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# Effects of Playing Surface and Shoe Type of ACL Tears in Soccer Players

Melissa Mansfield
*Union College - Schenectady, NY*

Effects of Playing Surface and Shoe Type

on ACL Tears in Soccer Players

By

Melissa Mansfield

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# Abstract


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ADVISOR: Ronald B. Bucinell, Ph.D., P.E

Anterior Cruciate Ligament injuries have become more common in athletes over the past decade which is believed to result from playing on more artificial turf surfaces. This study tested the playing surface theory by building upon a previous study conducted with Albany Medical Center which tested surface samples using an axial-torsion load frame located at Union College. The motion that causes most ACL noncontact injuries is replicated by the load frame which pushes and rotates a shoe against the playing surface and measures the torque it experiences.

The foot position, normal load, degree of rotation and rate of rotation were set to comply with ASTM standards. Four types of soccer shoes: round studded, bladed studded, soft ground, and turf shoes were fit on to a prosthetic foot to be tested. Kentucky bluegrass, new and old artificial turf with rubber infill, and gym turf were the playing surfaces considered. Each combination of shoe type and playing surface was tested five times and the average of those five trials was analyzed. It was determined that natural grass provides the traction needed for game play without reaching dangerous torque levels and has appropriate cushion to limit impact joint injuries in players. In addition, round studded cleats provide traction and relatively low torque on both natural and artificial turf surfaces. The results will allow players to choose an appropriate shoe for the surface being played on and influence what types of playing surfaces are installed, ideally reducing the number of ACL injuries in soccer players.

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# Introduction

What do Tiger Woods, Robert Griffin III and Tom Brady have in common? In addition to being high profile athletes, they have all suffered from a torn anterior cruciate ligament or ACL. They are far from being alone according to the American Orthopedic Society for Sports Medicine (AOSSM) who reported that approximately 150,000 ACL injuries occurred in the United States in 2011 [1]. This is a dramatic increase from their estimate of 80,000 ACL tears in 2000 [2], with the number of ACL injuries still continuing to grow. This escalation of ACL injuries has drawn a lot of attention in the medical and scientific community.

The knee is regarded as the largest and most complex joints in the body, only being held together by ligaments, muscles and tendons [3]. The ACL is one of the four major ligaments in the knee which connects the thigh bone (femur) to the shin bone (tibia). The ACL provides stability to the knee by preventing the tibia from sliding forward (see Figure 1) [3].

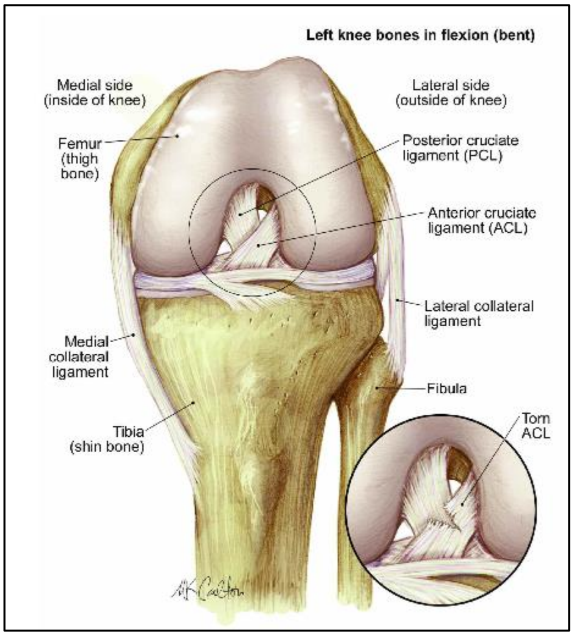



**Figure 1:** Shows the parts of the knee and an ACL tear [3].

AOSSM has carefully studied ACL tears and has approximated that 70% of the injuries occur in non-contact situations, while only 30% are due to contact [4]. Noncontact ACL injuries usually occur when “the running athlete changes direction or hyperextends their knee when landing from a jump” (see Figure 2) [3]. Contact ACL injuries occur when there is a direct hit to the knee where it is “forced into an abnormal position that results in the tearing of one or more knee ligaments” [3].

**Figure 2:** Shows the motion that causes most noncontact ACL injuries [4].

Doctors have discovered that repairing the ACL by stitching it back together is rarely successful [3]. Instead, they have developed techniques to reconstruct the ACL by replacing it with “tissue harvested from one of the other tendons around the knee or from an organ donor” [3]. It is common for doctors to remove a strip of tissue from the middle of the patella tendon and use it as a graft to reconstruct the ACL. Doctors can also harvest tissue from the hamstring, use a cadaver ACL or use cadaver tendons as grafts. A hole is then drilled through the femur and tibia where the new ligament is passed through and anchored in place [3]. The approximate cost

of performing one of these procedures in 2000 was $17,000; costing insurance companies around a billion dollars that year [2]. This amount excludes the cost of going to physical therapy before and after surgery. Most doctors recommended their patients to go to physical therapy three times a week for six months, which costs insurance companies approximately another billion dollars per year. This also does not account for doctor visits or "cost of treating the long-term complications of the posttraumatic degeneration that occurs in many patients who sustain ACL injuries, even those who undergo reconstruction" [2].

It can be understood how devastating tearing an ACL can be for athletes: having to undergo surgery, spend six months away from their sport while recovering in physical therapy and possibly suffer from long-term complications. This injury also costs insurance companies billions of dollars a year and requires doctors to perform over a hundred thousand of these surgeries a year. For these reasons, doctors and researchers have been trying to determine why so many ACL tears are occurring and they have discovered that there is no single answer to that question. They have discovered various internal and external factors that they believe could individually or collectively cause a person's ACL to become strained and tear. The internal factors that are thought to influence ACL tears are the anatomy of the person, increased hamstring flexibility, being flat-footed, hormonal effects and variations in the nerves and muscles which control the position of the knee [4]. The external factors consist of plays where the athlete's motion is disrupted by something else (another player, pothole, ball deflection etc.), if the player was wearing a brace, the type of footwear being worn, and the playing surface itself [4].

Each ACL case is different; therefore, it is impossible to determine the exact reason why a person's ACL tore. Surveys are collecting to determine if a particular trend can be found

between any of the internal and external factors and ACL tears occurring. Surveys may not be the most accurate method to determine what caused an athlete's injury since all athletes are different and there are so many factors that could have caused or contributed to that injury. Instead of using compiled data, controlled experiments can be performed where there are only a few internal or external factors being varied and studied.

This report will investigate the effects that playing surface and shoe type have on ACL tears in soccer players. The belief is that different shoe and playing surface combinations produce more torque than others. If the athlete's foot experiences more torque, then this effect will propagate up the leg to the knee, where the ACL will also have to withstand more torque. The overall goal of this study is to determine which combination of shoe type and playing surface produce the least amount of torque on the athlete's leg; thereby, decreasing the chance that the athlete will suffer from an ACL injury.

This study starts off by reviewing literature on similar experiments that have been conducted and the testing standards specified by the American Society for Testing and Materials. Then the setup of the playing surface samples, shoe samples and the testing apparatus will be presented. In addition, the constraints and testing parameters will be introduced along with the design of the experiment. The results from the experiment will then be analyzed, comparing the torque experienced by various playing surface and shoe combinations. From these results, conclusions are drawn and recommendations are made.

# Background

The need to test shoes on playing surfaces has become a common occurrence, which has led to the development of specific testing standards listed by the American Society of Testing and Materials. There are standards for both laboratory and field tests, allowing the tests and results to be replicated. This study will follow the ASTM standards for laboratory rotary testing compared to the studies conducted by Michigan State University and Penn State's Center for Sports Surface Research which used field testing [5,7,8].

This section of the report discusses the methodologies that Penn State and Michigan State used to conduct similar experiments, along with the method that was developed for this study. These studies are alike; each having a footform fitted with a shoe that is compressed and rotated against a playing surface in a controlled setting. The conditions and parameters in each study are discussed and compared to the desired setup specified by ASTM.

**Methodologies:**

The ASTM standard for this type of study specifies that "the normal loads can be applied by means of weights or hydraulic cylinders, springs in compression or other appropriate means and transmitted through a shaft to which the foot form is securely attached," and "the rotary motion may be applied manually or be means of a rotary actuator" [5]. This study will use a MTS servo-hydraulic axial-torsion load frame with hydraulic cylinders to apply the normal load and a rotary actuator to cause the rotary motion. This differs from the Michigan State and Penn State studies that used portable testing equipment with weights to apply the normal load and the rotary motion is manually applied [7,8]. ASTM does not recommend manual induction of motion because "it may be more variable than controlled mechanical actuators" which could

have caused some inaccuracy in their studies [5]. In addition, the apparatus used needs to be "anchored or have a large enough inertia to prevent it from being moved" during the testing procedure. A portable device is difficult to anchor, whereas an axial-torsion load frame is securely mounted at all times.

For laboratory-based testing, it is also specified that a "multi-axis force plate to which the surface being tested is securely attached" should be used to measure force and torque values [5]. A piece that complies with this standard was used in a previous study, "Traction Enhancing Products Affect Maximum Torque at the Shoe-Floor Interface: A Potential Increased Risk of ACL Injury," conducted for Albany Medical Center [6].

**Foot Form:**

ASTM specifies that the shoe being tested must be "pulled over a foot form, creating a tight fit capable of properly transmitting forces through the shoe material to the outsole-playing surface interface" and that the load must be "distributed entirely beneath the distal half or the forefoot region of the outsole" [5]. Michigan State used a compliant ankle as the foot form and mounted it in a flatfooted position [7]. It is possible that the compliant ankle would not properly transmit the forces, because some types are skinny and would not completely fill out a shoe. In addition, the foot was mounted in the worst case scenario, flatfooted position, with the load distributed through the heel, which does not comply with ASTM standards [7]. Penn State used cement as the foot form in the desired forefoot position [8]. The foot form is a rectangular cement block which appears to be distributing the load completely on the front edge [8]. This may not properly distribute the load across the forefoot of the shoe; instead it would apply the force to the forefoot only where the edge of the block is in contact with it. This study will use a SACH (Solid Ankle Cushioned Heel) type prosthetic foot in the forefoot position. The

prosthetic foot will allow the forces to be transmitted in a realistic manner and the forefoot position complies with ASTM standards.

**Shoes and Playing Surfaces:**

Michigan tested ten football cleats with five different cleat patterns [7], and Penn State tested eight soccer cleats with various cleat patterns [8]. Both studies found that varying the cleat pattern did not produce a statistically significant difference in torque except with certain turf shoes that produced less torque [7,8]. Based on these results, this study will only analyze the four main types of soccer cleats consisting of, bladed studded cleats, round studded cleats, soft ground cleats and turf shoes.

Michigan State tested FieldTurf, AstroPlay, sand-based grass, and native soil based grass [7], and Penn State tested FieldTurf Revolution, AstroTurf GameDay Grass 3D, Sportexe Omnigrass 51, and Kentucky bluegrass [8]. This study will test a new slit film artificial turf surface with various rubber thicknesses, ten year old slit film artificial turf surface with rubber infill, thatched turf with 1/2" blades and foam backing (no rubber), and soil based Kentucky bluegrass. By studying these surfaces, the effects of rubber infill depth, as well as the age of artificial turf on torque can be studied. In addition a comparison in torque values between artificial turf surfaces and natural grass can be analyzed.

**Testing Procedure:**

Rotary testing is needed to study the effects that shoe type and playing surface have on ACL injuries. The parameters that need to be set in rotary testing are the applied normal load, degree of rotation, rate of rotation, and number of trials [5]. ASTM recommends that the normal load be 225 ± 17 lbs the degree of rotation "shall be 90° unless the interacting surfaces deform or

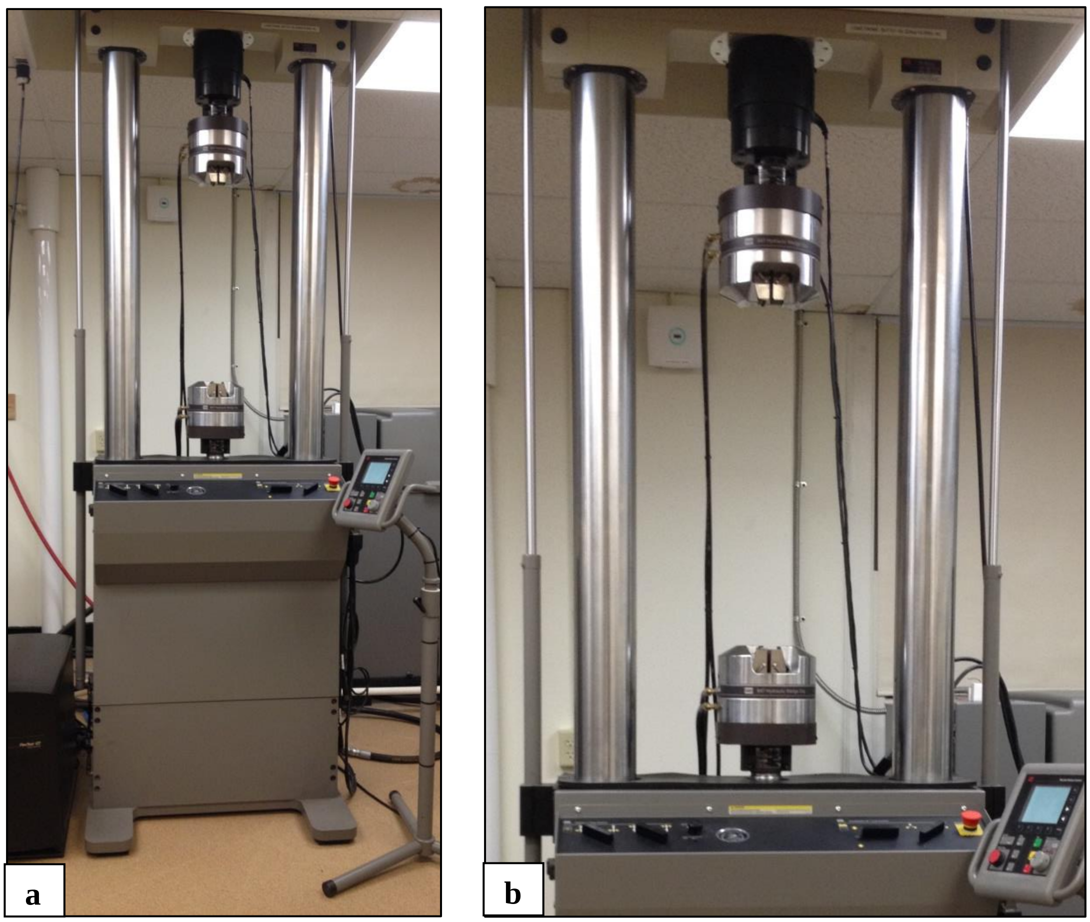
fail at a less rotation," the rate of rotation should be 45°/s or more, each combination of shoe and playing surface should be tested five times [5]. It is also specified that the data acquisition system should record the force, torque, angular velocity at a rate of 500 samples/s or greater [5].

The torque has been found to increase proportionally to the normal load applied [6]; therefore, this study will only conduct tests at one normal load of 225 lbs. Due to dimensional constrictions of the load frame, the foot form can only be rotated 45° which does not meet the 90° specification; however, both Michigan State's and Penn State's studies could not reach the desired 90° without deformation of the interacting surfaces occurring [7,8]. It is believed, based on Penn State's study, that the foot form will have reached the maximum torque during this 45° rotation [8]. The foot form will be rotated at the rate of 45°/s and each combination of shoe and playing surface will be tested five times, complying with the standards. In addition, the force, torque, and angular velocity will be measured at a rate of 500 samples/s as specified.

# Experimental Procedures

## Testing Apparatus:

This study was conducted using a MTS Servo-hydraulic axial-torsion load frame located in the Mechanics Lab at Union College. This load frame is capable of applying the desired normal load and then rotating the samples using hydraulics. The load frame can also record the time, rotation, angular velocity, normal load and torque for each trial the study. The distance between the two vertical columns of the machine, as seen in Figure 3, limited how large the playing surface samples could be and the degree they could rotate.



a b

**Figure 3:** The MTS Servo-hydraulic axial-torsion load frame used for testing (a) with the distance between the vertical columns being a limiting factor for the size of the playing surfaces (b).

**Shoes:**

The shoes that were tested were fitted on a men's size 12.5 SACH type prosthetic foot as seen in Figure 4. The large size of this prosthetic foot limited how small the playing surface samples could be. Four types of soccer shoes were tested: round studded cleats (Round Studded), bladed studded cleats (Bladed Studded), soft ground cleats (Soft Grounds) and turf shoes (Turf Shoes) that are shown in Figure 5. These four types of shoes represent the four major categories of shoes used in soccer.

**Figure 4:** The prosthetic foot used to anchor the shoes for testing.


**Figure 5:** The shoe used for testing: Round Studded cleats (a), Bladed Studded cleats (b), Soft Grounds (c) and Turf Shoes (d).

The prosthetic foot was then anchored into the load frame using a steel fixture. This fixture was designed to apply and distribute the load across the entire forefoot of the prosthetic. This was accomplished by using a 3D laser arm to scan the outside of one of the cleats and produce the contours in an image on the computer. A metal piece was then created from that 3D image to wrap around the forefoot and evenly transmit the load across that area (see Figure 6).

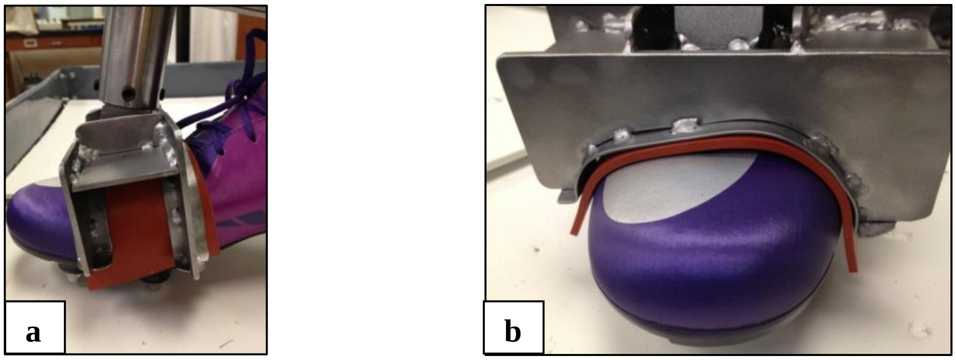



**Figure 6:** Side view (a) and front view (b) of the fixture designed to evenly distribute the normal load across the forefoot.

A second fixture was designed; using SolidWorks® CAD program, to attach the piece shown in Figure 6 to the axial-torsion load frame at a 12° angle. These pieces were connected at an angle to ensure that the heel of the foot form did not come in contact with the playing surfaces during testing and 12° was the maximum angle that the prosthetic foot could be bent without experiencing deformation. A third fixture was designed to stabilize the entire foot form and prevent the back of the foot from turning during testing. This fixture consists of two plates that are anchored around the metal tube in the prosthetic foot and around the second fixture with bolts (see Figure 7). This design allows the load to be applied to the entire forefoot and keep the heel of the foot stable and elevated while the playing surface is rotated underneath it.

**Figure 7:** The complete metal fixture that anchors the foot form and shoe into the top of the load frame.

**Playing Surfaces:**

A range of playing surfaces were obtained and tested. These surfaces included soil-based Kentucky bluegrass (Grass), thatched artificial turf with 1/2" blades and foam backing (Gym Turf), ten year old slit film artificial turf with rubber infill (Old Turf), and a new slit film artificial turf surface with 1" deep rubber infill (New Turf 1") and 1.5" deep rubber infill (New Turf 1.5"). Since testing was conducted in a laboratory, playing surface samples had to be created in wood boxes that could be mounted into the axial-torsion load frame. The size of the samples were limited by the size of the load frame, the size of prosthetic foot, the depth of base material needed underneath each playing surface and the number of trials wanted on each sample (for the Grass samples).

Mounting Box:

The playing surface samples needed to be firmly secured into the load frame to transmit the load and torque properly. The samples also needed to be easily removed loaded and removed, because the samples were switched often to minimize errors which will be explained later in the report. In order to accomplish both of these tasks, a mounting box was created that firmly anchors into a preexisting fixture made for the axial-torsion load frame that can transmit the load appropriately [6]. The mounting box has four walls to transmit the load and an open top that samples can be placed into and easily removed from (see Figure 8).

**Figure 8:** The mounting box that anchors into the load frame and holds all the playing surface samples.

Grass Samples:

Once the mounting box was created, playing surface samples could be made to fit inside of it. Grass boxes were created that housed 2" deep soil with Kentucky bluegrass sod placed on top. A wire mesh was placed in between the soil and the sod to give the roots something to anchor into. The process to create the grass boxes is shown in Figure 9.

**Figure 9:** The process followed to make the grass samples.

The samples were kept in a greenhouse where they were watered daily and cut weekly from the beginning of October to the end of November (see Figure 10). The root development of the grass during that time can be seen in Figure 11.

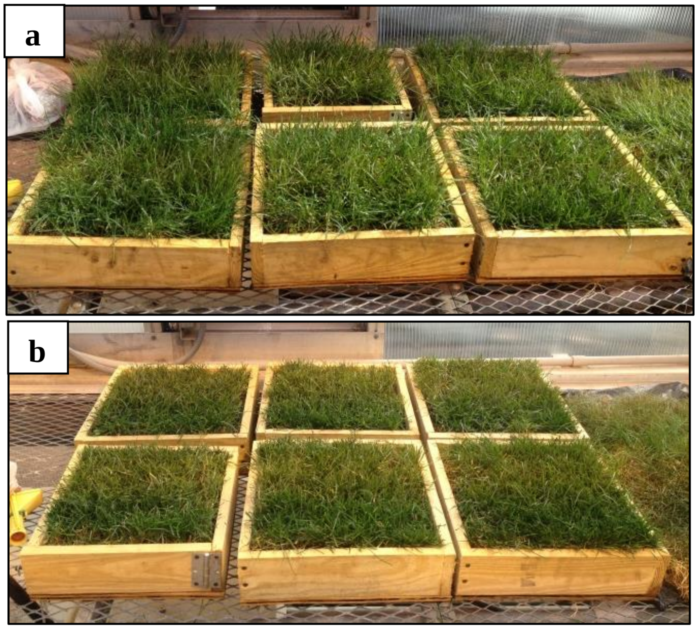



**Figure 10:** The grass samples before (a) and after (b) being cut that week.

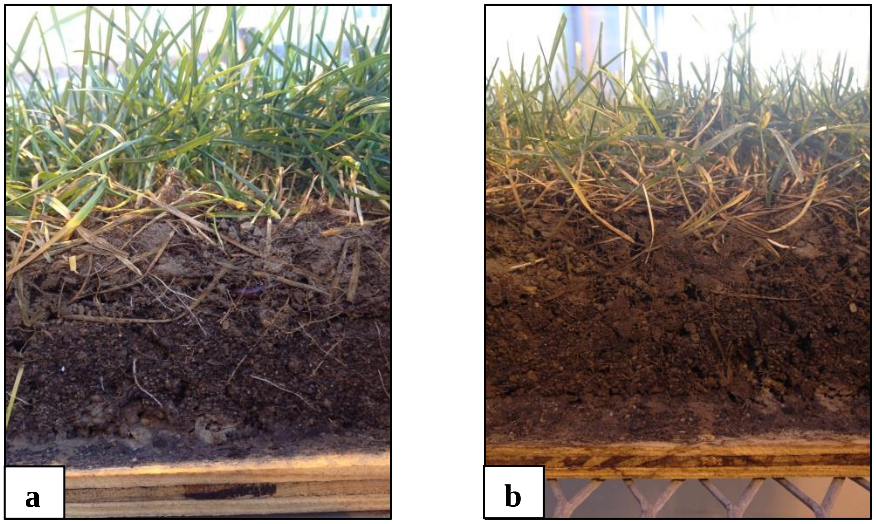



**Figure 11:** Shows the root development of the grass with thin white roots early in development (a) and thicker dark roots later in development (b).

The grass boxes were heavy and occupied a lot of space; therefore, the mounting box was anchored in a position that would allow four trials to be conducted in each grass box. To do this, the grass boxes were rotated so that each trial was on a section of untested grass. In addition, the sides of the grass boxes were cut down, so that the heel of the shoe would not scrap the sides of the boxes during testing as seen in Figure 12.

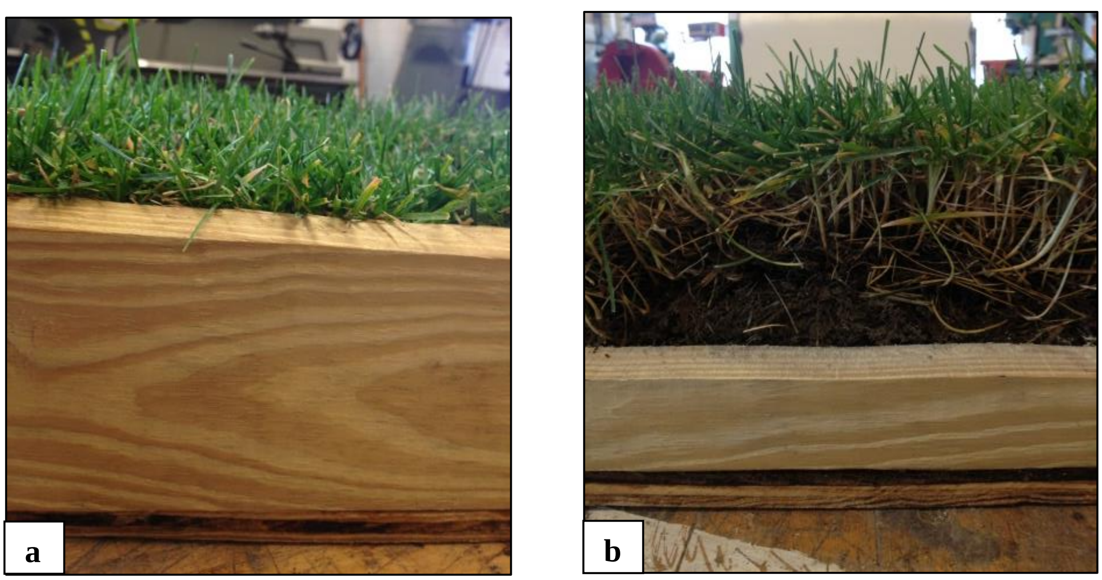



**Figure 12:** The grass boxes with high walls while grass is growing (a) and low walls for testing (b).

There were four shoes that needed to be tested five times resulting in a total of 20 grass trials. Each grass box can rotated to test on each side resulting in four tests per grass box. This allowed five grass boxes to be made, where each will be tested four times to account for the 20 necessary trials; instead of making twenty boxes that will be tested once. Figure 13 shows the final setup for grass sample testing.


**Figure 13:** The final setup for a grass sample test.

<u>Decomposed Granite Box:</u>

A thick base of soil was not only placed in the grass boxes to allow the sod to grow, but to also replicate the feel of a natural surface and how it reacts to torque. In order to replicate the base of artificial turf surfaces, a decomposed granite box was created that houses a 2" thick layer of coarse decomposed granite with a 2" thick layer of fine decomposed granite on top.

Decomposed granite or other aggregate stones are most commonly used under artificial turf surfaces for drainage and leveling purposes [9].

Since decomposed granite is heavy and no roots or artificial turf fibers interact with the granite, a separate box was created to hold the granite. This box was created in a way where the lighter artificial turf samples could be easily placed over the granite, instead of heavier samples with granite and artificial surfaces combined. The decomposed granite box is placed inside of the mounting box just as the grass boxes were (see Figure 14).

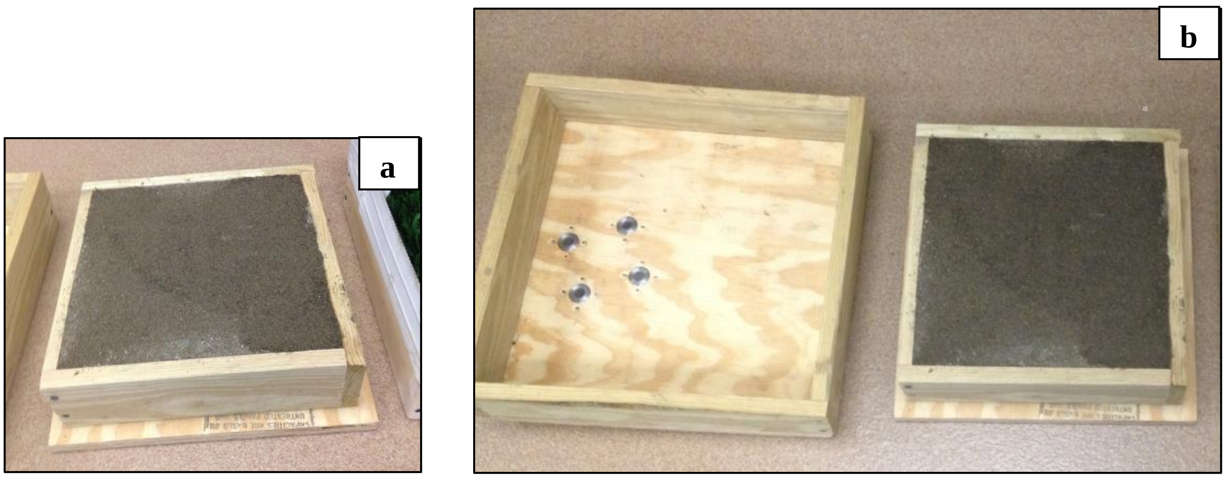



**Figure 14:** The decomposed granite box (a) and the decomposed granite box next to the mounting box that it fits inside (b).

<u>Artificial Turf Samples:</u>

The artificial turf samples were created by nailing pieces of turf to a wood frame. The frame allows the samples to be anchored along the edges while the area underneath the sample remains open. The frames fit in between the inner edges of the mounting box and the outer edges of the decomposed granite box and the bottom of the turf samples lay on top of the stone surface as seen in Figure 15.

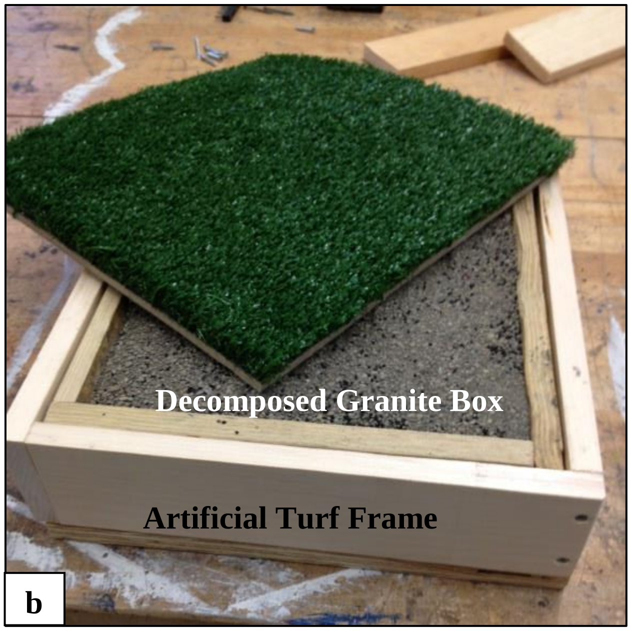




**Figure 15:** An artificial turf frame tipped on its side, exposing the open bottom (a) and an artificial turf frame without the turf attached around the decomposed granite box (b).

In addition, metal flashing was anchored to the perimeter of frames for artificial turf surfaces that contained rubber infill. This metal flashing kept the rubber infill from falling out of the sample during testing (see Figure 16).

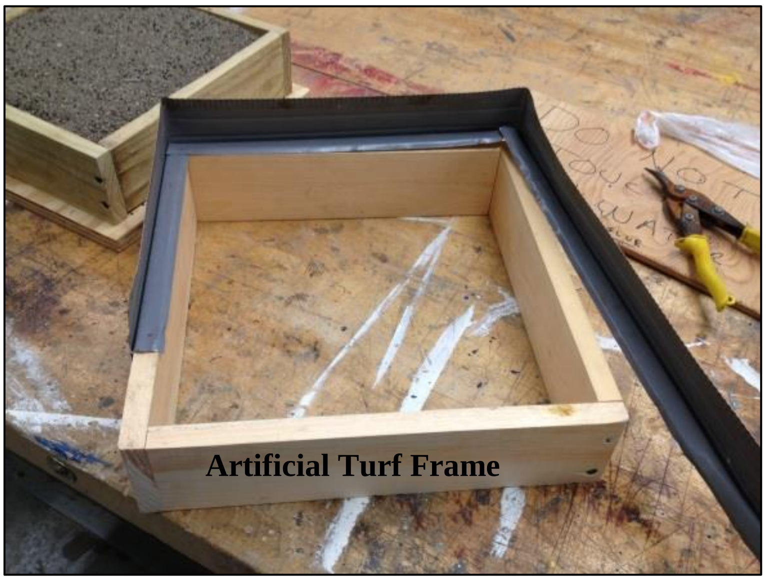



**Figure 16:** Metal flashing being placed around the perimeter of the artificial turf frame.

Three artificial turf frames were made for Gym Turf, Old Turf and New Turf. The New Turf frame was tested first with 1" deep rubber infill then was filled more to test 1.5" deep rubber infill (see Figure 17). The depth of the infill was measured by placing the frame over the decomposed granite box then measuring from the base to the top of the rubber using a caliper (see Figure 18).

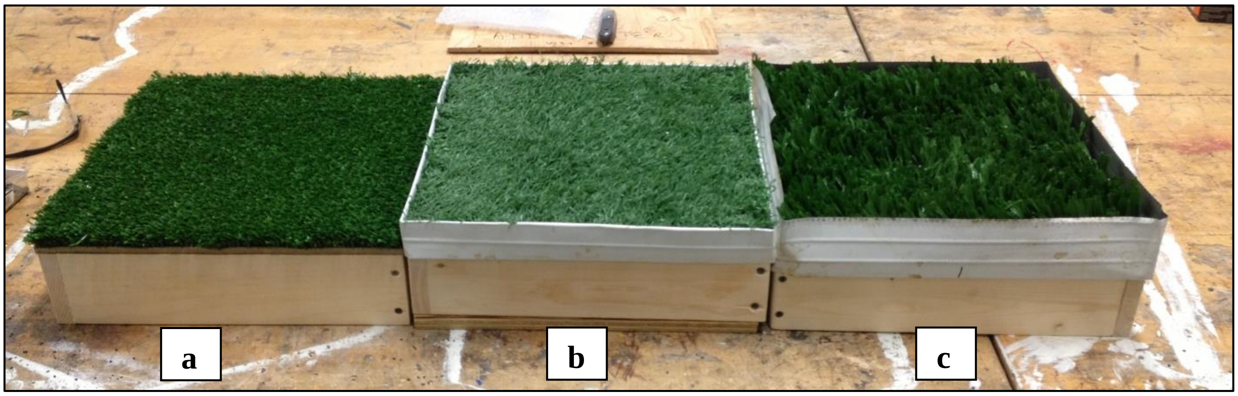



**Figure 17:** The three artificial turf samples made for testing consisting of Gym Turf (a), Old Turf (b) and New Turf (c).


**Figure 18:** The depth of the rubber infill in the New Turf sample being measured with a caliper (a) with the point of the caliper at the bottom of the infill and the base of the caliper at the top of the rubber infill (b).

**Methods:**

The testing order was designed to be as random as possible to decrease the chance of trends in the data being formed by uncertainties in the testing apparatus; however, due to time restraints, all of the Grass samples had to be tested first without mixing any turf samples into the order. To randomize these tests, each grass box was tested once and then switched out for another grass box, until all five grass boxes had been tested once. These boxes were switched in this manner four more times until each box was tested five times. Each time a box was tested, the orientation was rotated so that no spot of grass was tested twice. The order that the shoes were tested on the grass samples was also randomized. The shoes were tested in sets, switching shoes after every two or three trials. In addition, the testing order of the shoes was randomized in way that a certain shoe was not tested after another shoe two separate times. The grid used to determine the testing order of the grass samples is shown in Table 1.

**Table 1:** The testing order of Round Studded cleats (rs), Bladed Studded cleats (bs), Soft Grounds (sg) and Turf Shoes (ts) on the grass samples.

| Grass Box # | Shoe Type | Testing Order # | Shoe Type | Testing Order # | Shoe Type | Testing Order # | Shoe Type | Testing Order # |
|---|---|---|---|---|---|---|---|---|
| 1 | rs | 1 | bs | 6 | sg | 11 | ts | 16 |
| 2 | rs | 2 | bs | 7 | sg | 12 | ts | 17 |
| 3 | rs | 3 | bs | 8 | sg | 13 | ts | 18 |
| 4 | sg | 4 | ts | 9 | bs | 14 | rs | 19 |
| 5 | sg | 5 | ts | 10 | bs | 15 | rs | 20 |

The four remaining turf samples (Gym Turf, Old Turf, New Turf 1.0” and New Turf 1.5”) were tested in two sets of 40 trials since the New Turf sample first had to be tested with 1.0” rubber infill and then 1.5” rubber infill. This was accomplished by randomly testing half of the Gym Turf and Old Turf trials with all of the New Turf 1.0” trials in the first set, then testing

the remaining Gym Turf and Old Turf trials with all of the New Turf 1.5” trials. The shoe being tested was switched after every five trials and the playing surface sample was randomly alternated. The shoe testing was organized in a way where once again, the same shoe would not be tested after another type of shoe every time. This testing order was more confusing because both the shoe and playing surfaces were changing. The grids used to determine the testing order for the artificial turf surfaces is shown in Table 2. The complete testing order list is shown in Appendix A.

**Table 2:** The grids used to determine the testing order for Gym Turf (gt), Old Turf (ot), New Turf 1.0” (nt1) and New Turf 1.5” (nt1.5).

| | **nt1** | | **ot** | **gt** | **nt1** | | **ot** | **gt** | **nt1** | | **ot** | **gt** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **rs** | 1 | X | X | 2 | 5 | 3 | 4 | --- | --- | --- | --- | --- |
| **bs** | 9 | 6 | 7 | 8 | --- | X | --- | 10 | --- | --- | --- | X |
| **sg** | 12 | 14 | 11 | 13 | --- | 15 | X | --- | --- | X | --- | --- |
| **ts** | 18 | 16 | 17 | X | --- | X | 19 | 20 | --- | --- | --- | --- |
| **sg** | --- | --- | --- | --- | 21 | --- | X | 22 | 24 | X | 23 | 25 |
| **rs** | --- | X | X | --- | --- | --- | --- | 26 | 29 | 27 | 28 | 30 |
| **ts** | --- | --- | --- | X | 31 | X | --- | --- | 32 | 35 | 34 | 33 |
| **bs** | --- | --- | --- | --- | 37 | X | 36 | --- | 38 | 40 | X | 39 |

| | **nt1.5** | | **ot** | **gt** | **nt1.5** | | **ot** | **gt** | **nt1.5** | | **ot** | **gt** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ts** | 42 | X | 41 | 43 | 44 | --- | X | 45 | --- | --- | --- | --- |
| **sg** | 47 | 46 | 48 | X | --- | 50 | --- | 49 | --- | X | --- | --- |
| **bs** | X | 52 | 53 | 51 | 54 | --- | 55 | --- | --- | --- | --- | X |
| **rs** | 56 | 58 | 57 | 59 | X | 60 | --- | X | --- | --- | --- | --- |
| **bs** | X | --- | --- | --- | --- | 61 | --- | 62 | 63 | 65 | 64 | X |
| **ts** | --- | X | --- | --- | --- | 66 | X | --- | 70 | 67 | 69 | 68 |
| **rs** | --- | --- | --- | --- | X | --- | 71 | X | 72 | 74 | 73 | 75 |
| **sg** | --- | --- | --- | X | 77 | --- | 76 | --- | 80 | X | 78 | 79 |

Once the testing orders were determined, the shoes and playing surfaces could be loaded in to the axial-torsion load frame accordingly. Using Flex Test™ GT Station Manager Version 3.5C software, the angle of rotation was set to 45°, the rate of rotation was set as 45°/s and the sampling rate was set as 500 samples/s. The normal load of 225 lbs was then applied manually by pushing the playing surface into the shoe. Once the desired normal load was reached, the play button in the Flex Test™ program was selected and the playing surface rotated against the shoe. Once the motion stopped, the normal load was manually removed and the playing surface was rotated back to its original position. The data file was saved in the format TO-SH-SU-BX-RP where TO is the testing order number, SH is the shoe type, SU is the playing surface, BX is the box number (only for the grass samples) and RP is the replicate number or trial number. This process was repeated for the entire testing order sequence, where shoes and playing surfaces were rotated as specified.

The one hundred data files that were collected could then be uploaded into Microsoft Excel to be organized and analyzed for general trends. The data was then loading into the statistical program, JMP Pro®, where box whisker plots could be created and the P-values calculated to determine if the trends are statistically significant.

# Results

The acquired data was first used to determine general trends in the data. Typical curves for the various combinations were organized by playing surface (Appendix B) and by shoe type (Appendix C) to determine these trends. It was found that generally the torque increased as the playing surface varied in the following order: Gym Turf, Old Turf, Grass, New Turf 1.5" and New Turf 1.0". Generally, the torque also increased as the shoe being tested was changed as follows: Round Studded, Turf Shoe, Bladed Studded and Soft Grounds. Once the general trends were determined, the data was plotted in box-whisker graphs as seen in Figures 19 and 20.

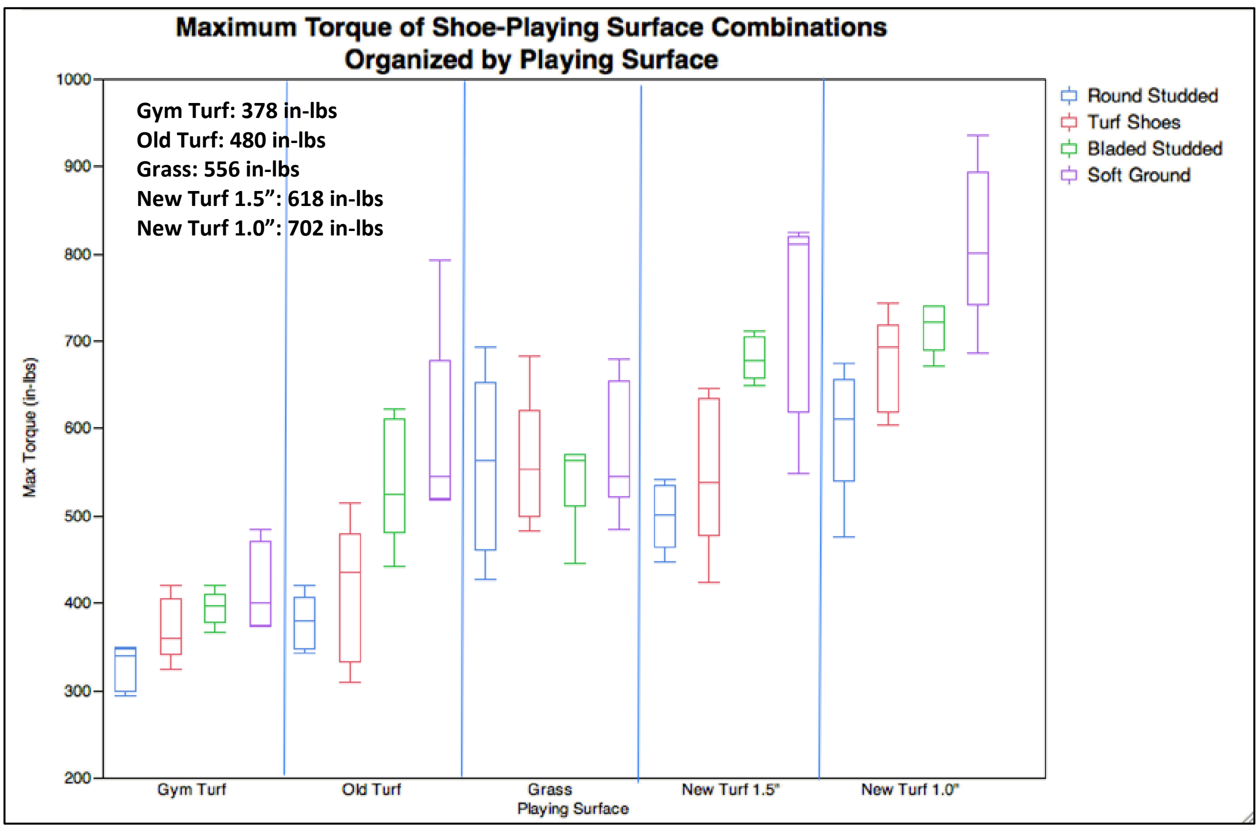



**Figure 19:** Box whisker plot displaying the maximum torque experienced by each playing surface-shoe combination organized by playing surface. The mean maximum torque values are displayed in the upper left corner.

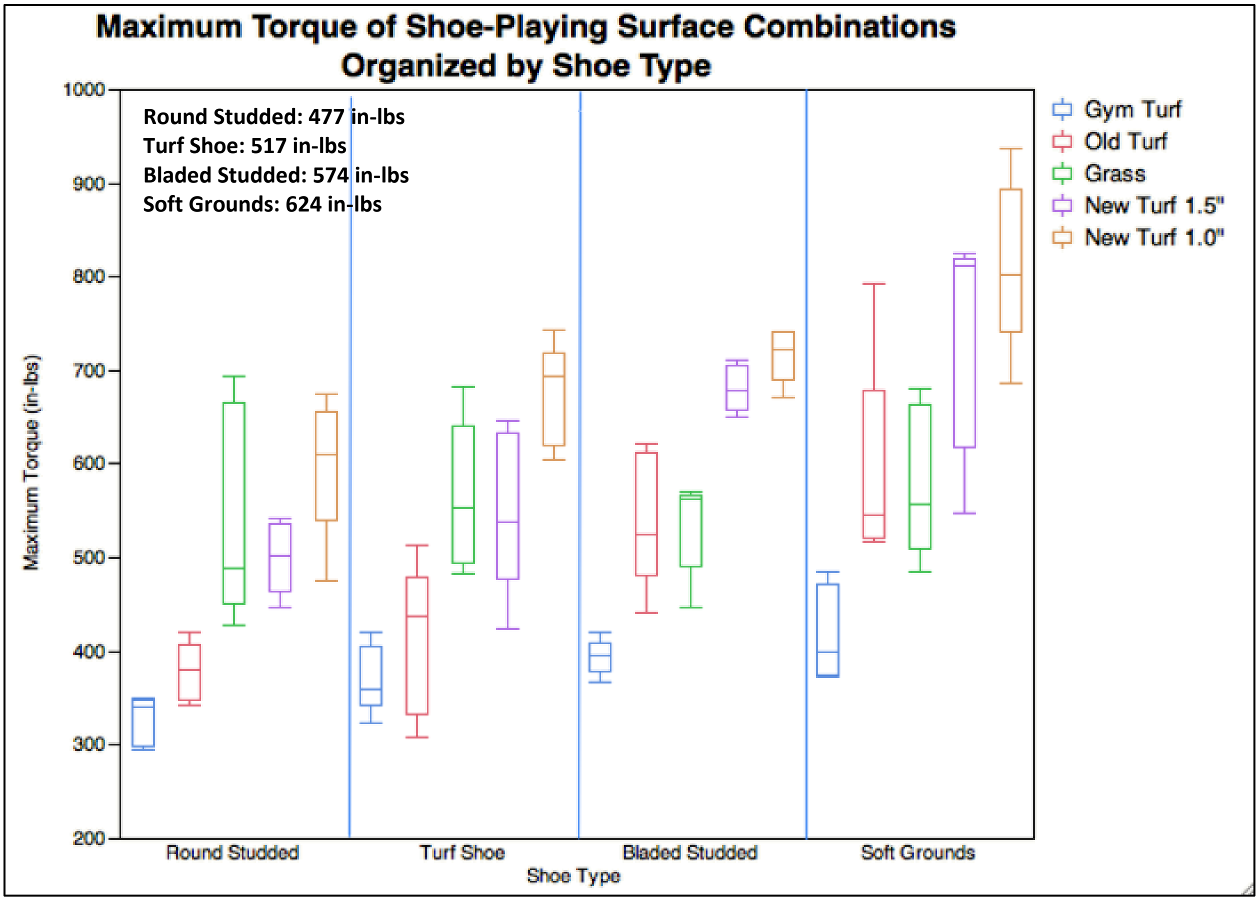



**Figure 20:** Box whisker plot displaying the maximum torque experienced by each playing surface-shoe combination organized by shoe type. The mean maximum torque values are displayed in the upper left corner.

In order to determine if the differences in torque between various shoe-playing surface combinations were statistically significant, t-tests were conducted and the P-values were recorded. Appendix D shows the P-values organized by playing surface and Appendix E shows the P-values organized by shoe type. If the P-value was below 5% it was found to be a significant difference and if the value was above 5% it was not found to be a significant difference. Tables 3 and 4 summarize the shoe-playing surface combinations that had P-values over 5% where Table 3 is organized by playing surface and Table 4 is organized by shoe type.

**Table 3:** Shows the combinations of shoe and playing surface that are not statistically different from each other organized by playing surface.

| Not Significantly Different Based on Playing Surface | | | |
|---|---|---|---|
| **Surface** | **Shoe** | **versus** | **Shoe** |
| Gym Turf | Round Studded | versus | Turf Shoe |
| | Turf Shoe | versus | Bladed Studded |
| | | versus | Soft Grounds |
| | Bladed Studded | versus | Soft Grounds |
| Old Turf | Round Studded | versus | Turf Shoe |
| | Bladed Studded | versus | Soft Grounds |
| Grass | Round Studded | versus | Turf Shoe |
| | | versus | Bladed Studded |
| | | versus | Soft Grounds |
| | Turf Shoe | versus | Bladed Studded |
| | | versus | Soft Grounds |
| | Bladed Studded | versus | Soft Grounds |
| New Turf 1.5" | Round Studded | versus | Turf Shoe |
| | Bladed Studded | versus | Soft Grounds |
| New Turf 1.0" | Round Studded | versus | Turf Shoe |
| | Turf Shoe | versus | Bladed Studded |
| | Bladed Studded | versus | Soft Grounds |

**Table 4:** Shows the combinations of shoe and playing surface that are not statistically different from each other organized by shoe type.

| Not Significantly Different Based on Shoe Type | | | |
|---|---|---|---|
| **Shoe** | **Surface** | **versus** | **Surface** |
| Round Studded | Grass | versus | New Turf 1.0" |
| | | versus | New Turf 1.5" |
| Turf Shoe | Gym Turf | versus | Old Turf |
| | Grass | versus | New Turf 1.5" |
| Bladed Studded | Old Turf | versus | Grass |
| | New Turf 1.5" | versus | New Turf 1.0" |
| Soft Grounds | Old Turf | versus | Grass |
| | | versus | New Turf 1.5" |
| | New Turf 1.5" | versus | New Turf 1.0" |

In order to more clearly see the trends along with which combinations are statistically significant from one another, Tables 5 and 6 were created. In these tables, if the colored boxes are touching then the difference in the maximum torque values were not statistically significant from each other.

**Table 5:** Shows the general trends for increasing torque of each combination, organized by playing surface, and how the values statistically differ. Areas where the colored boxes touch represent combinations that not statistically different from each other.

<table>
<tr><th></th><th colspan="5">Maximum Torque Trends with Statistical Significance</th></tr>
<tr><th rowspan="21">Generally Increasing Maximum Torque</th><th>Playing Surface</th><th colspan="4">Increasing Maximum Torque</th></tr>
<tr><td rowspan="4">Gym Turf</td><td>Round Studded</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Turf Shoe</td></tr>
<tr><td></td><td></td><td colspan="2">Bladed Studded</td></tr>
<tr><td></td><td></td><td colspan="2">Soft Grounds</td></tr>
<tr><td rowspan="4">Old Turf</td><td colspan="2">Round Studded</td><td></td><td></td></tr>
<tr><td colspan="2">Turf Shoe</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Bladed Studded</td></tr>
<tr><td></td><td></td><td colspan="2">Soft Grounds</td></tr>
<tr><td rowspan="4">Grass</td><td colspan="4">Round Studded</td></tr>
<tr><td colspan="4">Turf Shoe</td></tr>
<tr><td colspan="4">Bladed Studded</td></tr>
<tr><td colspan="4">Soft Grounds</td></tr>
<tr><td rowspan="4">New Turf 1.5”</td><td colspan="2">Round Studded</td><td></td><td></td></tr>
<tr><td colspan="2">Turf Shoe</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Bladed Studded</td></tr>
<tr><td></td><td></td><td colspan="2">Soft Grounds</td></tr>
<tr><td rowspan="4">New Turf 1.0”</td><td>Round Studded</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Turf Shoe</td><td></td></tr>
<tr><td></td><td colspan="3">Bladed Studded</td></tr>
<tr><td></td><td></td><td></td><td>Soft Grounds</td></tr>
</table>

**Table 6:** Shows the general trends for increasing torque of each combination, organized by shoe type, and how the values statistically differ. Areas where the colored boxes touch represent combinations that not statistically different from each other.

<table>
<tr><th></th><th colspan="5">Maximum Torque Trends with Statistical Significance</th></tr>
<tr><th rowspan="21">Generally Increasing Maximum Torque</th><th>Shoe Type</th><th colspan="4">Increasing Maximum Torque</th></tr>
<tr><td rowspan="5">Round Studded</td><td>Gym Turf</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Old Turf</td><td></td><td></td></tr>
<tr><td></td><td></td><td>New Turf 1.5”</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Grass</td></tr>
<tr><td></td><td></td><td></td><td>New Turf 1.0”</td></tr>
<tr><td rowspan="5">Turf Shoe</td><td colspan="2">Gym Turf</td><td></td><td></td></tr>
<tr><td colspan="2">Old Turf</td><td></td><td></td></tr>
<tr><td></td><td></td><td>New Turf 1.5”</td><td></td></tr>
<tr><td></td><td></td><td>Grass</td><td></td></tr>
<tr><td></td><td></td><td></td><td>New Turf 1.0”</td></tr>
<tr><td rowspan="5">Bladed Studded</td><td>Gym Turf</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Old Turf</td><td></td></tr>
<tr><td></td><td colspan="2">Grass</td><td></td></tr>
<tr><td></td><td></td><td></td><td>New Turf 1.5”</td></tr>
<tr><td></td><td></td><td></td><td>New Turf 1.0”</td></tr>
<tr><td rowspan="5">Soft Grounds</td><td>Gym Turf</td><td></td><td></td><td></td></tr>
<tr><td></td><td>Grass</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Old Turf</td><td></td></tr>
<tr><td></td><td></td><td></td><td>New Turf 1.5”</td></tr>
<tr><td></td><td></td><td></td><td>New Turf 1.0”</td></tr>
</table>

## Discussion

The data from this study clearly indicated that the shoe type and playing surface have an impact on the maximum torque experienced when a compressive load and rotation are applied between them. More specifically, it was found that the playing surface had a greater impact on the maximum torque value than shoe type. In addition, all the combinations were determined to exceed the published torsional value that results in failure of ACL's of 331 ± 148.7 in-lbs given the input parameters of 225 pounds normal load, 45° rotation at a rate of 45°/s [6, 10]. Since there are many other internal and external factors that could influence the torque on the ACL, the measured torque values are not accurate values by themselves; however, the maximum torque values of the various combinations can be analyzed relative to each other.

**Playing Surface**

There are many factors that are involved in choosing a playing surface: cost of installation and maintenance, resistance to weather change, versatility, amount of time it can be played on, quality and consistency of the surface, how the surface feels to the players and traction. Traction is necessary for players to perform maneuvers during game play; however, too much traction can lead to increased torque on the knee, putting players at a higher risk for injury.

This study determined that generally the maximum torque experienced by the shoe increased in the following order: Gym Turf, Old Turf, Grass, New Turf 1.5" and New Turf 1.0". Gym Turf is thatched turf with 1/2" blades and foam backing which is commonly used in gym/performance centers. This surface does not contain rubber infill, leading to low traction that causes players to slip. Although this surface experienced the lowest torque and would be the best option to reduce ACL injuries, players would not be able to perform maneuvers in game like

conditions. In addition, it does not contain rubber infill to provide cushion which could result in more impact related joint injuries if played on frequently.

Old Turf represents ten year old slit film artificial turf surface with a small amount of rubber infill that was used in an indoor soccer facility. The slit film turf blades and rubber infill provide more traction than that of Gym Turf while causing a relatively low torque on the body. This surface provides the traction needed for game play; however, similar to Gym Turf, the surface is considered to be "hard" which could cause impact joint injuries and discomfort in players.

Grass represents Kentucky bluegrass samples grown in 2" of soil. This study shows grass has more traction than Gym Turf and Old Turf but less than the New Turf samples. In addition, it was found that the maximum torque experienced by each shoe on Grass was statistically the same. This shows that Grass provides enough traction for maneuvers in games and it deforms as needed so the torque levels don't exceed a threshold value around 550 in-lbs. In other words, the Grass samples acted like a torque neutralizer between all the different shoe types. Grass acts as an ideal surface, providing cushion to decrease impact on joints, the traction needed for game play and having the ability to deform so a threshold torque value is not exceeding which would stress the ACL.

New Turf 1.0" and New Turf 1.5" are new slit film artificial turf samples with 1.0" and 1.5" rubber infill depths. Both of these surfaces generally produced a higher maximum torque than the previous three samples; however, the 1.5" rubber infill depth had less torque than the 1.0" depth. This difference could be due to wear on the surface because the 1.5" tests were conducted on the same sample as the 1.0" were previously. A more probable explanation is that

the increased rubber depth allowed the playing surface to deform more, reducing the torque produced. Since the artificial turf fibers do not rip out or deform easily, it is possible to decrease the torque by reducing contact with the fibers by adding more rubber infill; however, adding too much infill may affect traction and game play.

**Shoe Type**

There are many types of soccer cleats currently on the market. This study generalized all of these cleats into four types that produced maximum torque values that increase as follows: Round Studded, Turf Shoe, Bladed Studded and Soft Grounds. Certain shoes are not designed to be played on some surfaces they were tested on, such as turf shoes on grass and soft ground cleats on artificial turf; however, they were tested anyways to obtain complete sets of data.

Round Studded cleats and Turf Shoes experienced statistically similar maximum torque values on all playing surface samples. The Round Studded cleats were fairly worn down which could be the reason that they produced similar torque to Turf Shoes, which were hypothesized to produce the least amount of torque. Another explanation for the low torque values could be due to the rounded shape of the studs which allow the shoe to turn more easily in the playing surfaces compared to Bladed Studded cleats. In addition, Turf Shoes have small ridges on the bottoms, not studs, which allows the shoes to grip but not get "stuck" in the playing surfaces.

Bladed Studded cleats and Soft Grounds also produced statistically similar maximum torque values on all of the playing surfaces; however, these values were greater than the torque values experienced by Round Studded cleats and Turf Shoes. As previously mentioned, the difference in torque between Round Studded cleats and Bladed Studded could be due to the shape where a rounder shape stud allows the shoe to rotate more easily compared to longer

bladed studs. In addition, the differences in torque between Round Studded cleats and Soft Grounds which both have rounded studs could be due to the depth of the studs. Soft Grounds have much deeper studs that increase the surface area in contact with the playing surface, increasing traction and maximum torque experienced by the shoe.

## Conclusions and Recommendations

After considering the torque and feel of the surfaces on players' bodies, the optimal combinations of shoe type and playing surface can be determined. According to the data collected, wearing round studded cleats or turf shoes on old artificial turf surfaces provides the best traction for maneuvers in games while still allowing the shoe to slip out when dangerous torque levels are reached. On the other hand, bladed studded cleats or soft grounds on new turf without adequate rubber infill results in too much traction that can result in injury to the players.

Gym Turf does not provide enough traction or cushion for athletes and should not be installed for game play. Old Turf provides the traction needed for game play while producing relatively safe torque values; however, the surface does not have cushion needed to limit impact joint injuries. The New Turf samples contained enough rubber infill to provide cushion and traction, but the torque experienced was much greater than the other turf samples. The torque experienced on natural grass falls in between these two extremes and is not affected significantly by the type of shoe worn.

Natural grass provides all the benefits of cushion, traction and the ability to deform in order to reduce injuries. Based on these three criteria, playing on natural grass with round studded cleats is recommended; however, in the modern athletic domain avoiding playing on artificial turf surfaces is difficult. To limit stress on the ACL when playing on artificial turf surfaces, wearing turf shoes or round studded cleats is recommended. These recommendations along with other data presented in this report can help prevent ACL tears in soccer players by helping them choose appropriate footwear for the surface on which they are playing.

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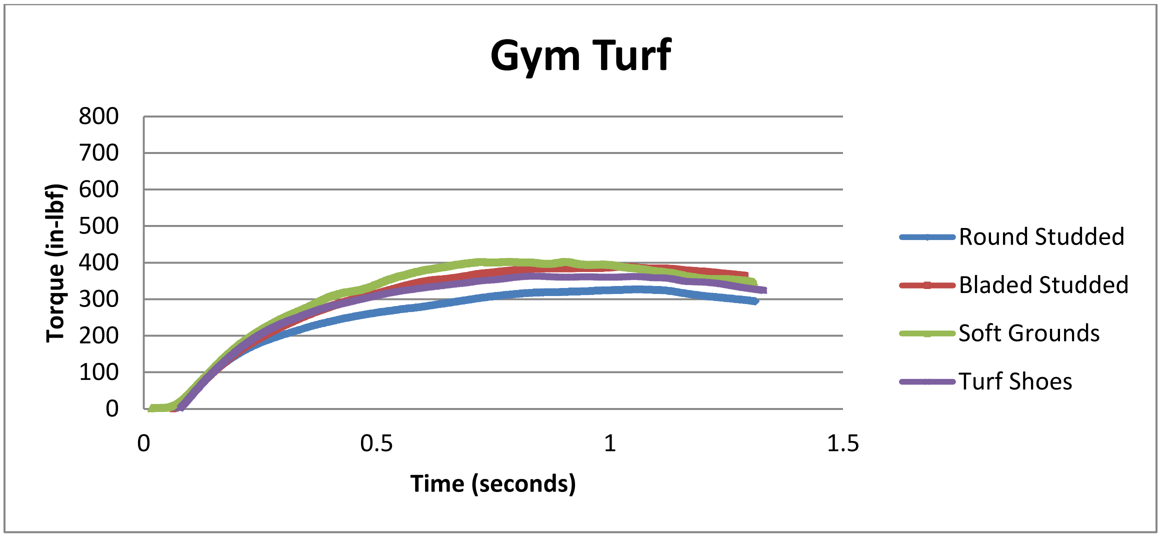
# Appendices

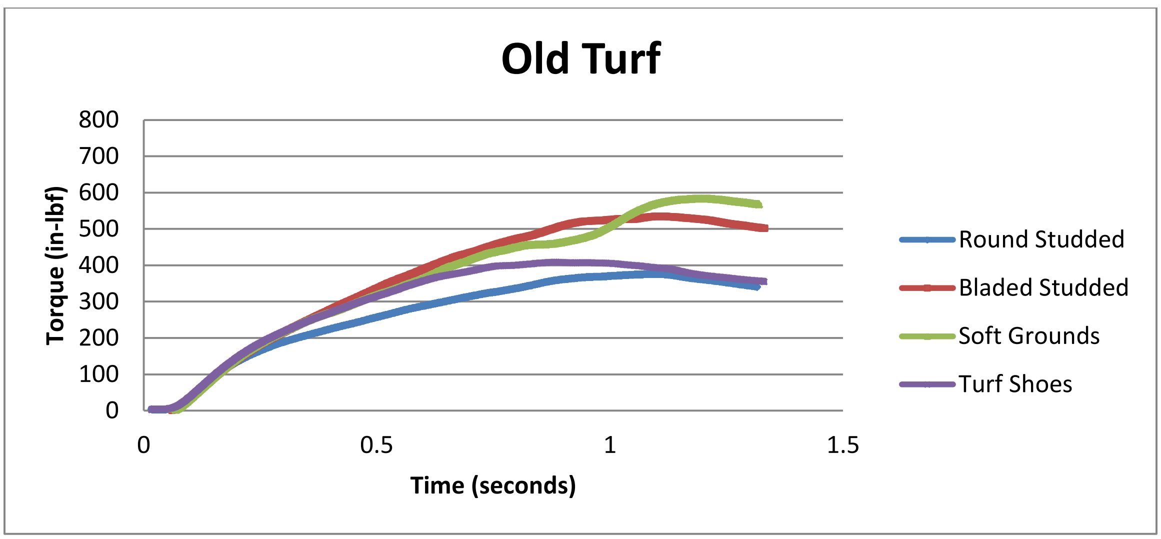
**Appendix A:** Complete testing order list consisting of Round Studded cleats (rs), Bladed Studded cleats (bs), Soft Grounds (sg) and Turf Shoes (ts) tested on Gym Turf (gt), Old Turf (ot), New Turf 1.0" (nt1) and New Turf 1.5" (nt1.5).

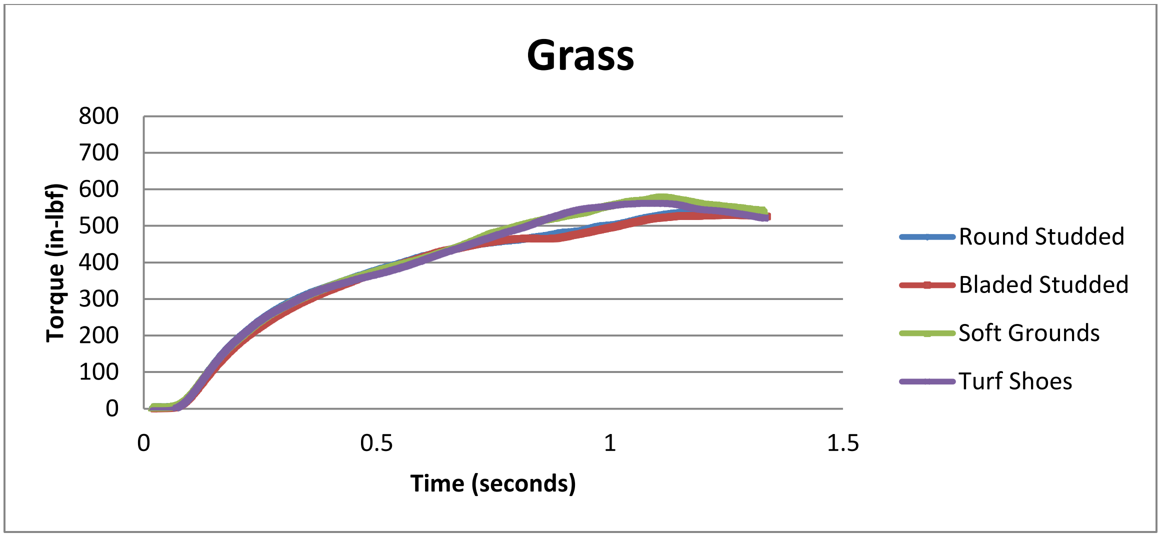
| Testing Order # | Shoe | Surface | Trial # | Testing Order # | Shoe | Surface | Trial # |
|---|---|---|---|---|---|---|---|
| **Grass Testing-November 2013** | | | | | | | |
| 1 | rs | grass | 1 | 11 | sg | grass | 3 |
| 2 | rs | grass | 2 | 12 | sg | grass | 4 |
| 3 | rs | grass | 3 | 13 | sg | grass | 5 |
| 4 | sg | grass | 1 | 14 | bs | grass | 4 |
| 5 | sg | grass | 2 | 15 | bs | grass | 5 |
| 6 | bs | grass | 1 | 16 | ts | grass | 3 |
| 7 | bs | grass | 2 | 17 | ts | grass | 4 |
| 8 | bs | grass | 3 | 18 | ts | grass | 5 |
| 9 | ts | grass | 1 | 19 | rs | grass | 4 |
| 10 | ts | grass | 2 | 20 | rs | grass | 5 |
| **Artificial Turf Testing with New Turf 1.0" – January 2014** | | | | | | | |
| 21 | rs | nt | 1 | 41 | sg | nt | 4 |
| 22 | rs | gt | 1 | 42 | sg | gt | 2 |
| 23 | rs | nt | 2 | 43 | sg | ot | 2 |
| 24 | rs | ot | 1 | 44 | sg | nt | 5 |
| 25 | rs | nt | 3 | 45 | sg | gt | 3 |
| 26 | bs | nt | 1 | 46 | rs | gt | 2 |
| 27 | bs | ot | 1 | 47 | rs | nt | 4 |
| 28 | bs | gt | 1 | 48 | rs | ot | 2 |
| 29 | bs | nt | 2 | 49 | rs | nt | 5 |
| 30 | bs | gt | 2 | 50 | rs | gt | 3 |
| 31 | sg | ot | 1 | 51 | ts | nt | 3 |
| 32 | sg | nt | 1 | 52 | ts | nt | 4 |
| 33 | sg | gt | 1 | 53 | ts | gt | 2 |
| 34 | sg | nt | 2 | 54 | ts | ot | 3 |
| 35 | sg | nt | 3 | 55 | ts | nt | 5 |
| 36 | ts | nt | 1 | 56 | bs | ot | 2 |
| 37 | ts | ot | 1 | 57 | bs | nt | 3 |
| 38 | ts | nt | 2 | 58 | bs | nt | 4 |
| 39 | ts | ot | 2 | 59 | bs | gt | 3 |
| 40 | ts | gt | 1 | 60 | bs | nt | 5 |

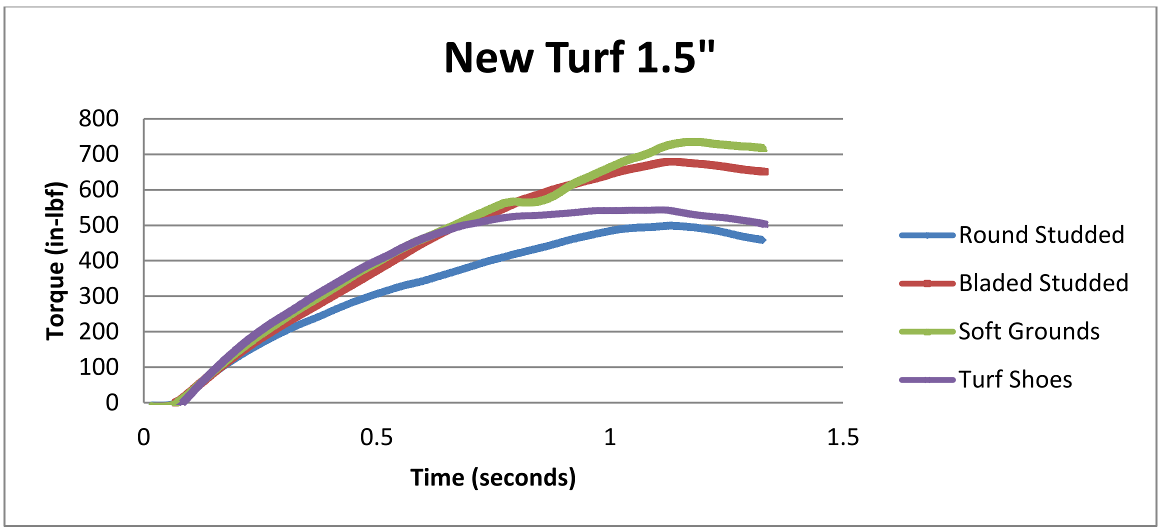
| Artificial Turf Testing with New Turf 1.5" – January 2014 | | | | | | | |
|---|---|---|---|---|---|---|---|
| 61 | ts | ot | 4 | 81 | bs | nt1.5 | 3 |
| 62 | ts | nt1.5 | 1 | 82 | bs | gt | 5 |
| 63 | ts | gt | 3 | 83 | bs | nt1.5 | 4 |
| 64 | ts | nt1.5 | 2 | 84 | bs | ot | 5 |
| 65 | ts | gt | 4 | 85 | bs | nt1.5 | 5 |
| 66 | sg | nt1.5 | 1 | 86 | ts | nt1.5 | 3 |
| 67 | sg | nt1.5 | 2 | 87 | ts | nt1.5 | 4 |
| 68 | sg | ot | 3 | 88 | ts | gt | 5 |
| 69 | sg | gt | 4 | 89 | ts | ot | 5 |
| 70 | sg | nt1.5 | 3 | 90 | ts | nt1.5 | 5 |
| 71 | bs | gt | 4 | 91 | rs | ot | 4 |
| 72 | bs | nt1.5 | 1 | 92 | rs | nt1.5 | 4 |
| 73 | bs | ot | 3 | 93 | rs | ot | 5 |
| 74 | bs | nt1.5 | 2 | 94 | rs | nt1.5 | 5 |
| 75 | bs | ot | 4 | 95 | rs | gt | 5 |
| 76 | rs | nt1.5 | 1 | 96 | sg | ot | 4 |
| 77 | rs | ot | 3 | 97 | sg | nt1.5 | 4 |
| 78 | rs | nt1.5 | 2 | 98 | sg | ot | 5 |
| 79 | rs | gt | 4 | 99 | sg | gt | 5 |
| 80 | rs | nt1.5 | 3 | 100 | sg | nt1.5 | 5 |

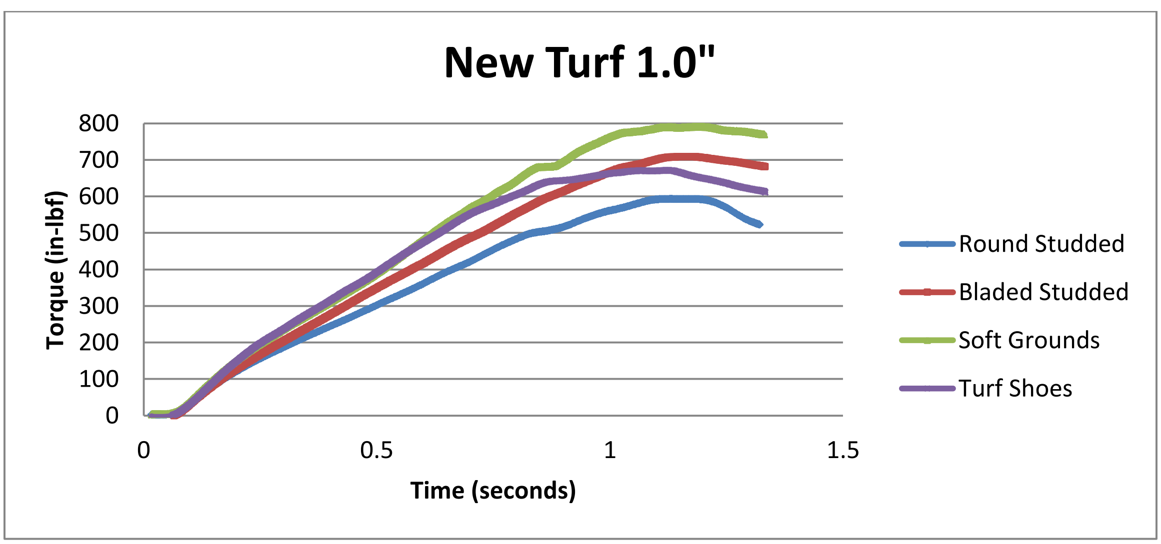
**Appendix B:** Typical torque curves of different shoes on various playing surfaces sorted by the playing surface.



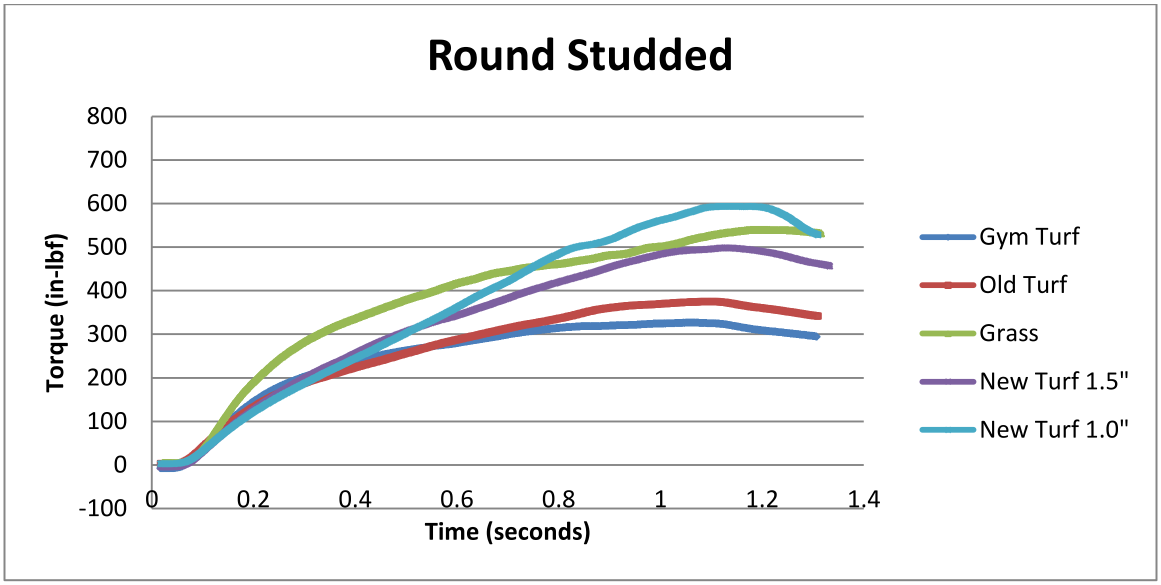



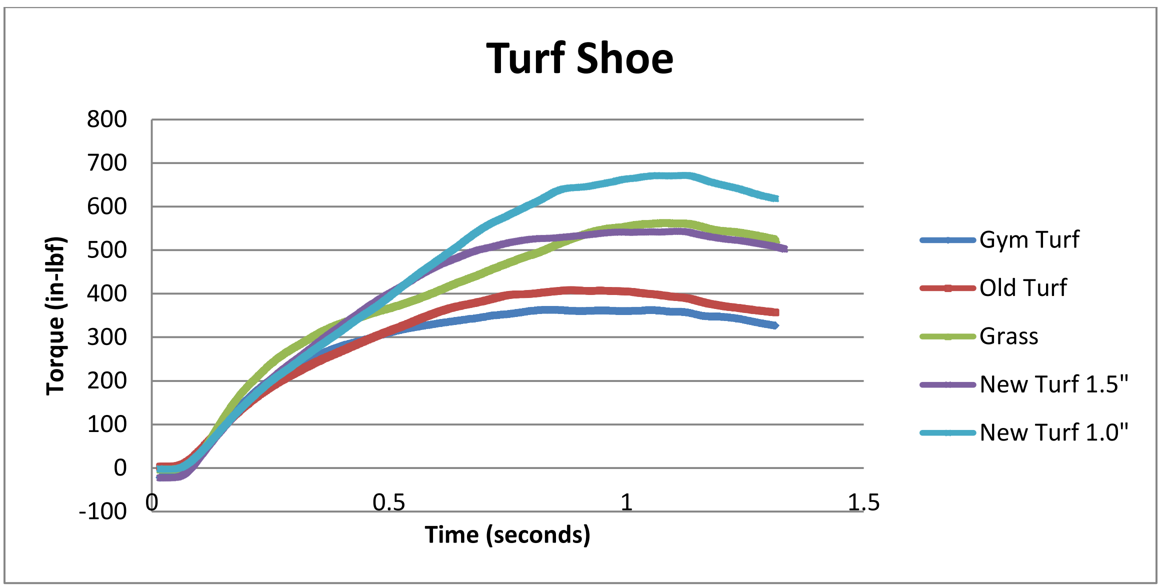

Grass
800
700
600
500
400
300
200
100
0
Torque (in-lbf)
0
0.5
1
1.5
Time (seconds)
Round Studded
Bladed Studded
Soft Grounds
Turf Shoes

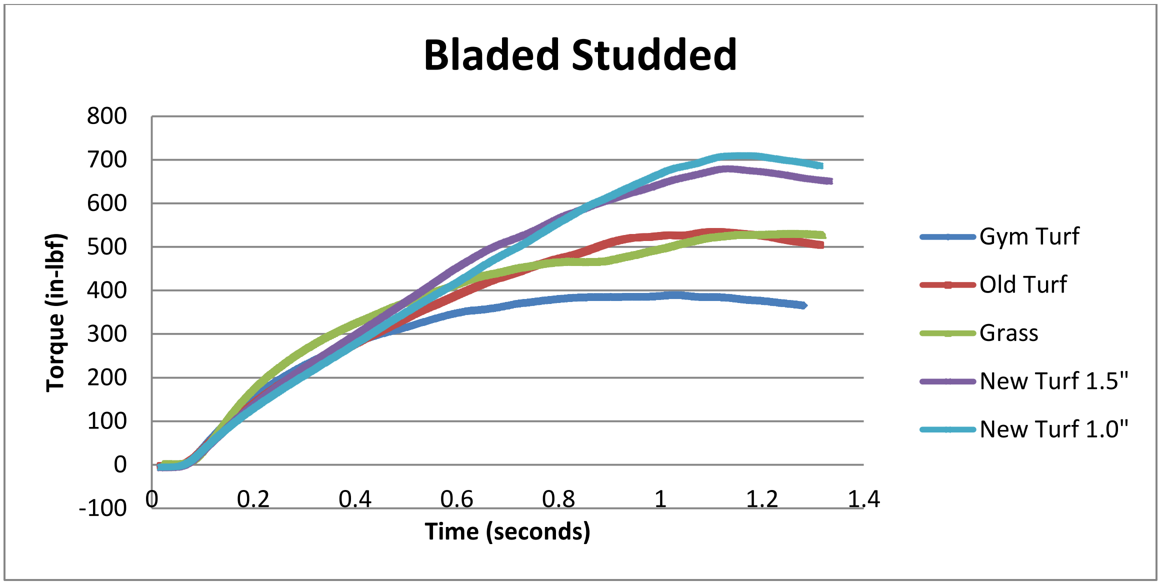

New Turf 1.5"
800
700
600
500
400
300
200
100
0
Torque (in-lbf)
0
0.5
1
1.5
Time (seconds)
Round Studded
Bladed Studded
Soft Grounds
Turf Shoes

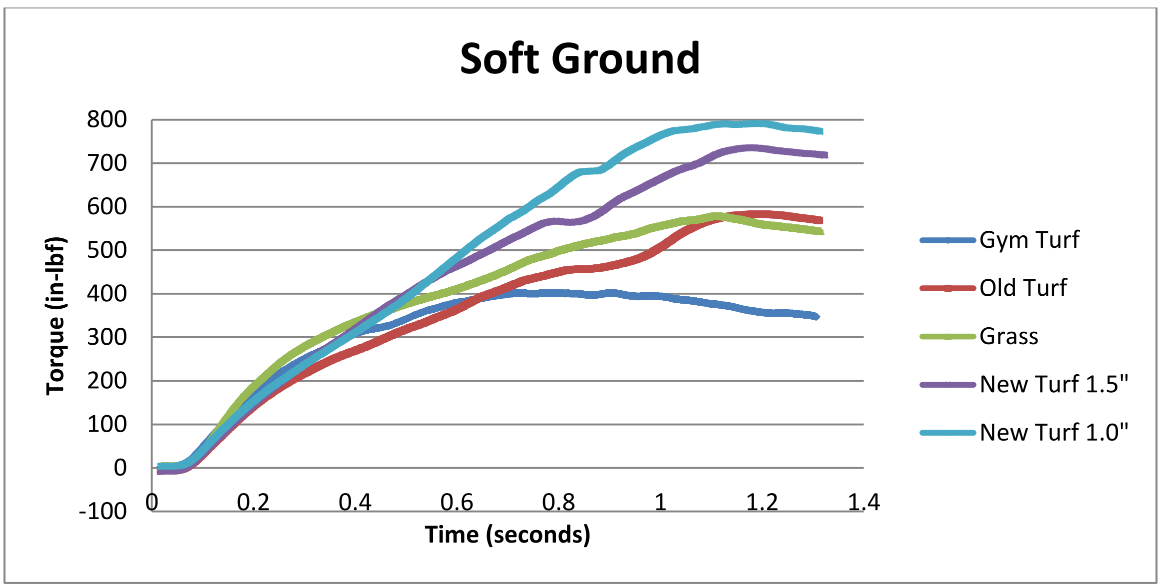

New Turf 1.0"
800
700
600
500
400
300
200
100
0
Torque (in-lbf)
0
0.5
1
1.5
Time (seconds)
Round Studded
Bladed Studded
Soft Grounds
Turf Shoes

**<u>Appendix C:</u>** Typical torque curves of different shoes on various playing surfaces sorted by the shoe type.




Bladed Studded
800
700
600
500
400
300
200
100
0
-100
Torque (in-lbf)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time (seconds)
Gym Turf
Old Turf
Grass
New Turf 1.5"
New Turf 1.0"


Soft Ground
800
700
600
500
400
300
200
100
0
-100
Torque (in-lbf)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time (seconds)
Gym Turf
Old Turf
Grass
New Turf 1.5"
New Turf 1.0"

**Appendix D:** T-test combinations and P-values organized by playing surface.

| Playing Surface | Shoe | versus | Shoe | P-value |
|---|---|---|---|---|
| Gym Turf | Round Studded | versus | Turf Shoe | 0.05976 |
| | | versus | Bladed Studded | 0.00164 |
| | | versus | Soft Grounds | 0.00689 |
| | Turf Shoe | versus | Bladed Studded | 0.23606 |
| | | versus | Soft Grounds | 0.12719 |
| | Bladed Studded | versus | Soft Grounds | 0.35543 |
| Old Turf | Round Studded | versus | Turf Shoe | 0.40262 |
| | | versus | Bladed Studded | 0.00000 |
| | | versus | Soft Grounds | 0.00445 |
| | Turf Shoe | versus | Bladed Studded | 0.02716 |
| | | versus | Soft Grounds | 0.02329 |
| | Bladed Studded | versus | Soft Grounds | 0.46883 |
| Grass | Round Studded | versus | Turf Shoe | 0.75155 |
| | | versus | Bladed Studded | 0.88058 |
| | | versus | Soft Grounds | 0.58402 |
| | Turf Shoe | versus | Bladed Studded | 0.51097 |
| | | versus | Soft Grounds | 0.77022 |
| | Bladed Studded | versus | Soft Grounds | 0.32915 |
| New Turf 1.5" | Round Studded | versus | Turf Shoe | 0.25685 |
| | | versus | Bladed Studded | 0.00002 |
| | | versus | Soft Grounds | 0.00290 |
| | Turf Shoe | versus | Bladed Studded | 0.01321 |
| | | versus | Soft Grounds | 0.02341 |
| | Bladed Studded | versus | Soft Grounds | 0.33116 |
| New Turf 1.0" | Round Studded | versus | Turf Shoe | 0.11805 |
| | | versus | Bladed Studded | 0.01275 |
| | | versus | Soft Grounds | 0.00372 |
| | Turf Shoe | versus | Bladed Studded | 0.16650 |
| | | versus | Soft Grounds | 0.01821 |
| | Bladed Studded | versus | Soft Grounds | 0.05023 |

**Appendix E:** T-test combinations with resulting P-values organized by shoe type.

| Shoe | Playing Surface | versus | Playing Surface | P-value |
|---|---|---|---|---|
| Round Studded | Gym Turf | versus | Old Turf | 0.02203 |
| | | versus | Grass | 0.00337 |
| | | versus | New Turf 1.5" | 0.00003 |
| | | versus | New Turf 1.0" | 0.00006 |
| | Old Turf | versus | Grass | 0.01438 |
| | | versus | New Turf 1.5" | 0.00054 |
| | | versus | New Turf 1.0" | 0.00029 |
| | Grass | versus | New Turf 1.5" | 0.44032 |
| | | versus | New Turf 1.0" | 0.38328 |
| | New Turf 1.5" | versus | New Turf 1.0" | 0.02854 |
| Turf Shoe | Gym Turf | versus | Old Turf | 0.32543 |
| | | versus | Grass | 0.00114 |
| | | versus | New Turf 1.5" | 0.00269 |
| | | versus | New Turf 1.0" | 0.00001 |
| | Old Turf | versus | Grass | 0.01656 |
| | | versus | New Turf 1.5" | 0.02948 |
| | | versus | New Turf 1.0" | 0.00031 |
| | Grass | versus | New Turf 1.5" | 0.81965 |
| | | versus | New Turf 1.0" | 0.03573 |
| | New Turf 1.5" | versus | New Turf 1.0" | 0.02983 |
| Bladed Studded | Gym Turf | versus | Old Turf | 0.00222 |
| | | versus | Grass | 0.00046 |
| | | versus | New Turf 1.5" | 0.00000 |
| | | versus | New Turf 1.0" | 0.00000 |
| | Old Turf | versus | Grass | 0.87495 |
| | | versus | New Turf 1.5" | 0.00348 |
| | | versus | New Turf 1.0" | 0.00101 |
| | Grass | versus | New Turf 1.5" | 0.00047 |
| | | versus | New Turf 1.0" | 0.00014 |
| | New Turf 1.5" | versus | New Turf 1.0" | 0.06954 |

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|---|---|---|---|---|
| Soft Grounds | Gym Turf | versus | Old Turf | 0.01672 |
| | | versus | Grass | 0.00519 |
| | | versus | New Turf 1.5" | 0.00057 |
| | | versus | New Turf 1.0" | 0.00003 |
| | Old Turf | versus | Grass | 0.90025 |
| | | versus | New Turf 1.5" | 0.08032 |
| | | versus | New Turf 1.0" | 0.00890 |
| | Grass | versus | New Turf 1.5" | 0.04087 |
| | | versus | New Turf 1.0" | 0.00259 |
| | New Turf 1.5" | versus | New Turf 1.0" | 0.28412 |