Gender Differences in Plantar Loading During an Unanticipated Side Cut on FieldTurf

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Objective: To determine whether force–time integral (FTI) and maximum force (MF) are significantly different between genders when performing an unanticipated side cut on FieldTurf.

Design: Thirty-two collegiate athletes (16 men and 16 women) completed 12 unanticipated cutting trials, while plantar pressure data were recorded using Pedar-X insoles.

Setting: Controlled Laboratory Study.

Participants: Division I cleated sport athletes with no previous foot and ankle surgery, no history of lower extremity injury in the past 6 months, and no history of metatarsal stress fracture.

Interventions: None.

Main Outcome Measures: Maximum force and the FTI in the total foot, medial midfoot (MMF), lateral midfoot (LMF), medial forefoot (MFF), middle forefoot (MiddFF), and the lateral forefoot (LFF).

Results: Males had a greater FTI beneath the entire foot (TF) ($P < 0.001$). Females had a significantly higher MF beneath the LMF ($P = 0.001$), MiddFF ($P < 0.001$), and LFF ($P = 0.001$). Males had a significantly greater MF beneath the MMF ($P = 0.003$) and greater FTI beneath the MMF ($P < 0.001$) and MFF ($P = 0.002$).

Conclusions: Significant differences in plantar loading exist between genders with males demonstrating increased loading beneath the TF in comparison with females. Females had overall greater loading on the lateral column, whereas males had greater loading on the medial column of the foot.

Clinical Relevance: The results of this study indicate that plantar loading is different between genders; therefore, altering cleated footwear to be gender specific may result in more optimal foot loading patterns. Optimizing cleated shoe design could decrease the risk for metatarsal stress fractures.

Key Words: plantar loading, cutting, soccer, metatarsal stress fractures

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INTRODUCTION

Stress fractures are one of the most common injuries accounting for 10% to 20% of all sports medicine injuries.1,2 Previous reports have indicated that men are commonly plagued with fifth metatarsal stress fractures, whereas women more often have stress fractures of the second and third metatarsal.3 Stress fractures are difficult to treat and can persist for extended periods of time. Fifth metatarsal stress fractures in particular are complicated by a high incidence of nonunion, delayed union, and refracture independent of postinjury treatment.4 Researchers have used plantar loading as a means of examining how the foot is loaded during different sporting activities to better understand potential injury risk.

Plantar loading assessment has been shown to be a reliable and reproducible measurement to use when examining foot and ankle injuries.5–10 In addition, plantar loading has been evaluated in athletic populations as a way to examine the effect of acute and overuse injuries, such as ankle inversion injuries and stress fractures.11–13 Loading of the foot has been reported to be altered based on running speed, type of movement, and shoe design.10,14 Previous work in the area has focused on single plane movements, such as walking and running, which limits the applicability of these studies to sporting populations.15–18 Walking and running studies have demonstrated that the greatest loads are seen in the heel and forefoot region.15,17 More recent work has begun to examine changes in plantar loading during sport-specific activities for football (American Soccer), and American football.15,10,11 Orendurff et al compared the peak pressures beneath 7 anatomic regions of the foot during running, accelerating, cutting tasks, and during jumping and landing in 2 different Nike shoes (Nike, Beaverton, OR). They found that sport-related movements loaded the plantar surface of the foot more than straight running.8 Eils et al5 also reported that during cutting movements, there was a significant difference in the pressures beneath various anatomic foot region when compared with running in a straight line. Based on the Eils et al study results, it was proposed that overuse injuries, such as stress fractures, could result from the increased loading that was seen beneath the foot during sporting activities.

Footwear can significantly influence plantar loading measurements. Significant differences in forefoot loading have
been previously reported based on the footwear worn during both cross and side cutting as well as during jumping and landing.\textsuperscript{14,19–21} These studies highlight the importance of considering footwear when determining injury risk patterns in athletic populations.

The influence of gender on plantar loading has been previously examined during limited tasks. Sims et al demonstrated that significant differences existed between genders when examining plantar loading. Men had higher plantar loading on the lateral portion of the midfoot and forefoot during sport-specific testing in contrast to women possibly explaining why men have a higher rate of fifth metatarsal stress fractures.\textsuperscript{10,22} Therefore, the movement performed, the footwear, the playing surface, and gender all seem to affect plantar loading and should be considered when examining injury risk factors during athletic movements.

It is important to recognize that plantar loading is not the only factor that can contribute to stress fracture. However, a significant challenge for past studies has been accurately and reproducibly replicating the movements and forces that are present during game activities. Therefore, the goal of this study was to use an unanticipated cutting task to better simulate game play conditions in cleated sports. The use of an unanticipated task allows for a better understanding of how the foot is being loaded during a task in which the player is not focused on how they are completing the task, but rather on the ability to complete the cut in the correct direction. The hypothesis based on previous literature was the men and women would demonstrate significant differences in loading in the midfoot and forefoot.

**METHODS**

A total of 32 participants (16 men and 16 women: mean (SD) age: 20.718 (1.727) years; height: 1.716 (0.116) m; and weight: 70.958 (13.257) kg) were recruited and tested during this study. All subjects were Division I collegiate soccer or lacrosse athletes at a single university with previous experience running and cutting in cleats. The men’s and women’s soccer and lacrosse teams were contacted and invited to participate. The first 35 subjects who responded were scheduled for testing with the goal of collecting data on 32 subjects. Subjects were excluded from participation if they had a history of lower extremity injuries within the past 6 months, foot or ankle surgery in the past 3 years, or had a history of a metatarsal stress fracture. Each subject was asked to read and sign informed consent, which was approved by the university institutional review board, before study initiation.

All subjects were allowed between 5 and 10 minutes to complete a warm-up. At the completion of the warm-up, the height, weight, and age of each subject was recorded. Subjects were then fit with the appropriately sized soccer cleat that was provided for testing (Nike Vitoria Hard Ground Boot, with 25 molded cleats) (Figure 1) to avoid differences in plantar loading based on footwear. The appropriately sized Pedar-X (Novel, St. Paul, MN) insole was placed within the shoes and was used to collect bilateral plantar loading data. The Pedar-X system has been reported to provide reproducible and reliable plantar loading data.\textsuperscript{6} The plantar pressure data were sampled at 100 Hz through Bluetooth technology. All insoles were calibrated before data collection to 9 bar using the company’s calibration protocol, (Novel).

Completion of the unanticipated cutting task (Figure 2) was demonstrated for each subject before data collection. Subjects were asked to run forward until the light was illuminated. They were instructed to plant and cut in the direction of the illuminated light and do their best to maintain the same speed into and out of the cut. All of the testing was completed on an indoor FieldTurf field to facilitate similar testing conditions.
conditions from 1 subject to another. Subjects were asked to run straight forward until a light was illuminated, which indicated whether they should be cutting to the left or right. When the light was illuminated, the subject was told they were to perform a side cut 45 degrees in the indicated direction. A series of cones were placed at a 45-degree angle from the center of the course, and the participants were asked to stay within the cones while cutting. Subjects were asked to complete approximately 12 unanticipated cutting trials, some to the left and some to the right. Subjects were allowed 1 minute of rest between trials to help diminish the effect of fatigue. Testing took approximately 45 minutes to complete for each subject.

To analyze the in-shoe pressure data, the foot was divided into 8 regions using the Novel Multiproject-ip software (Novel). The plantar loading masks that were used for this analysis have been previously reported for the assessment of plantar loading in various populations (Figure 3). The plantar loading mask that was used for analysis divided the midfoot into 2 anatomic regions (medial and lateral) and the forefoot into 3 anatomic regions (medial, middle, and lateral). The midfoot and forefoot regions were assessed to determine differences between men and women when completing an unanticipated cutting task. The dominate limb of each participant was identified as the limb that they would prefer to use as the plant foot when cutting. Each participant was asked to complete 5 cuts, and the plant foot that was used for the majority of trials was identified. Each participant was instructed to run toward the light box and cut left of right after planting either foot at the last cone before the 45-degree angle. Therefore, the mean of the 6 trials in which the participant planted on his/her dominant foot were used for all statistical comparisons. The plantar loading variables of interest in this study were maximum force (MF) and the force–time integral (FTI), and these were compared between men and women for each of the foot regions of interest. The MF was normalized to body weight (BW) to compare across genders. To examine differences in each of these plantar loading variables, an independent samples t test was completed with a P value of 0.05 indicating statistical significance. All statistical analysis was completed using SPSS version 21 (IBM Corp, Armonk, NY).

RESULTS

Significant differences existed between men and women regarding height and weight; however, no significant difference existed between the 2 groups with respect to age (Table). Males were found to have a significantly higher FTI (306.3 ± 40.19 Ns) beneath the entire foot (TF) in comparison with females (247.2 ± 21.19 Ns). The MF was conversely lower in males (2.601 ± 0.327 BW) than in females (2.668 ± 0.242 BW) for the TF; however, these differences were not significant. When comparing the males and females based on the anatomic regions of the foot, significant differences were found in the MF and the FTI. Maximum force was found to be significantly higher for males (0.23 ± 0.08 BW) than females [0.16 ± 0.04 BW] in the medial midfoot (MMF) (P = 0.003) (Figure 4). In contrast, the MF was significantly lower for males in the lateral midfoot (LMF) (P = 0.001), lateral forefoot (LFF) (P = 0.001), and the middle forefoot (MiddFF) (P < 0.001) (Figure 4). No significant difference between genders was found in the medial forefoot (MFF) (Figure 4). The FTI was greater for males in the MMF, LMF, LFF, MiddFF, and the MFF; however, only in the MMF (P < 0.001) and the MFF (P = 0.002) were the differences significantly different (Figure 5).

![FIGURE 3. Eight regions of the foot: Definition of the regions as percentage masks. H, hallux; LT, lesser toes; RF, rear foot.](image)

<table>
<thead>
<tr>
<th>TABLE. Subject Information by Gender</th>
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<tbody>
<tr>
<td><strong>Men (Mean ± SD)</strong></td>
<td><strong>Women (Mean ± SD)</strong></td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>21.13 ± 1.99</td>
</tr>
<tr>
<td>Height* (m)</td>
<td>1.79 ± 0.07</td>
</tr>
<tr>
<td>Weight* (kg)</td>
<td>81.99 ± 8.98</td>
</tr>
</tbody>
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*Indicates a significant difference P < 0.05 between genders.
**DISCUSSION**

Evaluation of foot kinematics and plantar pressures during simulated athletic activity can provide key insight into the stresses placed on the foot during various athletic activities. This study was designed to reproduce a game-like situation by having participants perform an unanticipated cross cut on a predetermined course and in so doing examine differences in the plantar loading patterns between men and women. When examining the TF, the FTI was significantly higher for males than females indicating that the men have a greater overall load placed on the foot during a dynamic unanticipated task. This is similar to previously reported results during a side-cut task, which also reported that men had a greater FTI when compared with women. Therefore, one can infer that males overall due to their size and speed place greater pressure over a longer period of time on their feet during game play situations. It is unclear based on the currently available literature if loading pattern is protective or could be a potential injury risk factor. Therefore, additional work is needed to understand the impact of both the magnitude of the load and duration of loading on the development of acute and overuse injuries.

When examining the foot by specific anatomic regions, our results demonstrated that female participants had greater loading beneath the lateral column of the midfoot and forefoot when compared with the males. In contrast, the males demonstrated an increase in loading beneath the medial column of the midfoot. The MF was significantly higher for females in the LMF, LFF, and the MidFF encompassing most of the lateral column. These MF measurements reported in this study are greater than those previously reported in the literature for females performing a side cut. The differences in lateral column loading between this study and previous reported values could be the result of the task being completed. In this study, subjects were asked to approach the cut as quickly as possible with a 5- to 7-step acceleration phase. In contrast, previously reported studies did not allow for this type of acceleration phase, and therefore, the subjects could have approached the cut at a much different speed. In addition, the unanticipated nature of this cut could have results in less balanced cut, which placed more load on the lateral side of the foot before the subject transferred load to the medial column to complete the cut. In previous studies, subjects were aware that they would be cutting in a specific direction at a specific point in time and therefore were going to complete the task in a way that would most efficiently maintain speed through the cut.

Athletic tasks, such as cutting and jumping, have been previously used in the assessment of plantar loading. When examining a side-cut task, the medial portion of the foot experiences more loading than the lateral portions of the foot. The results of this study are similar to those that have been reported previously with the largest loads being seen beneath the medial border of the foot. The similarity of the current results with the previous literature would indicate that during both planned and unanticipated cutting that the medial side of the foot experiences most of the load. In previous studies, it has been reported that men have increased load on the lateral column of the foot when compared with women during certain sport-specific tasks. In contrast to previous results, this study results indicate that women demonstrate a greater MF beneath the lateral column of the foot (LMF, LFF). These differences could be the result of the unanticipated nature of the movement. It is possible that during an unanticipated movement, the women remain on the lateral side of the foot longer before transitioning to the medial side of the foot to complete the task indicating that mechanical differences could exist between men and women when completing an unanticipated cut.

Although differences in plantar loading exist between men and women during an unanticipated side-cutting task, it does not seem that these differences would help to explain the difference in the incidence of fifth metatarsal stress fractures between genders. Previous literature has indicated that the lateral column of the foot is loaded more during a crossover cutting task than it is during a side-cut maneuver. Therefore, future work should examine an unanticipated crossover cut task that simulates game play to better understand the effect of gender differences and how these differences could impact fifth metatarsal injury risk.

There are a few potential limitations to this study. All of the plantar loading variables that were examined are based on...
the vertical force applied to the foot. The insoles that were used for testing are not capable of measuring the medial–lateral forces applied to the foot. Therefore, a potential limitation of this study is the lack of information about the medial–lateral forces that are applied to the foot during the cutting maneuvers. A second limitation of the study is the relatively low collection frequency, which could result in the loss of the true peak value. However, in order for information to be obtained for both feet, 100 Hz is the maximum collection frequency that is possible with the current system. The task that was selected for this study was an unanticipated movement. The nature of this movement could lead to differences in how the task was completed. These potential changes in movement task completion could lead to differences in plantar loading. Finally, the use of highly trained athletes (Division I) limits the boarder applicability of these results to the general population.

Future work will need to examine the differences between genders during a greater variety of game-like situations, including a crossover cut and other maneuvers that result in increased load beneath the lateral column of the foot. In addition, future work explaining the differences in plantar loading between genders with various cleat plate configurations would be useful when determining the need for gender-specific footwear design.

REFERENCES