sagittal, frontal and transverse planes. Using Visual3D™, all lower extremity segments were modeled as a frustra of cones while the pelvis was modeled as an cylinder. The local coordinate systems of the pelvis, thigh, leg and foot were derived from the standing calibration trial. In addition, the segment ends were identified from the standing calibration trial in order to locate the segment origins. Coordinate data were low-pass filtered using a fourth-order Butterworth filter with an 8 Hz cutoff frequency. Ground reaction force data were low-pass filtered using a fourth-order Butterworth filter with a 50 Hz cutoff frequency. Six degrees-of-freedom for each segment was determined from the segment's set of reflective markers. The kinematics of the model were calculated by determining the transformation from the set of markers to the position and orientation of each segment determined from the standing calibration.

Using Visual 3D™ software, 3D joint angles and moments for the hip and knee were calculated for each trial. All position data were resolved using Cardan angles which is equivalent to resolving about a Joint Coordinate System (Grood and Suntay, 1983). All kinetic data were normalized to body mass. The angle data were linearly interpolated to 101 data points, with each point representing one percent of the stance phase. Ensemble curves of five acceptable trials in each condition were created. The joint moments referred to in this investigation are the internal resultant moments. For example, an internal knee extension moment will tend to resist an external knee flexion load.

Based on the high-risk pattern identified in the in vitro literature (Markolf et al., 1995), peak hip adduction, hip internal rotation, knee abduction and knee internal rotation angles were measured during the first 40° of knee flexion of a randomly cued cutting maneuver. This typically occurs within the first 20–40% of stance. In addition, peak hip abduction, hip external rotation, knee adduction and knee external rotation moments were measured during the first 40° of knee flexion of a randomly cued cutting maneuver.

2.5. Statistical analysis

Differences between genders in selected hip and knee joint peak angles and moments occurring between the first 0° and 40° of knee flexion were compared using one-tailed t-tests. One-tailed t-tests were also used to determine the presence or absence of differences between genders in the percent of stance by which the initial 40° of knee flexion was reached.

In order to further evaluate mean differences, effect size (ES) was calculated to express such differences relative to the pooled standard deviation. Therefore, ES was calculated as the mean difference between genders divided by the pooled standard deviation. Cohen (1990) proposed that ES values of 0.2 represent small differences; 0.5, moderate differences; and 0.8+, large differences. The gender means, standard deviations, mean differences (females–males), effect sizes, and P-values from each measure are presented in tabular format. Together, the effect sizes and P-values were evaluated as the basis for discussing mean differences.

3. Results

Table 1 presents a summary of kinematic comparisons of variables of interest for males and females across the first 40° of knee flexion of the stance phase of a randomly cued cutting maneuver. Fig. 2 presents the ensemble 3D joint angles of the knee and hip for male and female athletes across the entire stance phase of a randomly cued cutting maneuver. There were no differences in the percent of stance which 40° of knee flexion was reached between males (27.13% ± 9.6%) and females (27.40% ± 5.5%) during the randomly cued cutting maneuver (ES = 0.03, $P = 0.93$). There were no gender differences in peak knee abduction, knee internal rotation or hip internal rotation angles during the first 40° of knee flexion. Although neither females nor males exhibited a hip adducted position during the first 40° of knee flexion, females demonstrated significantly less hip abduction than did the males (ES = 0.91, $P = 0.03$).

Table 1 also presents a summary of kinetic comparisons of variables of interest for males and females across the first 40° of knee flexion across the stance phase of a

Table 1
Comparisons (mean (SD)) of hip and knee joint peak angles (°) and moments (Nm/kg) across the first 40° of knee flexion of the stance phase of a randomly cued cutting maneuver

| Variable	Females	Males	Difference	Effect size	P-value
Peak angle					
Hip adduction	−3.43 (5.2)	−9.07 (7.2)	5.64	0.91	0.03
Hip internal rotation	3.37 (8.5)	3.58 (8.9)	−0.21	0.01	0.98
Knee abduction	2.39 (3.5)	1.53 (6.0)	0.86	0.17	0.68
Knee internal rotation	6.30 (5.9)	6.07 (5.9)	0.23	0.04	0.93
Peak moment					
Hip abduction	−0.98 (0.4)	−0.96 (0.3)	−0.02	0.06	0.74
Hip external rotation	−0.50 (0.2)	−0.47 (0.4)	−0.03	0.11	0.77
Knee adduction	0.37 (0.2)	0.31 (0.1)	0.06	0.38	0.36
Knee external rotation	−0.13 (0.1)	−0.09 (0.1)	−0.04	0.70	0.19
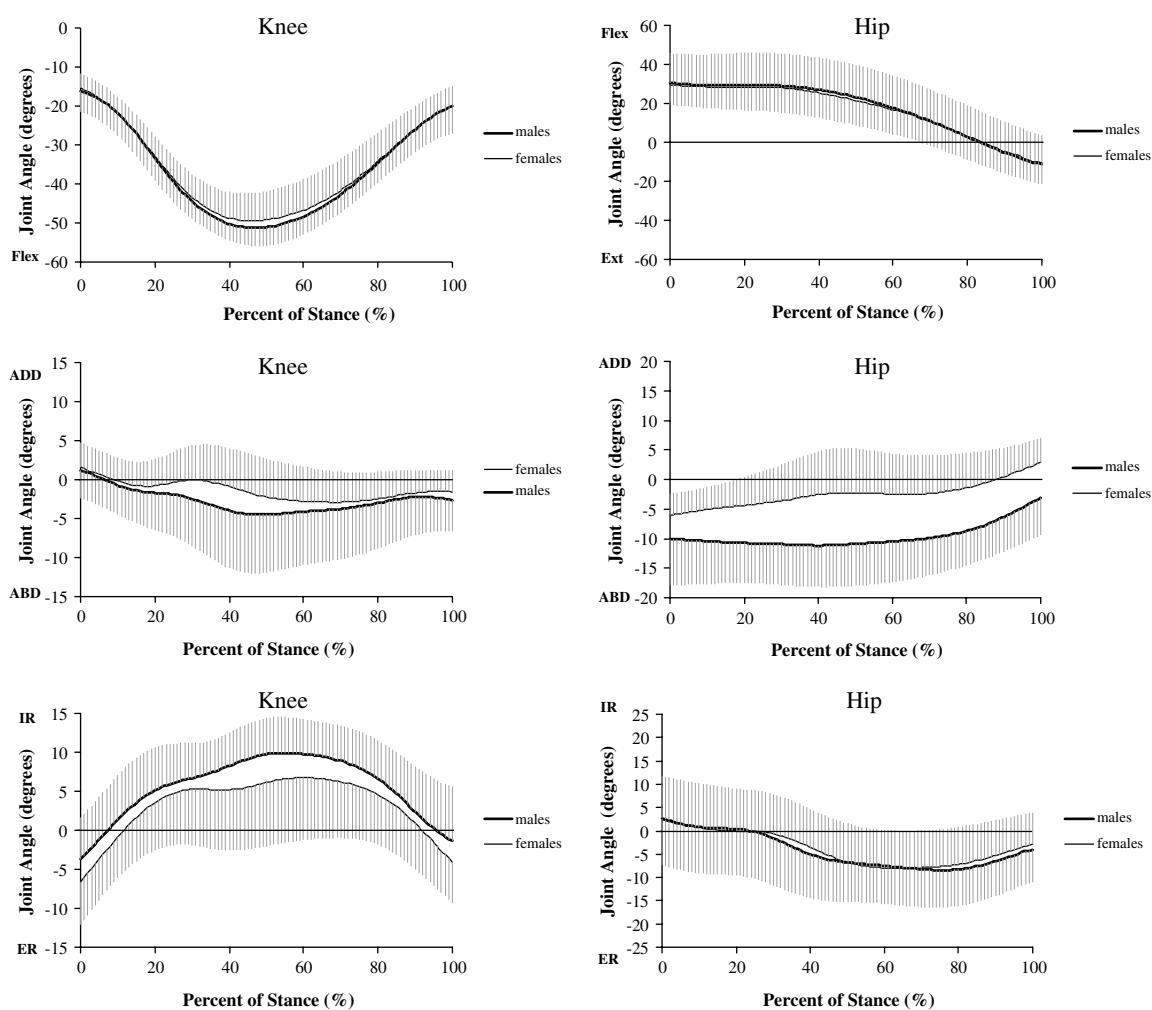
Fig. 2. Ensemble averages of knee and hip sagittal, frontal and transverse plane angular motion for males (thick line) and females (thin line) during the stance phase of a randomly cued cutting maneuver. (SD bars either +1 SD (bars above line) for that group or −1 SD (bars below line) for that group).

randomly cued cutting maneuver. Fig. 3 presents the ensemble frontal and transverse plane joint moments of the knee and hip for males and females across the stance phase of a randomly cued cutting maneuver.

There were no gender differences in peak knee adduction, knee external rotation, hip abduction or hip external rotation joint moments during the first 40° of knee flexion.
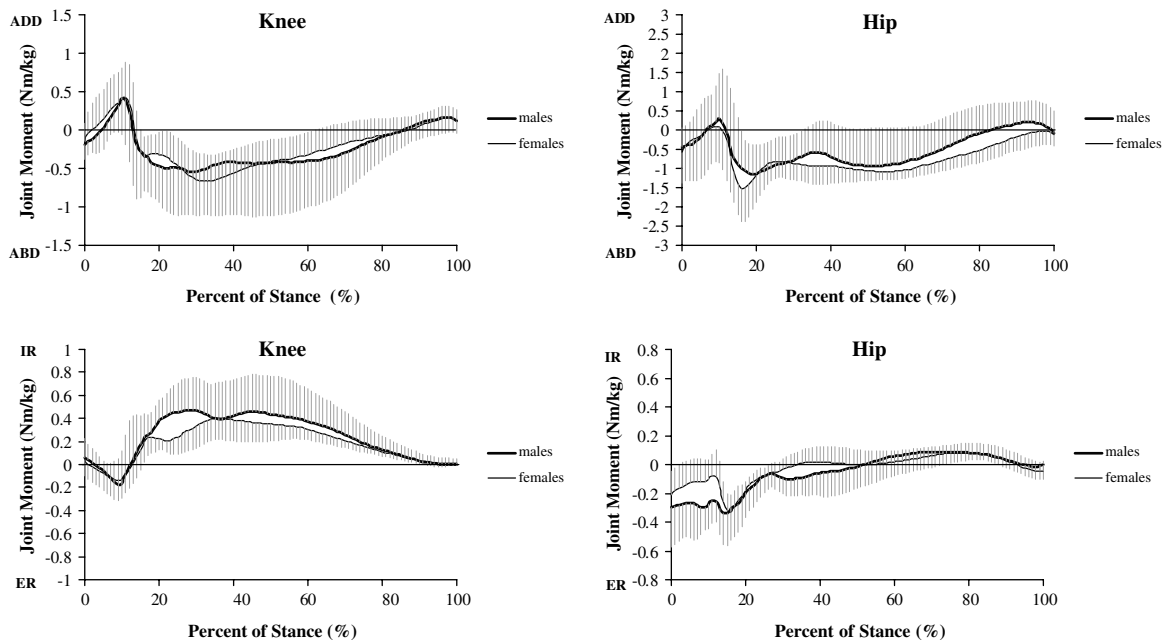
Fig. 3. Ensemble averages of knee and hip frontal and transverse plane joint moments for males (thick line) and females (thin line) during the stance phase of a randomly cued cutting maneuver. (SD bars either +1 SD (bars above line) for that group or −1 SD (bars below line) for that group).

Due to individual differences between subjects, data for both joint angles and moments across the first 40° of knee flexion are plotted as bar graphs to further explore the results (Figs. 4 and 5). It is evident, in certain planes, that individuals within each group of males and females exhibited different lower extremity mechanics across this critical region of the stance phase.

4. Discussion

The purpose of this study was to investigate 3D hip and knee joint kinematics and moments of female and male collegiate soccer athletes during a randomly cued cutting maneuver. These lower extremity mechanics were investigated to gain insight into why female athletes incur a greater number of non-contact ACL injuries as compared to their male counterparts. It is understood that these injuries predominantly occur during either a cutting maneuver or a landing task. In vitro investigations have identified a knee-loading pattern that places the greatest load on the ACL. It has been demonstrated that this loading pattern clearly occurs during 0–40° of knee flexion. However, there has been limited 3D biomechanical investigation of gender differences in both knee and hip joint kinematics and kinetics during a cutting maneuver. In addition, the majority of these investigations do not utilize a randomly cued protocol.

The current investigation revealed that there were no gender differences in peak knee joint abduction or internal rotation during the first 0–40° of knee flexion across

the stance phase. This is in contrast, in part, to the results reported by McLean et al. (1999). These authors investigated peak 3D sagittal, frontal and transverse plane knee joint kinematics of state level athletes (16 male and 14 female) across the stance phase of a pre-planned cutting maneuver. The subjects were described as "high performance" athletes; however, high performance was not defined. The subjects had prior knowledge that they would perform a cutting maneuver upon each approach to the force platform (pre-planned) and maintained an approach velocity of 5.5–7.0 m/s. Consistent with the current investigation, the authors reported no differences in transverse plane angular motion between males and females. However, McLean et al. (1999) reported that female athletes tended to land and remain in a more knee-abducted position than male athletes during the stance phase of a cutting maneuver.

Interestingly, the peak knee abduction angles across the stance phase for females in the McLean et al. (1999) investigation were over twice of those reported in the present investigation (approximately 10° vs. 4.4° for the current study). Similar to the work of McLean et al. (1999), Malinzak et al. (2001) investigated sagittal and frontal plane knee joint kinematics of recreational athletes (11 males and 9 females) across the stance phase of a preplanned cutting maneuver. Subjects approached the force platform and maintained a mean approach velocity of 5.15 m/s and 5.01 m/s for males and females respectively. Consistent with McLean et al. (1999), these authors reported that female athletes demonstrated greater knee abduction than male athletes during a cutting maneuver.
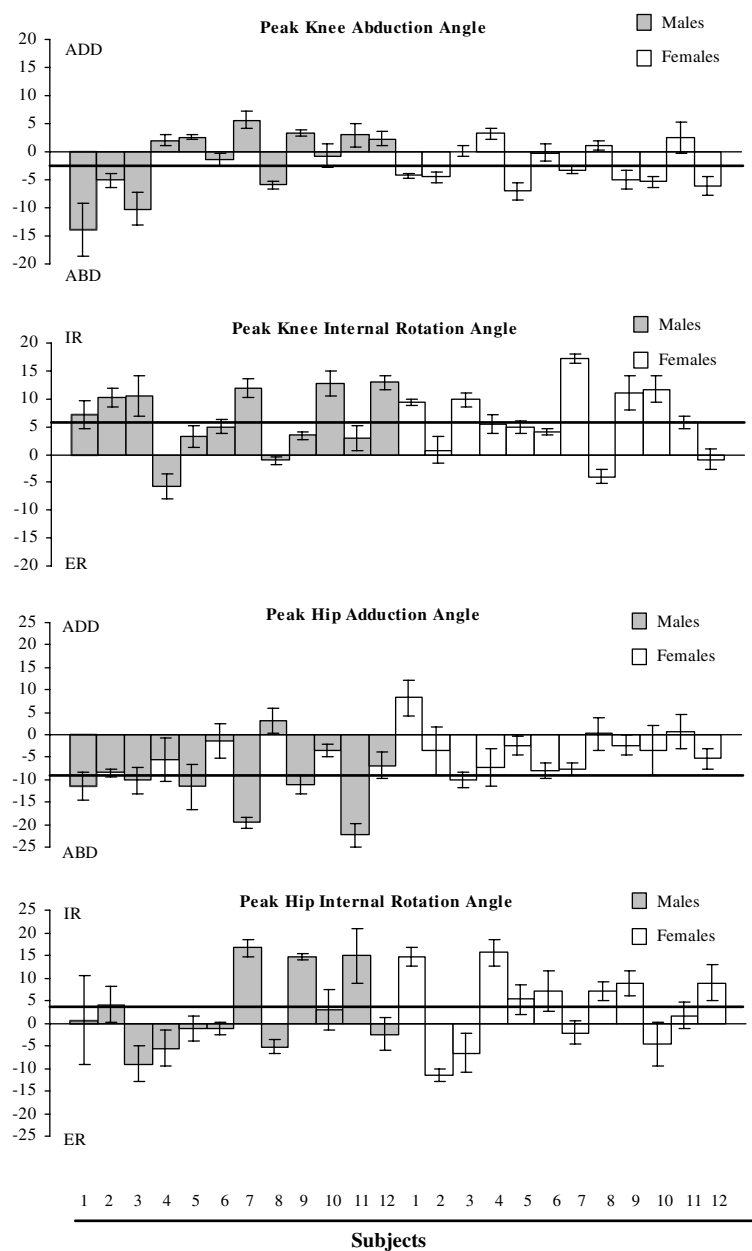
Fig. 4. Individual averages and standard deviations of peak knee and hip joint angles (°) across the first 40° of knee flexion of the stance phase of a randomly cued cutting maneuver (solid line indicates male group mean for this variable).

The results of the current investigation are in contrast to McLean et al. (1999) and Malinzak et al. (2001) and suggest that frontal and transverse plane knee kinematics do not differ between male and female collegiate soccer athletes when performing a randomly cued cutting maneuver. The differences in these studies may simply be due to different sample populations. Malinzak et al. (2001) investigated recreational athletes who may not have had equivalent training or years of exposure to highly competitive sports. McLean et al. (1999) investigated "high performance" athletes that were competitive at the state level. However, McLean et al. (1999) also reported years of experience (years performing a

cutting maneuver) per subject, which revealed that 10 female and 3 male subjects had 6 or less years of experience. All subjects included in the current investigation had at least 10 years of experience with an average of 13.7 and 12.3 years for males and females respectively. It is possible that there were no significant differences in knee frontal plane motions between genders due to the subject's high skill level and years of exposure to cutting activities.

Unique to this study was the investigation of differences in hip joint kinematics between male and female collegiate soccer players during a randomly cued cutting maneuver. The results revealed no gender differences in
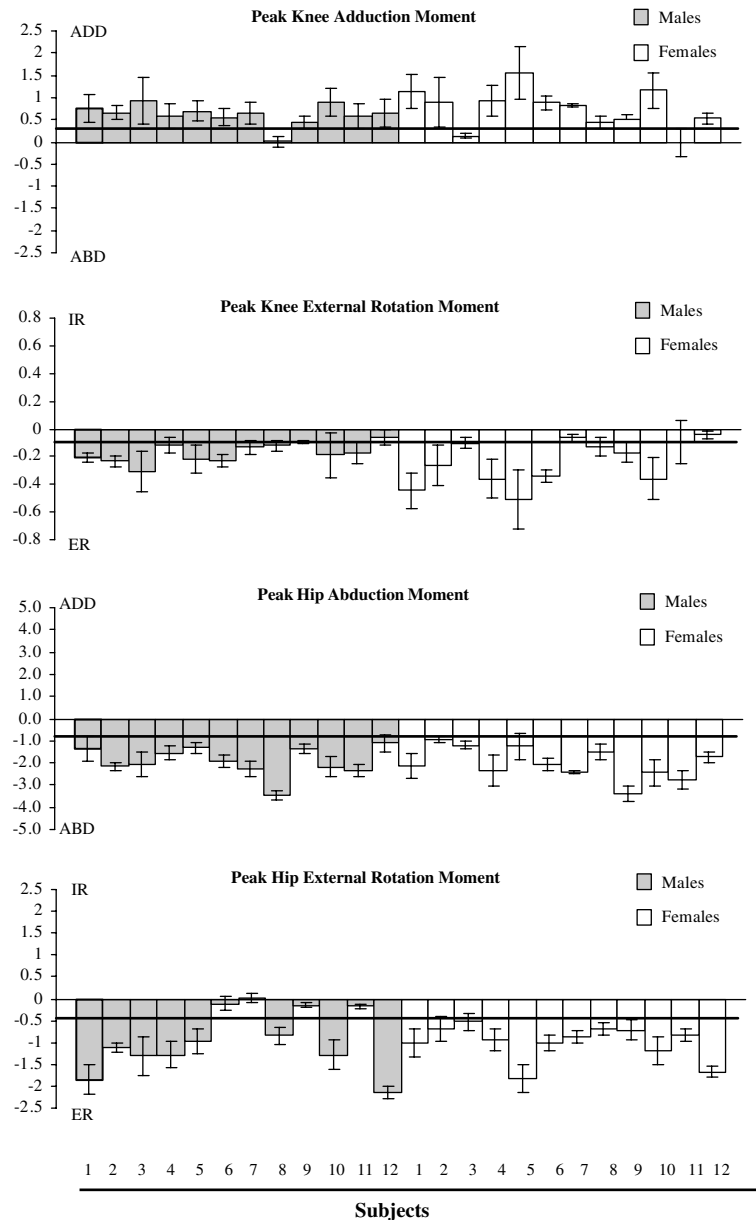
Fig. 5. Individual averages and standard deviations of peak knee and hip joint moments (Nm/kg) across the first 40° of knee flexion of the stance phase of a randomly cued cutting maneuver (solid line indicates male group mean for that variable).

peak hip joint internal rotation. Although neither males nor females demonstrated a hip adducted position during the first 40° of knee flexion, females demonstrated a greater tendency toward adduction than did males.

There has been limited investigation of differences in 3D hip kinematics during athletic activities between males and females. Ferber et al. (2003) reported that female recreational runners demonstrated greater hip internal rotation angles at heel strike and greater hip adduction angles throughout the first 60% of the stance phase of running as compared to males. While the patterns of hip motion are expected to be different between running and cutting, it was anticipated that the gender differences reported in running would also be present

during cutting. Although differences in hip internal rotation were not found, females did demonstrate similar differences in hip adduction as did the females performing a running task in the Ferber et al. (2003) study. It is well understood that hip adduction can contribute to increased knee abduction. Although there were no differences between males and females in knee abduction, this proximal joint difference in the frontal plane may suggest that the knee is loaded differently. While hip strength measures were not taken, females may have had weakness of the hip musculature. It is possible that hip abductor weakness could result in increased hip adduction or relatively decreased hip abduction during a dynamic lower extremity task.

The results of this study showed no differences between genders in peak frontal and transverse plane knee and hip joint moments during the first 40° of knee flexion. The lack of differences in both hip and knee joint moments were not surprising considering the similarity in both knee and hip joint kinematics in this sample population. Even though the randomly cued condition was utilized, this group of male and female collegiate soccer players demonstrated very similar lower extremity dynamics.

Finally, even though there were minimal group kinematic and kinetic differences, it was apparent that some subjects (including males) exhibited mechanics thought to be related to increased ACL injury risk at both the knee and hip (Figs. 4 and 5). For example, when examining individual differences in peak hip internal rotation (Fig. 4) across the first 40° of knee flexion, it is clear that 3 males (subjects 7, 9 and 11) demonstrated large peak hip internal rotation angles. These large angles effectively raised the mean peak angle (3.58°) for the male group. However, when examining individuals across genders, it is evident that only 4 males, as compared to 7 females, demonstrated peak hip internal rotation angles that were greater than the male group mean. Therefore, these individuals within each gender group may have demonstrated an at-risk lower extremity pattern. Interestingly, this group of individuals who presented with large hip internal rotation angles was comprised of a greater number of females.

While individual differences in lower extremity kinematics and kinetics were apparent, a potential contributor, and limitation of the study, may have been the variability in how the tasks were performed. Even though many aspects of the cutting maneuver were controlled (i.e. velocity, angle of cut), opportunity remained for subjects to demonstrate individual differences in performance.

5. Conclusions

In conclusion, aside from frontal plane hip motion, male and female collegiate soccer players demonstrated similar hip and knee joint kinematics and kinetics while performing a randomly cued cutting maneuver. This suggests that the collegiate athlete's acquired training and exposure to sport results in more similar hip and knee joint kinematic and kinetic patterns between genders. Further investigation is necessary to continue to investigate potential biomechanical mechanisms of non-contact ACL injury with an emphasis on understanding differences between sports; for example, the mechanism of injury for a soccer player may be considerably different than that of a basketball or netball player.

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