

# Sex Differences in Knee Flexion Angle During a Rapid Change of Direction While Running

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*Investigation performed at the University of Texas Medical Branch, Galveston, Texas, USA*

**Background:** Females experience greater overall rates of athletic anterior cruciate ligament (ACL) injury than males. The specific mechanisms of the predisposition remain unclear.

**Hypothesis:** Modeling of knee kinematics has shown that the more extended the knee joint, the greater the strain on the ACL. The authors hypothesized that female athletes would have a lesser degree of knee flexion than male athletes at initial ground contact while performing change-of-direction cutting maneuvers.

**Study Design:** Controlled laboratory study.

**Methods:** Twenty female and 20 male high school soccer athletes with at least 1 year of experience were recruited for the study. Athletes were excluded if they had a history of any major lower limb injury or current knee pain causing a reduction in training and/or competition. Reflective markers were attached at the greater trochanter of the femur, the lateral epicondyle of the knee, and the lateral malleolus of the ankle to enable motion capture. Each athlete performed 6 change-of-direction maneuvers in random order in front of 2 cameras. Multiple regression analysis was used to determine differences between the sexes from the motion data captured;  $P < .05$  defined significance.

**Results:** Statistically significant differences existed in knee flexion angles between male and female participants at the 90° and 135° cutting angles. At 90°, males and females showed initial contact knee flexion angles (mean  $\pm$  SD) of 39.0°  $\pm$  6.8° and 29.3°  $\pm$  6.2°, respectively ( $P < .0001$ ), and mean maximum flexion angles of 56.4°  $\pm$  6.9° and 49.7°  $\pm$  7.0°, respectively ( $P = .0036$ ). At 135°, males and females showed mean initial contact knee flexion angles of 36.8°  $\pm$  7.9° and 29.7°  $\pm$  7.8°, respectively ( $P = .0053$ ), and mean maximum flexion angles of 60.7°  $\pm$  8.1° and 51.6°  $\pm$  9.4°, respectively ( $P = .0017$ ).

**Conclusion:** The research conducted is intended to foster an awareness of injury disposition in female athletes and guide future endeavors to develop, test, and implement a proactive approach in lowering female noncontact athletic ACL injury rates. This project adds to the literature as wider side-cut maneuvers ( $\geq 90^\circ$ ) were studied, as compared with previous studies using small side-cut angles ( $< 90^\circ$ ), offering a model for alternative sports actions.

**Keywords:** ACL; anterior cruciate ligament; flexion; sex; injury; kinematics; knee; motion analysis; soccer

Injury to the knee is quite common in soccer.<sup>16</sup> Among knee injuries, anterior cruciate ligament (ACL) tear or rupture is one of the most severe. Rupture of an ACL commonly leads to surgical repair, weeks of rehabilitation, and multiple training sessions and competitions missed. Among those sustaining the injury, some never return to the same level of athletics.<sup>13</sup>

In collegiate soccer, ACL injury rates have been reported at 0.12 for males and 0.32 for females per 1000 athlete-exposures (or 14 per year for males and 30.5 per year for females).<sup>5</sup> ACL

injuries have been described in a variety of sports and can be classified as both contact and noncontact.<sup>2</sup> Noncontact ACL injury has been reported to have a prevalence of 70% to 75% of all ACL injuries in selected sports.<sup>2,12</sup> Noncontact mechanisms of injury include hyperextension, deceleration, deceleration with tibial medial rotation or femoral lateral rotation on fixed tibia, and hyperflexion. These translate to activity movements of planting and cutting, straight-knee landing, one-step-stop landing with knee hyperextended, pivoting, pivoting while decelerating, and pure deceleration—maneuvers common in soccer, football, and basketball.<sup>2,14</sup>

The mechanism for sex differences in ACL injury rates in soccer remains unknown despite a multitude of joint kinematic and kinetic studies.<sup>1,4,10</sup> A set of studies by Landry et al<sup>10,11</sup> found differences in muscle activation between sexes when performing cross-cut and side-cut maneuvers at 45°: Female athletes had increased rectus femoris activity compared with males during side-cutting, but no differences in kinematics were noted. We believed that a 45° cutting maneuver, while

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common for comparing knee kinetics and kinematics, is not the right maneuver for assessing sex differences in ACL injury because it is a shallow cut that does not place as great a stress on the athlete as a 90° or 135° cut might, which are common maneuvers in both soccer and basketball.

Knee flexion increases as the angle of side-cutting increases.<sup>7</sup> Increased knee flexion has been linked to increased ACL protection. This implies that at increased side-cut angles, the ACL is better protected through a natural response to increased knee flexion. No published studies have been performed assessing sex differences in knee flexion during a rapid change-of-direction maneuver  $\geq 90^\circ$ . We hypothesized that female athletes flex the knee more shallowly compared with their male counterparts at initial ground contact and peak flexion while performing cutting maneuvers at and beyond 90°.

## METHODS

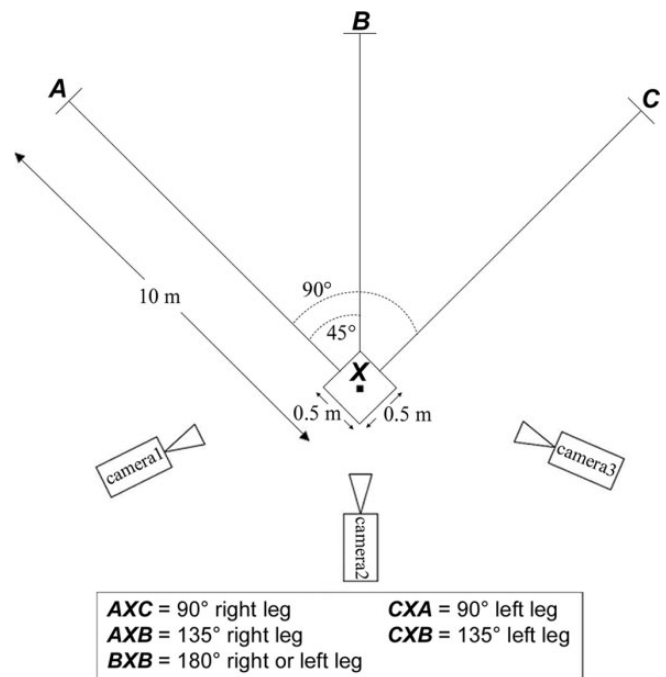
### Subjects

A total of 40 local high school soccer players, 20 males and 20 females, were recruited to participate in this institutional review board–approved study. All subjects recruited had to be currently participating in a school-sponsored soccer league. The mean age of participants was 15.7 years (males, 15.8 years; females, 15.6 years; range, 15–19 years). Parental consent and child assent were obtained for all athletes 17 years and younger, and adult consent was obtained for athletes 18 years and older. Athletes were excluded if they had ever had a major lower limb injury (eg, fracture, dislocation, or ligament tear) or current knee pain causing a reduction in training and/or competition.

### Procedure

All experimental procedures took place during team practices at a local high school recreational facility. A flat, grassy area was used for the motion capture arena. A calibrated 2-camera SIMI Motion (SIMI Reality Motion Systems GmbH) system running at 60 Hz was focused on a 0.5 × 0.5-m square known as the “activity zone” for motion capture. Before motion capture, athletes warmed up according to the coach’s protocol and were pulled 1 at a time from practice to perform side-cut maneuvers for motion capture. All subjects also responded to a verbal questionnaire requesting demographic information (age, sex, height, weight, leg dominance), athletic history, training regimen, whether menarche had begun, and medication use (oral contraceptives).

Only the dominant limb was analyzed during cutting maneuvers. Dominance was self-determined by the kicking or leading extremity. Motion-capture balls were attached to each athlete by the same examiner at the following anatomic sites: dominant greater trochanter, dominant lateral condyle of the knee, and dominant lateral malleolus. Athletes performed a total of 6 side-cut maneuvers, 3 each at 90° and 135°, for motion capture. A side-cut maneuver is defined as a change of direction while moving such that the subject plants with a designated foot and moves in the opposite direction of the foot plant. For example, a 45° side-cut



**Figure 1.** Data collection setup. Note: Camera 2 was not used for collection, as it did not affect data analysis.

maneuver may have an athlete plant with the right foot and attempt to continue moving 45° to the left of what would be a straight-line run. To assist subjects in visualizing the proper cut angle, 2 cones were placed 3 m from the activity zone, 10° on either side of the proper cutting angle. The order of cutting maneuvers was counterbalanced, and all 3 trials for each angle were sequentially performed.

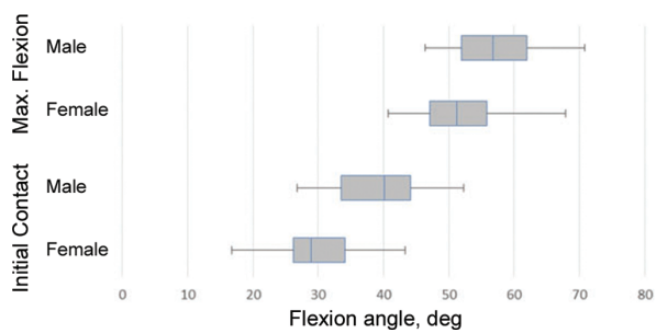
Each recording trial consisted of an athlete standing 10 m out from the activity zone. The athlete was instructed to approach at the maximum speed possible in which they were still able to perform the required maneuver. Athletes were given a 30-second rest period between each maneuver. After 3 successful maneuvers at the first cutting angle, athletes then completed 3 trials at the next randomized cutting angle until all cutting angles were completed. The data collection setup is illustrated in Figure 1.

### Analysis

All knee flexion angles were extracted for initial contact (IC) and peak flexion (PF) using SIMI Motion software. A multivariable linear regression and 2-tailed Student *t* tests were used to test for differences between means to assess the influence of sex and the aforementioned variables collected on the outcome of knee flexion.

## RESULTS

Statistically significant differences were found in knee flexion angles in male and female participants at the 90° and 135° cutting angles.



**Figure 2.** Mean flexion angle at initial contact and maximum flexion during a 90° cutting maneuver. Error bars represent SD.

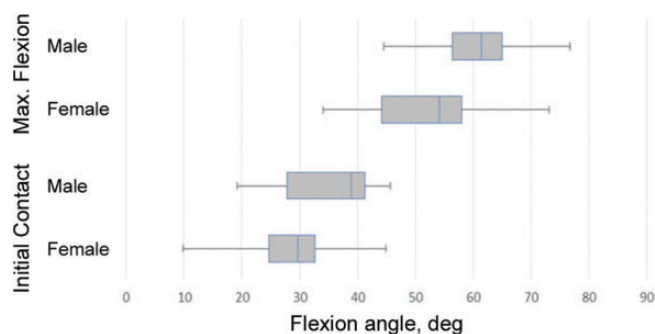
At 90°, males and females demonstrated a mean ( $\pm$ SD) IC knee flexion angle of  $39.0^\circ \pm 6.8^\circ$  and  $29.3^\circ \pm 6.2^\circ$ , respectively ( $P < .0001$ ). At 135°, males and females demonstrated a mean IC knee flexion angle of  $36.8^\circ \pm 7.9^\circ$  and  $29.7^\circ \pm 7.8^\circ$ , respectively ( $P = .0053$ ).

At 90°, males and females demonstrated a mean maximum flexion angle of  $56.4^\circ \pm 6.9^\circ$  and  $49.7^\circ \pm 7.0^\circ$ , respectively ( $P = .0036$ ) (Figure 2). At 135°, males and females demonstrated a mean maximum flexion angle of  $60.7^\circ \pm 8.1^\circ$  and  $51.6^\circ \pm 9.4^\circ$ , respectively ( $P = .0017$ ) (Figure 3).

## DISCUSSION

The goal of this study was to characterize and assess a risk factor for female athletic ACL injury in terms of biomechanical sex differences. By identifying sex-specific risk factors for noncontact athletic ACL injury, future efforts may develop athletic training techniques aimed at reducing risk.

The central hypothesis was that female athletes do not flex the knee joint as much as males during IC of the planting foot while performing a side-cut maneuver at and beyond 90°. Current understanding and modeling of knee kinetics indicate that the more extended the knee joint, the greater the strain placed on the ACL. In 5° of hyperextension, the ACL experiences anywhere from 50 to 240 N.<sup>20</sup> At 30° of flexion, isometric contraction places significant strain on the ACL, which does not occur at 90°.<sup>20</sup> Furthermore, during active extension, the ACL does not experience strain between 50° and 110°.<sup>20</sup> A more extended knee joint during IC and subsequent loading in a side-cut maneuver may be partially to blame for increased ACL injury rates in women. This hypothesis is based on our pilot study demonstrating shallower IC knee flexion in females performing sharp side-cut maneuvers and literature pertaining to biomechanical movement and muscle activation in female athletes. Our pilot study, which involved 5 male and 5 female participants with athletic backgrounds, yielded positive results trending toward a difference in IC knee flexion between sexes during a 90° side-cut maneuver. Moderate differences were found for PF. Sex differences in 90° side-cut PF were used for power analysis to determine maximum sample size.



**Figure 3.** Mean flexion angle at initial contact and maximum flexion during a 135° cutting maneuver. Error bars represent SD.

## Significance

Most studies have focused on single factors (eg, planting, change of direction, experience, fatigue) in testing for kinematic and kinetic differences between sexes and within sexes while performing athletic maneuver analogs that are thought to predispose to ACL injury but have not been confirmed to do so. A set of studies by Landry et al<sup>10,11</sup> found differences in muscle activation between sexes when performing cross-cut and side-cut maneuvers, and females had increased rectus femoris activity compared with males during side-cutting, but no differences in kinematics were noted. This explained a small variance of joint moment forces, and Sigward and Powers<sup>15</sup> found that athletic experience affected joint moment forces in the knee without affecting kinematics between elite and amateur athletes. Tsai et al<sup>18</sup> found that knee abduction and internal rotation increased with fatigue. The injury implication of these results is unclear; however, the change in kinematics suggests that fatigue influences the adoption of biomechanics that promote better balance and, potentially, injury prevention. Vanrenterghem et al<sup>19</sup> showed increased knee flexion with increased approach speed but did not compare data between sexes. Hewett et al<sup>7</sup> uniquely studied neuromuscular control and kinematics with regard to prediction of ACL injury. Female athletes performed a vertical jump procedure prior to the start of a season (soccer, basketball, and volleyball). Kinematic, kinetic, and neuromuscular control measures were taken from the procedure to predict ACL injuries that occurred throughout the season. It was found that injured athletes had less knee flexion than uninjured athletes by 10° (result not significant). Knee abduction moments, namely, imbalances between legs in injured athletes, were the most predictive of future ACL injury.<sup>6</sup> The study did not include a comparison with male athletes.

These studies tease out differences that have not been shown to be relevant in ACL injury predisposition; namely, differences in muscle activity theoretically may increase strain on the ACL, but no physiological studies have been able to define to what degree and if it is significant enough to cause injury. These studies, even taken together, have not been able to explain the wide gap in ACL injury rates between sexes. We hypothesized that a 45° cutting maneuver, while standard for comparing knee kinetics and

kinematics, is not the right maneuver for assessing sex differences in ACL injury because it is a shallow cut that does not place as extreme stress on the athlete as a 90° or 135° cut might, which are common maneuvers in both soccer and basketball.

Knee flexion increases within sexes as the angle of side-cutting increases.<sup>9</sup> Increased knee flexion is linked to increased ACL protection. This implies that at increased side-cut angles, the ACL is better protected through a natural response to increase knee flexion. How male athletes increase knee flexion in response to increased side-cutting angles and whether female athletes increase knee flexion to the same degree has not been studied. If females do not increase knee flexion to the same degree as males as side-cut angles increase, we can conclude that females are placing greater strain on the ACL than their male counterparts during large-angle side-cut maneuvers, making them a risky maneuver for ACL injury in the female athlete.

By observing wider side-cut maneuvers ( $\geq 90^\circ$ ), this research adds to current literature concerning primarily small side-cut angles ( $< 90^\circ$ ) and offers a model for alternative sports maneuvers. Biomechanical and electromyographic studies have revealed pertinent physiological data to support the hypothesis that a deceleration and change of direction maneuver strain the ACL and that shallow knee flexors may be more prone to ACL injury, owing to greater strain on the ACL. During rapid deceleration, the quadriceps act both as the heavy mover in deceleration force and eccentric stabilization of the knee joint.<sup>5</sup> This dual action places extra strain on the ACL since the quadriceps antagonize the ACL and act to displace the tibia anteriorly.<sup>17</sup> These forces are in excess of what is usually tolerated by the ACL, exceeding maximal isometric contraction force as confirmed by electromyography.<sup>6</sup> This strain caused by quadriceps contraction is most significant when the knee is flexed less than 45°, being the greatest at 0° or hyperextension.<sup>3</sup> These studies strongly suggest that the degree of knee flexion interacts synergistically with a direction change maneuver, which depends on the quadriceps to pose varying degrees of strain on the ACL correlating with ACL injury.<sup>8</sup>

There were several limitations to our study. The current study focuses solely on knee flexion angles at greater sport level angles that are implicated in athlete cutting kinematics; it would be interesting to include hip kinematics, ankle motion, and vertical alignment as those are factors that may influence knee kinematics. The standard deviations were larger than anticipated in the greater angle cohort, although results were statistically significant. A larger study group would be beneficial for future studies. Additionally, although the 2-camera SIMI Motion System running at 60 Hz was sufficient for this study, the system did not include a force plate and higher frequency data capture capabilities seen in newer systems. There was also a possibility of user error with data extraction as each individual video frame was analyzed for the IC and PF moment. However, the data were verified and confirmed by 2 blinded observers.

The research conducted is intended to foster an awareness of injury disposition in female athletes and guide clinicians to develop, test, and implement a proactive approach

in lowering female noncontact athletic ACL injury rates. Outcomes of this study suggest underlying reasons for a specific ACL injury mechanism in soccer players. During athletic side-cut maneuvers of 90° and 135° angles, knee flexion angles at initial contact and peak flexion are significantly different between sexes. Results of this study may aid in the prevention of ACL injury and serve as a road map for categorizing biomechanical disparities and developing conditioning programs to prevent injuries. Future endeavors will need to identify causes and solutions to biomechanical differences between populations that experience a disparity in specific injury rates and to develop effective preventive training and programs to mitigate a high injury risk.

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