Lower Extremity Mechanics During Cutting Tasks in Different Shoe-Turf Combinations

Rafael Garcilazo: McNair Scholar

Dr. Michelle Sabick: Mentor

Mechanical and Biomedical Engineering

The demands placed on the lower extremity when performing jumping and cutting maneuvers are depending, in part, on the interaction between the playing surface and the athlete's footwear. Higher demands are likely to result in increased incidence of injury, so for safety reasons it is important to quantify how the shoe-turf interface affects joint loads. The purpose of this study is to compare the forces on the lower extremity while landing and side cutting (rapid direction change at approximately 45 degrees) on artificial football turf with different styles of football cleats.

Introduction

Footwear and floor surfaces are factors that can lead to an injury related to athletic activities. In the past 20 years there are an estimated 80,000 ACL tears each year in the United States alone,[8,9] and approximately 50,000 ACL reconstructions are performed annually, leading to a total cost of these injuries of almost $ 1 billion per year.[8,9] ACL injuries are caused either by a contact or a non-contact situation. A contact situation would be a collision between players. A non-contact situation would include falls, sudden stops while running, or side cutting which is rapid change of direction. Approximately 70% of the ACL injuries occur in non-contact situations.[9] As Glen A. Livesay mentioned in his research, from an injury prevention perspective, there are numerous possible causes for these non-contact ACL injuries, but a primary factor implicated in many of them is the interaction between the player's shoe and the playing surface.[9] There for, it important to consider the footwear and floor surface for the performance and safety of an athlete.

The objective of this study is to compare the forces on the lower extremity while landing and side cutting (rapid direction change at approximately 45 degrees) on artificial football turf with different footwear. This study will also help gather information to identify kinematics or kinetic changes that may occur during athletic competition with different footwear on artificial turf.

To have a clear understanding of the factors involved with different combinations of footwear and surfaces, the following goes over research that has been done in the past. First, the friction and traction on different shoe-surfaces combination will be looked at. Second, the different surfaces on football fields that have been and are being used today. Last, but not least will be the ground reaction forces involved with natural grass and football turf.

Friction and traction

Research has been done looking at the friction and traction with different shoe-surface. One study was done by combining the shoe-surface that determined the frictional forces that are connected with the injury frequency, i.e. the higher the frictional resistance the higher the injury frequency.[15] Tennis surfaces for example have been shown to influence the occurrence and frequency of tennis injuries dramatically.[15] Which fallows with Segesser research. It was speculated that the difference in injury frequency are directly related to the difference in the frictional properties of the surfaces. Surfaces with low frictional resistance are assumed to cause fewer injuries than surfaces with high frictional resistance.[15] With these two perspectives in mind, the combination with shoe-surface conditions fall between a rang of not enough friction, which slipping occurs, and too much friction, which foot fixation occurs.

There are two kinds of friction, static friction and dynamic friction. The coefficients of friction are material dependant constants. In athletic activity movements like running, quick stops and starts, and rapid change of direction result in the development of high horizontal forces between the shoe and the playing surface. In football, athletes perform many cutting and shuffling movements that could result in these high horizontal forces. For example, some forces could have a magnitude of sideway forces that may reach or exceed the athlete's bodyweight, [16] which slippage could occur. To help prevent slippage, a higher traction coefficient between the shoe and the surface is required.

In a landmark study, Lambson et al examined shoes with 4 different cleat designs and tracked the relative incidence of ACL tears with each design in a group of 3119 high school football players between 1989 and 1991.[9] The authors concluded that the cleat design most likely to be associated with a major knee injury on natural grass used long, irregular cleats placed at the peripheral margin of the sole, with a number of smaller, and pointed cleats positioned interiorly.[9]

Another research study done by Martyn Shorten, was about the first generation synthetic turf athletic fields. Athletes found cleats designed for natural turf fields did not provide enough slip resistance on synthetic turf. The resulting slips and falls lead to only minor injuries, but also started a trend towards the use of shoes with more and loner cleats.[16] Although these new outsole designs solved the slip problem, they increased the risk of the "foot fixation", which occurs when excessive resistance to rotation or "rotational traction" prevents the shoe from moving freely during twists, pivots and cuts.[16] Foot fixation leads to the development of high forces in the knee during rotational movements and is believed to be factor in the aetiology of knee injury.[16]

Surfaces

A new generation of synthetic surface is call Field-Turf, which is composed of a polyethylene and polypropylene fiber blend stabilized with a graded silica sand and ground rubber infill. It was developed to duplicate the playing characteristics of natural grass. Some examples on different turfs see Figure 1

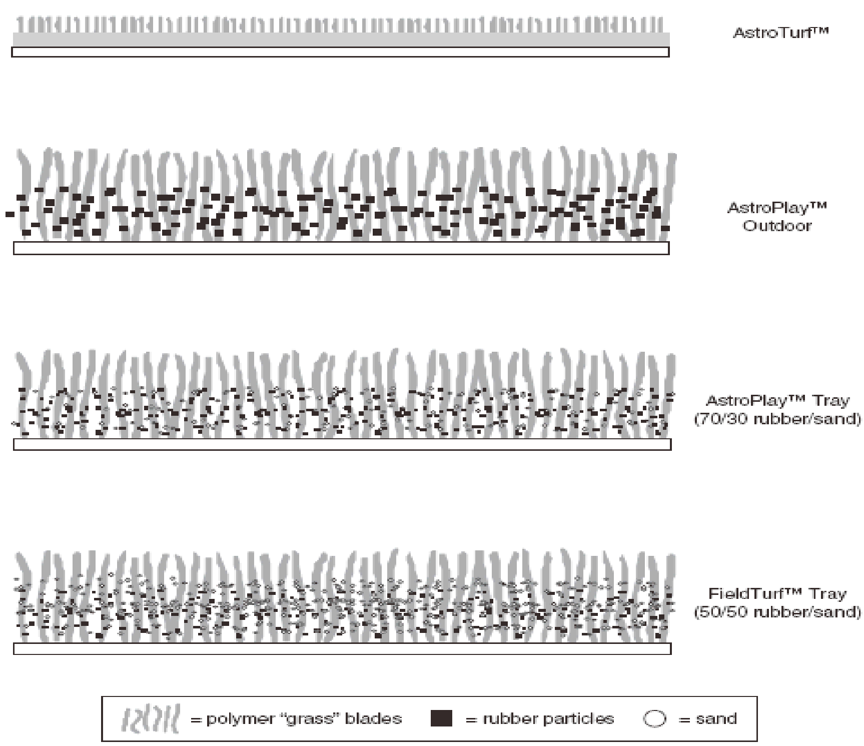

Figure 1: Four different types of turfs (Dr. Livesay, American J. of Sports Medicine, 2006 (34))

In Dr. Meyer's research, a total of 240 high school games were evaluated for game-related football injuries sustained while playing on Field-Turf or natural grass during the 5-year period. The final facts overall, 150 (62.5%) team games were played on Field-Turf versus 90 (37.5%) team games played on natural grass. A total of 353 injuries were documented, with 228 (64.6%) occurring during play on Field Turf as compared to 125 (35.4%) on natural grass.[2] It was discussed that there was a greater incidence of muscle-tendon overload injuries on Field Turf.

The authors mentioned that more consistent artificial composition enhances the speed of the game but may also allow for greater opportunity for injury because of overextension and greater fatigue potential of muscle as players perform at a greater rate of acceleration, speed, and torque. Although numerous other mechanisms may be at play, risk factors including pivoting, change of direction, direct contact with an opposing player, deceleration, unfortunate mishaps (eg, piling on, moving pileup), and being jolted during an uncontrolled or compromised movement. Others have identified equipment (eg, shoe/cleat design), the abrasive nature of artificial surfaces, and various anatomical and biomechanical influences as other causes of injury.[2] Figure 2 shows an example of two different cleat designs.

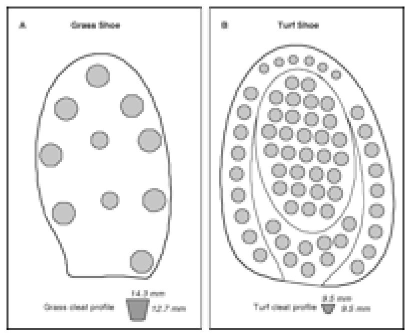

Figure 2: On the left, is a cleat pattern on the forefoot of the traditional soccer-style grass shoe. On the right, cleat pattern on the forefoot of the turf shoe. (Dr. Livesay, American J. of Sports Medicine, 2006 (34))

Shoe-surface combinations that develop high peak torques may put athletes at increased risk of injury.[1] At the same time, this does not necessarily mean that every athlete or trainer will necessarily want to switch to a shoe-surface combination with lower peak torques; there is a trade-off involved. Lower peak torques may be safer, but they may also compromise performance.[9]

Because the shoe-surface interface involves both the cleat pattern on the shoe and the playing surface, it can be dangerous to make generalization as to what constitutes an "unsafe" cleat, as the performance of a given cleat may change on different playing surfaces. At the present times, the majority of field sports are played on either natural grass or a synthetic surface such as Astroturf, Astroplay, or FieldTurf.[9]

Ground Reaction Forces

Research has been done and has shown that ground reaction forces vary with different terrains. A 5-year prospective study was done by Michael C. Meyers, PhD and Bill S. Barnhill, MD on the "Incidence, Causes, and Severity of High School Football Injuries on Field-Turf Versus Natural Grass" this study was done in 2004. It was seen that over the past decades, numerous studies have attributed a greater risk and incidence of articular and concussive trauma to playing on artificial turf when compared to natural grass.[2] Another research, on the review of the effects of artificial turf and natural grass on surface-related traumatic injuries in soccer suggests that surfaces with artificial turf produce more abrasion injuries then surfaces with natural grass.[3]

A difference in injury pattern and injury mechanism when playing on different types of surfaces has been suggested, as well as an increased injury risk for frequent alternating between different playing surfaces.[3] High school football teams that alternate playing on nature grass to artificial turf increase the player's chances of an injury.[3]

A research on footwear can addressed biomechanical measurements, comparing different types of shoe materials on applied forces and foot motion during running and jumping. Studies show that the ground reaction forces were not changed by shoe materials or even between shod and barefoot conditions[6,7,8] while another revealed increased impact force with a harder shoe.[9]

Materials and Methods

Subject

In this study there were eight subjects, collegiate athletes from Boise State University football team only running backs and receivers ages around 18-25. The subjects wore comfortable clothes in shorts, and different styles of football cleats.

Material

A marker configuration was put on the subjects to collect data. A total of 18 surface markers (small lightweight plastic balls approximately ½" diameter) were attached to specific anatomical locations starting from the waist down to the toe and heel using double sided skin tape. These markers are tracked by the VICON motion analysis system to track the subject's motion while performing the protocol.

The ground reaction fc 1 acting on each leg were recorded 2 g the two force platforms mounted side-by-side at ground level, see figure 3. The ground reaction forces were recorded at 1250 Hz. The force platform number 1 recorded the peak force for the right leg and force platform number 2 recorded the peak force for the left leg. The impact forces were obtained from the data provided, using the vertical forces.

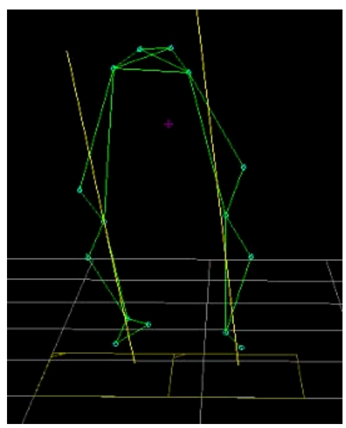

Figure 3: The two force platforms (yellow), #1 is located on the right side of the subject and #2 is located on the left.

Procedure

Before testing, the subjects were provided with well instructions on the jumping and landing protocol. The subjects were also well oriented to the lab equipment and familiarized with the protocol. The subjects performed a total of 9 jumps landing and side cutting maneuvers. Athletes performed two-footed jumps upward and forward, landing with their feet in the center of two ground-level force platforms. The jumps were taken at a horizontal distance of five feet. In addition, they jumped over a small hurdle 15 inches off the ground. The subjects jumped as described above landed on both feet and then sprinted off the force platforms for several steps either straight ahead, or at approximately a 45 degree angle to the right or left. All eight football athletes performed a series of side cutting maneuver unanticipated. For unanticipated trails, subjects were required to rapidly respond and adjust movement response while in the air immediately prior to landing, based on a series of randomly activiated light stimuli. Figure 4, is an example of one of the subjects during the jump-cut paradigm.

Figure 4: The jump-cut paradigm

The force platforms recorded the ground reaction forces during impact. Lower extremity movement during the landing was recorded using six infrared cameras to track reflective markers attached to the body segments. These cameras are part of the VICON motion analysis system. The motion data gathered was used to quantify variables such as knee and hip flexion angles during landing. With this data gathered a summary of the jump landing mechanics were collected.

All of these jumps were conducted in the Intermountain Orthopaedic Sports Medicine and Biomechanics Research Laboratory located in the Micron Engineering Center on campus, Boise State University.

Results

The mean peak vertical ground reaction forces (GRF) for the cleat and turf shoes were compared to assess the difference in impact force at landing. In the research eight subjects performing nine trials each with football cleats and turfs shoes results a total of 144 trials. Looking at the vast range of dynamical movements that athletes perform out in the field. It is difficult to obtain consistent data of the forces involved while an athlete is performing movements like landing, pivoting, twisting, cutting, and accelerating from a force plate. The fallowing Figures 5-8 show an example of the vertical GRF acting on the left leg while performing a right cut with football cleats or turf shoes. The figures show a good visual example of the variability of the ground reaction forces between different footwear of football cleats and turf shoes. Figures 5 and 6 show the GRF of three trials from subject DL with football cleats and turf shoes. Figures 7 and 8 show the same but with subject GT.

Referring to Figures 5 and 7 were the subjects are using football cleats for the footwear. The figures show that both subjects using cleats were able to execute a force of 4000 N.

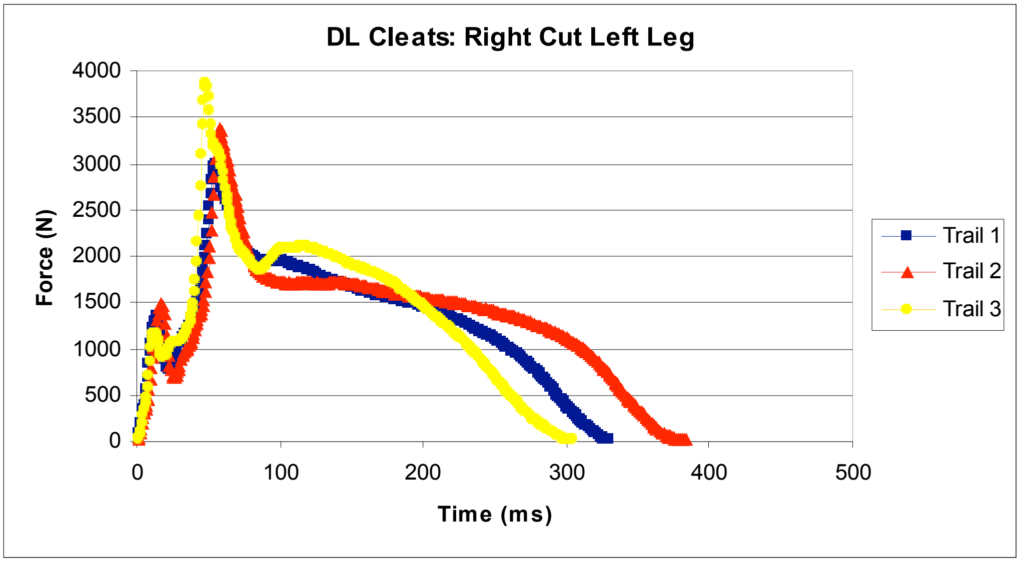

Figure 5: Vertical ground-reaction forces on the left leg with football cleats performing a right cut

Figures 6 and 8 the subjects are using turf shoes for the footwear. Figure 6 show peaks forces below as 2000 N, half of the peak force with the cleats on Figure 5, and an inconsistency with the forces.

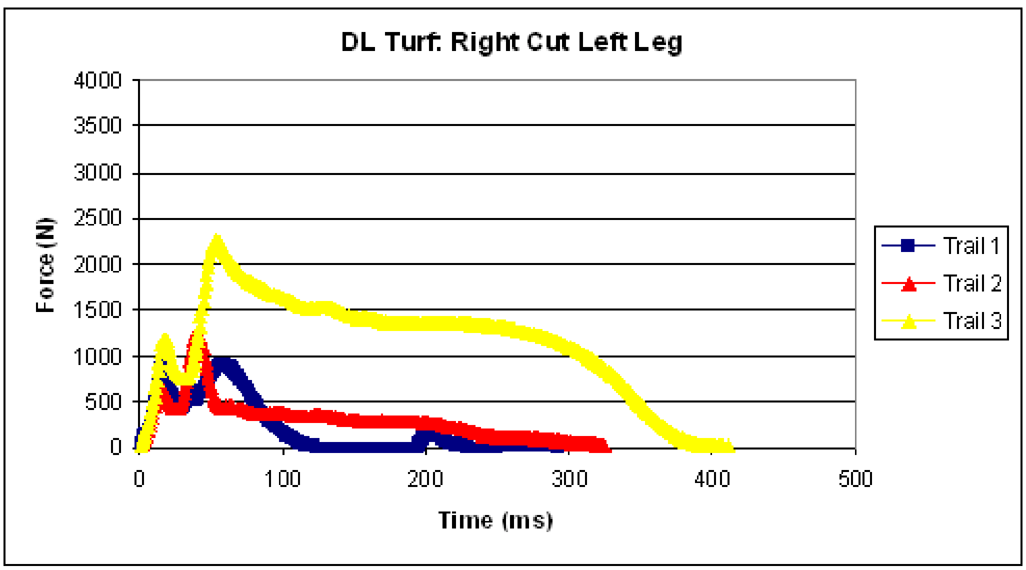

Figure 6: Vertical ground-reaction forces on the left leg with turf shoes performing a right cut

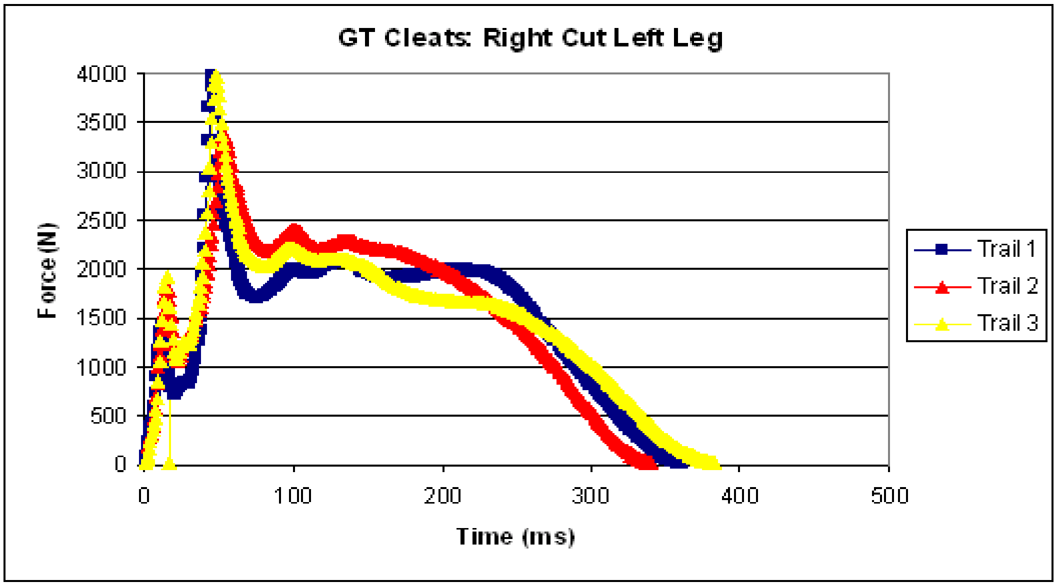

Figure 7: Vertical ground-reaction forces on the left leg with football cleats performing a right cut

Figure 8 using turf shoes, is more consistent with the forces compared to Figure 6. Although, it still ranges at low magnitudes of force and it also takes longer push of time from the force plates ranging around 425 to 475 ms.

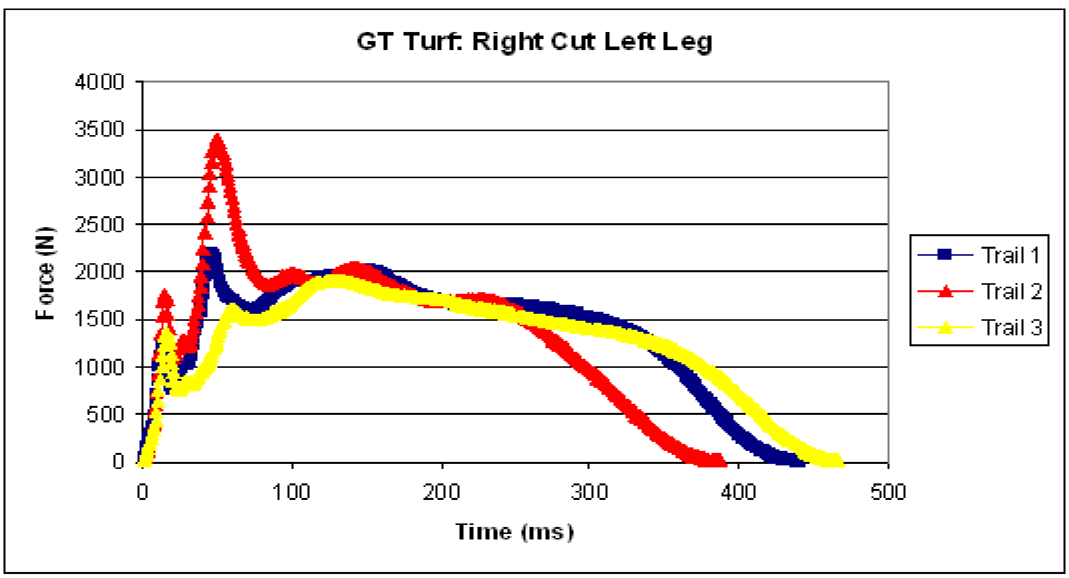

Figure 8: Vertical ground-reaction forces on the left leg with turf shoes performing a right cut

Figure 9, shows the mean peak vertical ground reaction forces for the cleats and turf shoes at landing. The left leg forces in cuts to the right were significantly greater in the cleats than in turf shoes (cleats 3238.7±557.7 N vs. Turf shoes 2332.7±685.8 N, p=0.066, Table 1). In all other cases, footwear did not significantly affect peak vertical ground reaction force. For both shoe conditions, cuts to the left resulted in large forces on the right leg and vice versa. For the straight run, the forces on the right leg tended to be higher than those for the left leg.

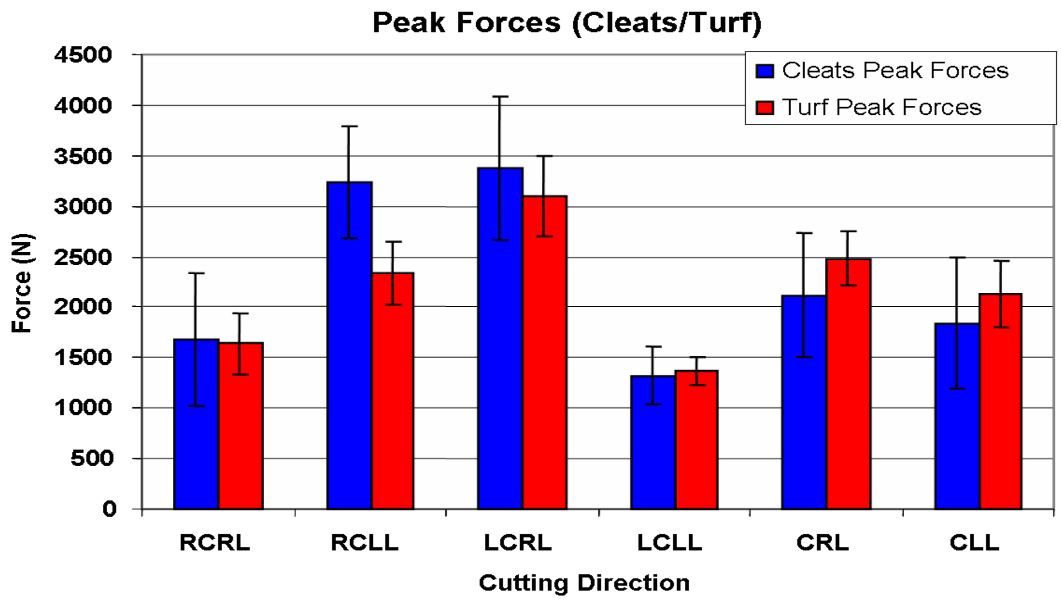

Figure 9: Cleat and turf peak vertical ground reaction forces (RC= Right Cut, LC= Left Cut, RL=Right Leg, LL=Left Leg, C=Center). Peak force indicates the impact GRF.

Table 1 is a summary of the statistical comparisons between cleats and turf shoes. The highlighted numbers in the table are the peak forces between cleat and turf shoes. Rows Cleat and Turf on Table 1 are the mean peak forces from all eight subjects.

	Right Cut		Left Cut		Center	
	Right	Left Leg	Right	Left Leg	Right	Left Leg
Cleat (N)	167	3238.7	3371.7	1321.9	2118.4	1836.5
Stdev (N)	663.	557.	710	288.	617.	649.
Turf (N)	1636.4	2332.7	3093.2	1372.5	2479.2	2122.6
Stdev (N)	429	685.	929.	231	608.	251.
% Difference	2.4	38.8	9	3.8	17	15.6
T-	0.87	0.06	0.42	0.81	0.31	0.20

Table 1: Statistical comparison of the footwear conditions.

Discussion

This study with eight subjects did not demonstrate many statistically differences in peak vertical ground reaction force due to choice of footwear. This is likely due to several factors including: (1) the relatively small number of subjects, (2) large variability in GRF between trials, and (3) differences in landing styles among the subjects. However, we did notice some interesting trends from our data. Subjects obviously planned their movements before landing, as evidenced by the higher GRFs on the push off leg when signaled to perform a cut (left leg for a right cut). Subjects also demonstrated evidence of limb dominance. In trials in which they were signaled to run straight after landing, peak force tended to be greater on the right leg, regardless of shoe condition. Looking at the right and left cuts and the limb dominance on Figure 9, this data shows that using cleat shoes the subject has a greater potential to provide higher magnitudes of force. Further analysis of the shear (traction) forces during cutting is currently underway, and may provide more insight as to the effect of footwear on cutting performance.

For this research other methods were attempted to find a relationship between the two different footwears. For example, looking at each axial force (x, y, and z) and finding the differences in the impact on the joints. Do to the variability on GREs this attempt was difficult to complete. Another attempt, was analyzing the two peak forces during the protocol; first peak force was the landing force and the second peak force was the push off force, or cutting force, from the force plates.

This research is to be continued and improved. By increasing the number of subject and finding better methods to help reduce the variability in the ground reaction forces will help to obtain better data. Being able to collect enough data to find out how the aspects of performance are related to the available traction. For example, to distinguish the traction between the shoe and the field to the extent to which a football player can lean into the surface or make cutting movements without slipping. Being able to prove that using footwear with better traction helps improves acceleration and agility; one can plant a foot and change direction or speed at higher rates. Also, finding the desirable traction between a shoe and a playing surface, that will lie in an optimum range that provides adequate slip resistance for dynamic movements without producing excessive resistance to rotation or foot fixation. The desirable traction will allow athletes to provide fast dynamic movements and safe competitive performance. The optimum range of the resilience of the turf field is also to be found.

On the next approach it would be important to measure how much energy is loss in collision with the surface. By doing so using an object like a basketball and dropping it at a certain height to see how much energy is lost. If it bounces back to its certain height then there is no losses but if the height of the bounce is smaller then its certain height then a loss of energy has occurred. With this data the resilience of certain turfs will be found, which then could be compared to the athletes running speed. The athletes running speed can be seen as the stride length, which could be found by taking the distance between footfalls and dividing it by the time it takes the foot to hit the ground. Being able to find the resilience of each turf is also important to see the impact on a head collision.

References

1. Lee A. Methods of impact absorption when landing from a jump. Eng Med. 1981;10:207-211.
2. McNitt-Gray JL. Kinematics and impulse characteristics of drop landings from three heights. Int. J Sport Biomechanics. 1991;7:201-224.
3. Ramey MR, Williams KR. Ground reaction forces in the triple jump. Int J Sport Biomechanics. 1985;1:233-239.
4. Dufek JS, Bates BT. The evaluation and prediction of impact forces during landings. Med Sci Sports Exerc. 1990;22:370-377.
5. McNair Pj, Prapavessis H Normative data of vertical ground reaction forces during landing from a jump. J Sci Med Sport. 1999;2:86-88.
6. De Wit B, De Clercq D, Aerts P. Biomechanical analysis of the stance phase during barefoot and shod running. J Biomech. 2000;33:269-278.
7. Ferris DP, Liang K, Farley, CT. Runners adjust leg stiffness for their first step on a new running surface. J Biomech. 1999;32:787-794.
8. Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. J Am Acad Orthop Surg. 2000;8:141-150.
9. Glen A. Livesay, Dawn R. Reda, Eric A. Nauman. Peak torque and rotational stiffness developed at the shoe-surface interface: the effect of shoe type and playing surface. Am J Sports Med. 2006;34:415-422.

10. Gross TS, Bunch RP. Material moderation of planter impact stress. Med Sci Sports Exerc 1989;5:619-624.
11. Hennig EM, Valiant GA, Liu Q. Biomechanical variables and the perception of cushioning for running in various types of footwear. J Appl. Biomech. 1996;12:143-150.
12. Nigg BM. Biomechanics, load analysis and sports injuries in the lower extremities. Sports Med. 1985;2:367-379.
13. Ekstrand J., Nigg BM. Biomechanics, Surface-related injuries in soccer. Sports Med. 1989 Jul;8(1): 56-62.
14. Lejeune TM, Willems PA, Heglund, NC. Mechanics and energetics of human locomotion on sand. J Exp Biology 1998;201:2071-2080.
15. Nigg BM, Segesser B. The influence of playing surfaces on the load on the locomotor system and on football and tennis injuries. Sports Med. 1988;6:375-85
16. McClay, I.S., Robinson, J.R. A profile of ground reaction forces in professional basketball. Journal of applied Biomechanics. 1994;10:222-236
17. Martyn Shorten, Bret Hudson, Jennifer Himmelsbach. Shoe-surface traction of conventional and in-filled synthetic turf football surfaces. BioMechanica LLC. 2006