Differences Between Sexes in Lower Extremity Alignment and Muscle Activation During Soccer Kick

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Background: Injury risk in soccer varies by sex. Female soccer players face a greater risk of anterior cruciate ligament injury and patellofemoral problems, while male players are more likely to experience sports hernia symptoms. The purpose of this study was to test the hypothesis that females have different lower-extremity alignment and muscle activation patterns than males during the soccer kick.

Methods: Thirteen male and twelve female college soccer players underwent three-dimensional motion analysis and electromyography of seven muscles (iliacus, gluteus maximus, gluteus medius, vastus lateralis, vastus medialis, hamstrings, and gastrocnemius) in both the kicking and the supporting lower extremity and two additional muscles (hip adductors and tibialis anterior) in the kicking limb only. Five instep and five side-foot kicks were recorded for each player. Muscle activation was recorded as a percentage of maximum voluntary isometric contraction.

Results: The male soccer players had significantly higher mean muscle activation than their female counterparts with respect to the iliacus in the kicking limb (123% compared with 34% of maximal voluntary isometric contraction; p = 0.0007) and the gluteus medius (124% compared with 55%; p = 0.005) and vastus medialis muscles (139% compared with 69%; p = 0.002) in the supporting limb. The supporting limb reached significantly greater mean hip adduction during the stance phase of the kick in the females compared with that in the males (15° and 10°, respectively; p = 0.006).

Conclusions: Differences between the sexes in lower extremity alignment and muscle activation occur during the soccer instep and side-foot kicks. Decreased activation of the hip abductors and greater hip adduction in the supporting limb during the soccer kick in female athletes may be associated with their increased risk for anterior cruciate ligament injury.

Clinical Relevance: Programs targeting these differences in muscle activation and lower extremity alignment during the kick should be evaluated for use in injury prevention in soccer athletes. Future research is warranted to investigate how differences between the sexes at the hip may relate to differences in the risk of lower extremity injury among athletes in soccer and other sports.

Soccer is the most popular sport worldwide with an estimated 200 million active players, and it is among the fastest growing sports in the United States with approximately twenty million registered players and an annual increase in participation of >20%. There has been a dramatic increase in female participation over recent years, both in the U.S. and the rest of the world. The number of girls playing high-school soccer in the U.S. grew from 700 in the 1972-1973 school year to >340,000 in 2008-2009, and participation in collegiate women’s soccer increased from 103 teams and 2743 players in 1982-1983 to 868 teams and 19,467 players in 2001-2002.

The incidence of soccer-related injuries is estimated to be ten to forty-two per 1000 playing hours in adult male players, and is often higher in younger and less skilled players. Approximately 60% to 80% of severe injuries occur in the lower extremities, most commonly at the knee or ankle. Female soccer players have at least twice the risk of anterior cruciate ligament injury compared with their male counterparts and a significantly increased risk of a torn meniscus. Female players also face a greater relative risk of patellofemoral problems, while males are more likely than females to have sports hernia symptoms. The majority of injuries that occur in soccer are noncontact injuries, and it has been proposed that the knee is susceptible to injury during kicking.

The two main techniques of kicking are the side-foot kick (the medial aspect of the midfoot strikes the ball with the foot...
in neutral or dorsiflexion) and the instep kick (the dorsum of the plantar flexed foot strikes the ball)\(^9\).

Electromyography has been used for the study of muscle function since the pioneering work of Inman et al. in 1944\(^2\). While thorough electromyographic studies have been done to evaluate sports activities such as throwing a baseball\(^{21-24}\), studies of electromyographic activity associated with the soccer kicking motion have not assessed muscle activation throughout the entire lower extremity\(^{25-31}\). A recent study has described lower extremity alignment and muscle activation in both the kicking and the supporting leg during the instep and side-foot kick in male collegiate soccer players\(^9\). Reports have noted muscle activation patterns during cutting-related maneuvers in female soccer players\(^{32-35}\), but no study to date has described lower extremity alignment and muscle activation during kicking in female soccer athletes or compared these patterns between male and female soccer players.

The goal of the current study was to better understand the potential role of kicking in soccer player injuries by comparing lower extremity alignment and muscle activation during kicking between male and female soccer players. This study was designed to test the following hypotheses: (1) females have different lower-extremity alignment than males during the soccer kick—specifically, increased pelvic obliquity, increased hip abduction, and increased knee valgus; and (2) females have different lower-extremity muscle activation patterns than males during the soccer kick, particularly for the hip flexors (iliacus), hip abductors (gluteus medius), knee extensors (vastus medialis and vastus lateralis), and knee flexors (medial hamstrings).

**Materials and Methods**

Institutional review board approval was obtained prior to this investigation, and all subjects provided informed consent before participating in this study. As the study was designed to compare lower extremity alignment and muscle activation between male and female collegiate soccer players, a power analysis was performed for selected kinematic outcome measures. Assuming a standard deviation of 5\(^\circ\), the a priori 80% power analysis indicated that a cohort of twelve male and twelve female subjects would be sufficient to avoid a type-II error when detecting a 5.3\(^\circ\) difference between the sexes in knee alignment (e.g., 4.8\(^\circ\) varus for males and 0.5\(^\circ\) valgus for females).

Based on the power analysis, twenty-five high-level collegiate soccer players, thirteen males and twelve females, with no history of clinically important lower-extremity injury were evaluated prospectively in our motion analysis laboratory (Table I).

The testing protocol has been previously described in an initial report for male collegiate soccer players\(^9\) and is summarized here. Briefly, electromyography electrodes and retroreflective markers were applied; data from maximal voluntary isometric contraction trials (for normalization) and static standing trials (for kinematic model calibration) were collected; warm-up kicking trials were conducted (for task familiarization); and, finally, the kicks used for data analysis were completed.

The electromyographic activity from sixteen muscles in the hip and lower extremity was measured with use of a combination of surface electrodes and fine-wire indwelling electrodes\(^2\). Wire electrodes were placed in the iliacus of both lower extremities. Surface electrodes were used for the gluteus medius, gluteus maximus, vastus medialis, vastus lateralis, hamstrings, and gastrocnemius of both lower extremities as well as the hip adductor and tibialis anterior of the kicking lower extremity only.

Surface electrodes were placed on the specific muscles as follows. On the gluteus maximus, an electrode was positioned at the bisection of the line between the ischial tuberosity and the medial tibial epicondyle; on the gastrocnemius, at the most prominent bulge; and on the vastus lateralis, at approximately two-thirds of the distance between the anterior superior iliac spine and the lateral side of the patella; on the vastus medialis, at approximately 80% of the distance of the line from the anterior superior iliac spine to the knee joint space anterior to the medial collateral ligament; on the hamstrings, at the bisection of the line between the ischial tuberosity and the medial tibial epicondyly; on the gastrocnemius, at the most prominent bulge of the medial gastrocnemius; on the hip adductors, at the most prominent bulge; and on the tibialis anterior, at one-third of the distance between the tip of the fibula and the tip of the medial malleolus. On the basis of the method used by Dörge et al.\(^2\), bipolar fine-wire electrodes (Nicolet Biomedical, Madison, Wisconsin), consisting of 0.025-mm-diameter insulated wires threaded through a 22-gauge needle, were inserted into the iliacus in a sterile fashion just over the pelvic brim to an appropriate depth. The needle was withdrawn, and the wires were secured to the player’s skin with tape, leaving several centimeters of exposed wire between the tape and the location of the wire exiting the skin, to allow excursion during kicking.

Each set of bipolar recording electrodes per muscle was preamplified and then connected to an adjustable-gain electromyographic unit (MA300 Multi-Channel EMG System; Motion Lab Systems, Baton Rouge, Louisiana). Electromyographic data were collected simultaneously with the three-dimensional motion-capture-system data. The analog sampling rate ranged from 1000 Hz with a 350-Hz low-pass filter to 5000 Hz with a 2000-Hz low-pass filter. The sampling rate was the maximum possible on the basis of the equipment available at the time of testing, and as equipment was upgraded during the course of this project, the sampling rate was increased.

After the electrodes were applied to the subjects, electromyographic signals were tested to maximize muscle signal.

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**TABLE I Demographics**

<table>
<thead>
<tr>
<th></th>
<th>Male Subjects</th>
<th>Female Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Age(^*) (yr)</td>
<td>19.8 ± 1.6</td>
<td>19.4 ± 1.4</td>
</tr>
<tr>
<td>Height(^*) (cm)</td>
<td>178.6 ± 8.1</td>
<td>166.1 ± 8.0</td>
</tr>
<tr>
<td>Weight(^*) (kg)</td>
<td>75.0 ± 8.8</td>
<td>63.0 ± 8.7</td>
</tr>
</tbody>
</table>

\*The values are given as the mean and the standard deviation.
amplitude and minimize noise due to electrode motion over the skin according to a standard testing protocol. Following signal adjustment, reflective markers for kinematic motion capture were applied and the subjects then completed a series of maximal voluntary isometric contractions to serve as a normalization factor for each muscle in accordance with usual practice when quantifying electromyographic data. The same examiner (S.B.) directed the maximal voluntary isometric contractions and performed the electromyographic analysis for all subjects.

The twenty-one retroreflective markers, ranging from 12.5 mm to 25 mm in diameter, were attached to the subject’s lower extremities and torso with double-sided tape, according to a standard marker-placement protocol used for routine motion analysis. In addition, a single marker was placed on the ball to provide an estimate of the time of ball impact and ball velocity. A three-dimensional video motion capture system (Motion Analysis, Santa Rosa, California) with a minimum of eight and a maximum of ten cameras (240 frames per second) was used to record and synchronize marker trajectories and analog signals for both static standing (model calibration) and dynamic kicking trials. During the course of this investigation, two additional cameras were added to the original eight cameras available for data capture in the motion analysis laboratory.

After measurement of the maximal voluntary isometric contractions and application of the surface markers, static standing (model calibration) trials were completed. The subjects were allowed to wear comfortable footwear of their choice, typically running or flat shoes. Each athlete warmed up and performed several of each type of kick prior to performing the kicks that were used for analysis. For all kicks, the subjects kicked a fully inflated, standard size-five soccer ball from a stationary position on a level floor into a small goal five yards from the ball (Fig. 1). Each subject performed five instep kicks and five side-foot kicks with the dominant kicking leg.

Fig. 1
Example of a soccer player kicking the ball in the laboratory.
The raw marker trajectory data were reconstructed in Cortex (Motion Analysis) and then processed in Visual3D (C-Motion, Germantown, Maryland) with use of standard segment and joint definitions (OrthoTrak; Motion Analysis) to calculate three-dimensional ankle, knee, hip, pelvis, and torso kinematics for both the supporting and the stance limb. All but one of the raw marker trajectories were filtered digitally at 6 Hz with a second-order, bidirectional Butterworth filter. The single marker on the ball was not filtered as any filtering of this trajectory created ambiguity in the identification of the specific frame when ball impact occurred. Event identification during the kicks was automated to allow for standardized and consistent definitions of each phase of the kick across all subjects.

The kicking motion was broken down into five phases (Table II)\(^2\). Phase I, the preparation phase, begins with the last heel-strike of the kicking leg prior to the kick. This phase ends with toe-off of the kicking leg, marking the beginning of Phase II, the back swing phase. Phase II ends with maximum hip extension of the kicking leg. This event marks the transition to Phase III, the leg-cocking phase, which lasts until maximum knee flexion of the kicking leg. After reaching maximum knee flexion, the kicking leg starts to accelerate forward in Phase IV, the leg acceleration phase. Ball contact marks the transition to Phase V, the follow-through phase, which lasts until toe velocity inflection, i.e., the toe velocity magnitude reaches a local minimum following impact. In order to focus on limb-specific differences related to kicking, comparisons between the sexes were made for lower extremity alignment and muscle activation during the combined Phases II, III, and IV—the most consistent phases of the kick with an isolated stance role for the supporting limb and an isolated swing role for the kicking limb.

Phase duration, lower extremity alignment, and muscle activation data were collected. Phase duration was calculated both as time (in seconds) and as a percentage of the kick. Lower-extremity alignment measurements included maximum and average pelvic obliquity, i.e., the angle of the pelvis relative to the long axis of the trunk. Maximum and average knee flexion and hip extension (in degrees) were collected for the kicking limb, while hip abduction-adduction and knee valgus-varus data were collected for the supporting limb. Following electromyographic signal rectification, the signal from each muscle was normalized to the maximum averaged amplitude recorded over 0.48 second from the maximal voluntary isometric contraction trials, which was used as the normalization value for each muscle. The mean normalized activation (percentage of maximal voluntary isometric contractions) was calculated for each phase and during the combined Phases II, III, and IV. As the average activation was calculated within a phase, no linear enveloping was required.

**Statistical Analysis**

Descriptive statistics were calculated for all measures. Two-sample t tests were used to test the differences between the sexes for maximum and average pelvic obliquity and hip and knee coronal alignment during Phases II, III, and IV of the kick. The generalized estimating equations method was used to compare muscle activation between the sexes by taking into account the correlations between repeated experiments (i.e., five instep kicks and five side-foot kicks per subject). Sex, kicking type (instep kicks compared with side-foot kicks), and phase (II, III, and IV) were included in the generalized estimating equations model. Interaction effects between sex and phase were not significant, implying Phases II, III, and IV are consistent.

### TABLE II: Events Used to Define the Phases of Kicking

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
<th>Start Event</th>
<th>End Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Preparation</td>
<td>Heel-strike of kicking leg</td>
<td>Toe-off of kicking leg</td>
</tr>
<tr>
<td>II</td>
<td>Back swing</td>
<td>Toe-off of kicking leg</td>
<td>Max. hip extension</td>
</tr>
<tr>
<td>III</td>
<td>Leg cocking</td>
<td>Max. hip extension</td>
<td>Max. knee flexion</td>
</tr>
<tr>
<td>IV</td>
<td>Acceleration</td>
<td>Max. knee flexion</td>
<td>Ball impact</td>
</tr>
<tr>
<td>V</td>
<td>Follow-through</td>
<td>Ball impact</td>
<td>Toe speed inflection</td>
</tr>
</tbody>
</table>

### TABLE III: Lower Extremity Alignment During Phases II, III, and IV of the Kicking Motion

<table>
<thead>
<tr>
<th></th>
<th>Male Subjects*</th>
<th>Female Subjects*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic obliquity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max.</td>
<td>8.2° ± 2.9°</td>
<td>9.1° ± 2.1°</td>
</tr>
<tr>
<td>Avg.</td>
<td>4.5° ± 2.9°</td>
<td>4.7° ± 1.8°</td>
</tr>
<tr>
<td>Supporting limb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip abduction†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max.</td>
<td>2.7° ± 3.4°</td>
<td>1.5° ± 5.4°</td>
</tr>
<tr>
<td>Avg.</td>
<td>−5.3° ± 3.2°</td>
<td>−7.2° ± 5.4°</td>
</tr>
<tr>
<td>Min.†</td>
<td>−10.3° ± 3.6°</td>
<td>−14.8° ± 3.8°</td>
</tr>
<tr>
<td>Knee alignment‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. varus</td>
<td>8.5° ± 6.2°</td>
<td>11.0° ± 2.6°</td>
</tr>
<tr>
<td>Avg.</td>
<td>2.5° ± 5.3°</td>
<td>4.0° ± 3.6°</td>
</tr>
<tr>
<td>Min. varus</td>
<td>0.2° ± 5.2°</td>
<td>2.4° ± 3.2°</td>
</tr>
</tbody>
</table>

*The values are given as the mean and the standard deviation.
†Positive values indicate abduction, and negative values indicate adduction. ‡The difference was significant (p = 0.006). §Positive values indicate varus alignment, and negative values indicate valgus alignment.
Source of Funding
There was no external source of funding for this study.

Results
Phase Timing
No differences between the sexes existed for phase timing or ball velocity. Ball velocity and phase timing were similar across style of kick as well as for sex.

Fig. 2
Comparison of the sexes with regard to mean muscle activation in the kicking limb during combined Phases II, III, and IV. The error bars indicate the standard deviation. MVIC = maximal voluntary isometric contraction, Tib Ant = tibialis anterior, Gastroc = gastrocnemius, Med Ham = medial hamstrings, Vas Lat = vastus lateralis, Vas Med = vastus medialis, Hip add = hip adductors, Glut max = gluteus maximus, and Glut med = gluteus medius.

Lower Extremity Alignment
Pelvic obliquity and hip and knee frontal plane alignment are shown in Table III. The female supporting hip reached significantly more adduction than the male supporting hip during Phases II, III, and IV of the kick (average, 15° compared with 10°; p = 0.006). No significant difference between the sexes with regard to pelvic obliquity was found. Average pelvic obliquity was approximately 5° in both sexes, while the peak

Fig. 3
Comparison of the sexes with regard to mean muscle activation in the supporting limb during combined Phases II, III, and IV. The error bars indicate the standard deviation. MVIC = maximal voluntary isometric contraction, Gastroc = gastrocnemius, Med Ham = medial hamstrings, Vas Lat = vastus lateralis, Vas Med = vastus medialis, Glut max = gluteus maximus, and Glut med = gluteus medius.
pelvic obliquity was 8.2° in the males and 9.1° in the females. Although the coronal knee alignment reached approximately 2° more varus in the females compared with the males, the difference was not significant.

Lower Extremity Muscle Activation

The mean normalized muscle activation during Phases II, III, and IV for each muscle is summarized in Figure 2 (kicking limb) and Figure 3 (supporting limb). The iliocaud in the kicking limb was significantly more active in males compared with females (123% compared with 34% of maximal voluntary isometric contraction; p = 0.0007). In the supporting limb, male players also had greater muscle activation than female players with respect to the gluteus medius (124% compared with 55% of maximal voluntary isometric contraction; p = 0.005) and vastus medialis (139% compared with 69% of maximal voluntary isometric contraction; p = 0.002). There was a trend toward higher activation of the gluteus maximus in the supporting limb in the males (113% compared with 78% of maximal voluntary isometric contraction; p = 0.07). No significant difference between the sexes was found for the other muscles in either limb.

Discussion

This study found differences in lower extremity alignment and muscle activation between male and female subjects during the soccer kick. The hip of the supporting limb reaches greater adduction in female soccer players during the soccer kick. Male soccer players have greater activation of the iliocaud in the kicking limb and of the abuctors and vastus medialis in the hip of the supporting limb compared with female soccer players. These differences in muscle activation and knee alignment may relate to sex-based differences in injury risk among soccer players.

As mentioned previously, female soccer players face a much higher risk of anterior cruciate ligament injury than their male counterparts. Investigators have looked at a variety of factors and their possible role in the difference between the sexes in anterior cruciate ligament injury patterns. While no study has proven a single etiology, a number of these investigations are relevant to the findings of the present study. One biomechanical study has shown that female intercollegiate athletes performed a single-leg squat with greater hip adduction than their male counterparts. The authors speculated that females may have difficulty controlling the hip musculature, specifically the gluteus medius, during a dynamic movement. Poor hip control because of underactivation of the gluteus medius leads to hip adduction when the joint is loaded. A previous study of collegiate soccer players found that females landed with significantly greater hip adduction angles compared with males at initial contact during a single-leg agility maneuver. Overall, females averaged 100% greater hip adduction during these landings compared with males. Hip adduction moment has been shown to be correlated to knee abduction moments in anterior cruciate ligament injured subjects as hip adduction leads to internal rotation of the femur and knee valgus. This sequence of events can lead to the position of "no return" as described by Ireland.

While the decreased activation of the hip abductors likely relates directly to the increased hip adduction in the supporting limb, the primary cause of these differences is not clear. The shape of the female pelvis, in contrast to the male pelvis, and resultant changes in muscle alignment and contraction could be more relevant than dynamic neuromuscular control of the hip. Other factors could contribute as well. Regardless of the etiology, there is a net effect on frontal plane hip movement, which may be an area to target in injury prevention programs.

The current investigation shows that differences between the sexes in lower extremity muscle activation vary between the supporting limb and the kicking limb, which may be very important in terms of understanding injury mechanisms. Males appear to use a "hip dominant" approach to kicking, which may be consistent with the previously proposed theory that females are quadriceps dominant. The hip abductor in the dominant supporting limb has been shown to be weaker than the hip abductor in the dominant kicking limb in female soccer players, a difference not seen in male soccer players. The decreased recruitment of the supporting limb hip abductors by females during kicking may contribute to this side-to-side difference. A recent study has shown that noncontact anterior cruciate ligament injuries are more likely to occur in the dominant supporting limb in female soccer players than in male players. The decreased activation of the hip abductors and increased hip adduction in the supporting limb during kicking among females may contribute to their increased risk of noncontact anterior cruciate ligament injuries in this limb.

Kicking may play a direct role in anterior cruciate ligament injury in female players. During an average ninety-minute game, a player has an average of fifty-one contacts with the ball, twenty-six of which are with the foot. An analysis of injury risk during soccer matches found that kicking accounted for 51% of potential actions that could lead to injury. Studies have shown that players on the offensive team are more likely to experience an anterior cruciate ligament injury. It has also been shown that a majority of anterior cruciate ligament injuries occur to the player who is the ball possessor. With less activation of the hip abductors and greater hip adduction in the supporting limb, females may be at greater risk for noncontact or even contact-associated anterior cruciate ligament injury during the kick.

Even though kicking does not often play a direct role in anterior cruciate ligament injury, it may have an important indirect role in the risk for noncontact anterior cruciate ligament injury in two ways. First, if male and female soccer teams undergo similar soccer-related training activities, particularly given the high volume of kicking during soccer training and competition, the male athletes use and strengthen the hip abductors considerably more than do their female counterparts. Second, the neuromuscular patterning learned or at least reinforced during kicking may increase the tendency of females...
to go into a position of risk during other dynamic tasks such as cutting and landing. Decreased use of the hip abductors, resulting from weakness, decreased recruitment, or some combination thereof, may contribute to femoral adduction, hip internal rotation, and knee valgus, predisposing female soccer players to noncontact anterior cruciate ligament injury.\textsuperscript{38,40,53} As female soccer players have been shown to benefit from neuromuscular training regimens\textsuperscript{34,58}, focused training designed to increase the strength and recruitment of the hip abductors may decrease their risk of noncontact anterior cruciate ligament injury.

Differences between the sexes during the soccer kick may contribute to the disparity in risk for other injuries as well. Patellofemoral problems are more common in females in general and, specifically, among soccer athletes.\textsuperscript{36} Because of the decreased activation of the vastus medialis in the supporting limb during the soccer kick, female soccer players do not get as much conditioning of the medial quadriceps from soccer-specific training. This may place the patellofemoral joint at increased risk in terms of both tracking and joint contact pressures. Whether this is cause or effect, it suggests that female soccer players may benefit from targeted strengthening of the medial knee extensors.

An important aspect of the present study is the inclusion of electromyographic measurements of hip flexor activation during kicking activities. To our knowledge, this is the first study to take into account hip flexor electromyographic measurements in the assessment of differences between male and female athletes. Hip dominance may be protective at the knee but detrimental around the pelvis as greater activation of the iliacus in the kicking limb may contribute to more hip and groin pathology in male soccer athletes. This suggests hip flexor stretching should be evaluated as potentially protective against sports hernia symptoms, particularly in male soccer athletes. The interaction between the activity of the iliacus and the abdominal musculature was not directly documented in this study and is an area that would benefit from further investigation.

It is not clear why female soccer players kick with significantly less activation of the iliacus in the kicking limb and of the hip abductor and vastus medialis in the supporting limb. It is possible that females use greater relative activation of the rectus femoris compared with the iliacus during the kicking motion to power hip flexion. A study of adolescent soccer players found increased rectus femoris activity in females compared with males during an unanticipated cutting maneuver.\textsuperscript{39} This could be the case during kicking as well, and such an imbalance has the potential to shift the knee extensor-to-flexor ratio. Hamstring-quadriceps imbalance has been shown to be associated with anterior cruciate ligament injury in female soccer players.\textsuperscript{37} The decreased activation of the hip abductors appears to be consistent with other studies of dynamic tasks showing decreased use of the hip abductors in female athletes. Two recent studies appear to agree with our findings of greater vastus medialis activation in males during the soccer kick. In one study of elite soccer players performing an un-anticipated cutting maneuver, it was found that females contracted the vastus lateralis to a greater extent than the vastus medialis, whereas the males had greater activation of the vastus medialis.\textsuperscript{56} Another study of college soccer athletes performing side-step cutting maneuvers noted greater vastus lateralis activity in females compared with malesom.

Limitations of this study include the relatively small sample size and the lack of kinetic data. This study was performed on relatively high-level athletes without a history of a clinically important injury. Although the differences between the sexes while kicking are postulated to contribute to differences in injury risk, there is no direct connection between these findings and actual injury. Furthermore, soccer athletes kick with a wide variety of styles and footwear and use different parts of the foot, depending on the desired trajectory of the ball. The laboratory setting does not reproduce all types of kicking used in soccer, nor does it reproduce the exact shoe-surface interaction seen in a typical game or practice. Finally, although muscle activation of >100% may appear difficult to interpret, this is not an uncommon finding as the amplitude of the electrical activity of the muscle during dynamic tasks can exceed the amplitude recorded during a static, isometric task.\textsuperscript{27,49,59,60}

Despite these limitations, this is the first study to compare lower extremity alignment and muscle activation between male and female soccer athletes during kicking. Less hip abductor activation and greater hip adduction while kicking may contribute to the disparity between the sexes with regard to the risk of anterior cruciate ligament injury among soccer players. Greater use of the vastus medialis may be protective against patellofemoral problems in male players, while greater use of the iliacus may contribute to a higher risk of sports hernia symptoms in male players. Specific intervention programs may modify these patterns and possibly reduce sex-specific injury risk in soccer athletes. More generally, this study suggests that differences between the sexes at the hip may relate to differences in the risk of injury to the lower extremity, including the knee. Future research should investigate this potential connection among athletes in soccer and other sports.


