Investigating the Effect of Shoe-surface Interaction on Traction; Analyzing Four Different Playing Fields with a Possible Correlation to Non-contact Lower Extremity Injury

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Abstract:

Lower extremity injuries, including injuries to anything below the waist (ACL tear, Ankle breaks, Femur fractures, etc…), are one of the most commonly seen injuries in sports. When a person themselves generates excessive loading and movement this creates stress which in turn can result in a non-contact injury to occur.   Sports require these rapid movements in all directions and the ability to change direction quickly is essential. Athlete's ability to accelerate and decelerate is largely influenced by available traction. One extrinsic factor that can have a large effect on athletic performance is the playing surface. Different surfaces have different coefficients of friction, or what affects the force it takes to move one surface horizontally over another.. In addition it is important for athletes to choose the proper footwear to prevent sliding and give the player proper traction. It is expected to find that natural grass playing surfaces will obtain higher coefficients, or more traction, leading to a possible decrease in athletic non-contact injuries to the lower extremity. The purpose of this study is to find what playing surface could be the safest for athletes, with a possible correlation to reduce injury in sports. This study found that natural grass playing surfaces exhibited a higher μ at all testing locations when compared to artificial turf, with a significance found between mean values of both groups (turf vs grass). This could possibly lead to an increased athletic performance on grass surfaces and a possible reduction in rates of injuries for athletes.

Introduction:

Lower extremity injuries, including injuries to anything below the waist (ACL tear, Ankle breaks, Femur fractures, etc…), are one of the most commonly seen injuries in sports. A study conducted by Jonathan Webb (2000), predicts to see 500 significant knee injuries a year throughout a population of 400,000. Sports play a major role in society and entertainment as well as having the possibility to be rewarding to athletes who make it to the higher level. Sports such as snowboarding, skiing, and mountain biking have shown a growing increase in popularity despite having such high rates of injury (Majewski, 2006). According to Bing Yu (2007), most lower extremity injuries occur in non-contact situations. Non-contact injuries occur the most on average during a sudden deceleration, landing, or pivoting action. When a person themselves generates excessive loading and movement this creates stress which in turn can result in a non-contact injury to occur. Injuries to the lower extremity, especially the ankle and knee, are the most common cause of loss of practice and game time among athletes (Thacker, 2003). The study analyzing "Prevention of Knee Injuries" by SB Thacker (2003) found ACL injuries result in 50,000 surgeries annually in the United States alone. Knee injuries occur most commonly during basketball and volleyball from its excessive landing and cutting maneuvers, as well as soccer, football, and rugby due to both cutting and direct contact. Extrinsic factors, which are sport specific, include equipment, playing surface, shoes, and weather conditions (Stroup, 2003). These factors can influence an athlete's ability to perform, therefore leading to an effect on injury rates. Sports require rapid movements in all directions and the ability to change direction quickly is essential. An estimated 1500-3100 meters of running is performed every professional soccer match/game; during 10% of this the athlete is accelerating and during 7% the athlete is decelerating (Thomson, 2019). Athlete's ability to accelerate and decelerate is largely influenced by available traction. One extrinsic factor that can have a large effect on athletic performance is the playing surface. Different surfaces have different coefficients of friction, or what affects the force it takes to move one surface horizontally over another. One example of this was found in a study conducted by J. Dragoo (2012) where it was found that non-contact lower extremity injuries were more likely to occur on turf when compared to natural grass playing surface. In this study, despite being maintenance and cost effective, turf had a negative impact on players' traction which in turn led to an increase in injury (Dragoo, 2012). Another example of an extrinsic factor that plays a major role in players traction as well as injury is footwear. Shoes are designed to attenuate impact loading and promote stability (Sinclair, 2017). In this study, Sinclair (2017) also found that It is important for athletes to choose the proper footwear to prevent sliding and give the player proper traction. Translational traction, or the horizontal force required to overcome the resistance between the shoe outsole and playing surface, has a direct effect on availability of traction . In this study, it has been found that a higher/increase in translation traction led to an improved performance . Optimal shoe-surface conditions should maintain translational or playing performance A study in 2019 by Thompson et al. Traction varies according to shoe type as well as the characteristics of the playing surface. The results from this journal shows that it is expected for natural grass playing surfaces to have higher rates of available traction in comparison to artificial turf, this could result in a positive effect on rates of non-contact injuries to the lower extremity in sports.

Method:

Two different athletic playing surfaces were tested on four different sports fields. The first site, a natural grass pitch at Hudson Falls High School, was a freshly cut grass football field. The second testing site, an artificial turf pitch at Glens Falls High School, was a slightly worn turf football field containing rubber infill. The first two testing sites were in Upstate New York and trials were conducted in the afternoon. The third location, the second artificial turf pitch at Ocean City High School, was a fairly new turf football field containing cork infill. The fourth, also at Ocean City High School, was a grass practice football field. These testing sites were in New Jersey and trials were conducted throughout scattered times.Weather conditions were calculated prior to testing at each site. Extrinsic factors that may affect shoe-surface interactions including temperature, humidity, time, and condition of the field itself were taken down for further analysis on the effect they may have had.

All images provided by Doyle, 2022

Hudson Falls High School Football Field
Date - 8/18/22
Temperature- 79°F
Rainfall in last 24 hours- 25"
Humidity- 44%
Freshly mowed grass
Time - 5:00 pm - 6:30 pm
Natural Grass Playing Surface

Glens Falls High School Football Field
Date - 8/18/22
Temperature- 75°F
Rainfall in last 24 hours- 25"
Humidity- 55%
Worn turf (rubber infill)
Time - 6:45 pm - 8:30 pm
Artificial Turf Playing Surface

Figure 1, Preliminary extrinsic factors and weather conditions HFHS and GFHS (Doyle, 2022)

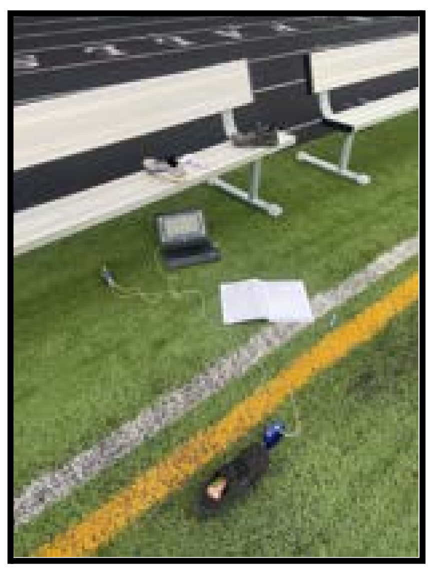
Ocean City High School Football Field
Date - 8/24/22
Temperature- 85°F
Rainfall in last 24 hours- 0"
Humidity- 48%
New turf (cork infill) installed in 2016
Time - 1:30 pm - 2:35 pm
Artificial Turf Playing Surface

Ocean City High School Practice Football Field
Date - 8/25/22
Temperature- 71°F
Rainfall in last 24 hours- 0"
Humidity- 78%
Grown grass (slightly wet - morning dew)
Time - 8:00 am - 9:30 am
Natural Grass Playing Surface

Figure 2, Preliminary extrinsic factors and weather conditions OCHS turf vs grass (Doyle, 2022)

Three different mens athletic training shoes manufactured by Nike and Puma were tested and kept constant throughout the experiment. The Nike Air Zoom Pegasus ©, Nike Zoom ©, and Puma Axelions © were the three shoes tested. Prior to testing, each shoe was cleaned thoroughly with a solution containing warm water and dish soap to obtain the most accurate results. After the conclusion of trials at each individual testing site each shoe's outsole was cleaned again using the same soapy solution. Each shoe was given a rating on condition ranging from new to old and this was assessed regarding outsole wear prior to the experiment. The shoes were categorized regarding outsole wear to see if this could have any correlation to an increase or decrease in traction when conducting post-data collection analysis.

In order to obtain the force of friction, in Newtons, a PS-2104 force sensor was used. The force sensor contains a PASPORT Link Device that was inserted into a computer, in the case of this experiment a chromebook was used. The device was then attached to the front, toe cap, of each shoe by means of the metal hook on the front of the force sensor. A 2 pound Reebok dumbbell was placed in the full foot of the shoe, laying down parallel to the insole, to represent the downward force of an athlete. This weight is applied through the shoe directly into the playing surface below and did not change during the experiment.



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Once set-up was complete, measurements were taken by pulling the shoe, using the attached force sensor, across the surface horizontally. Each shoe was pulled at a slow, constant speed, parallel to the surface, the entire pull at each location. The shoe would initially be pulled while at rest until the shoe-surface tension breaks and then continued to be pulled constantly while in motion for a few seconds.

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From this trial the force of static friction (F□), could be found from the maximum point on the graph. This peak of the graph shows a sudden spike in force as the friction between the surface and shoe increases and then drops allowing for the shoe to be set in motion. Following this point, the average of the flat portion of the graph would be taken to find the force of kinetic friction (F□). The average of this segment of the graph represents how much resistance the shoe-surface experiences as the shoe is in motion moving horizontally. These two values are important because they allow for essential maneuvers such as an athlete's ability to cut, stop, accelerate and decelerate. All recorded values had an accuracy of ±1% over a range of ±50 Newtons. All trials were conducted by a single operator and pulled by hand. Operator practiced maintaining a constant pull prior to commencing the experiment. A set of 10 trials was conducted for each shoe at all 4 separate testing sites, 120 trials in total.

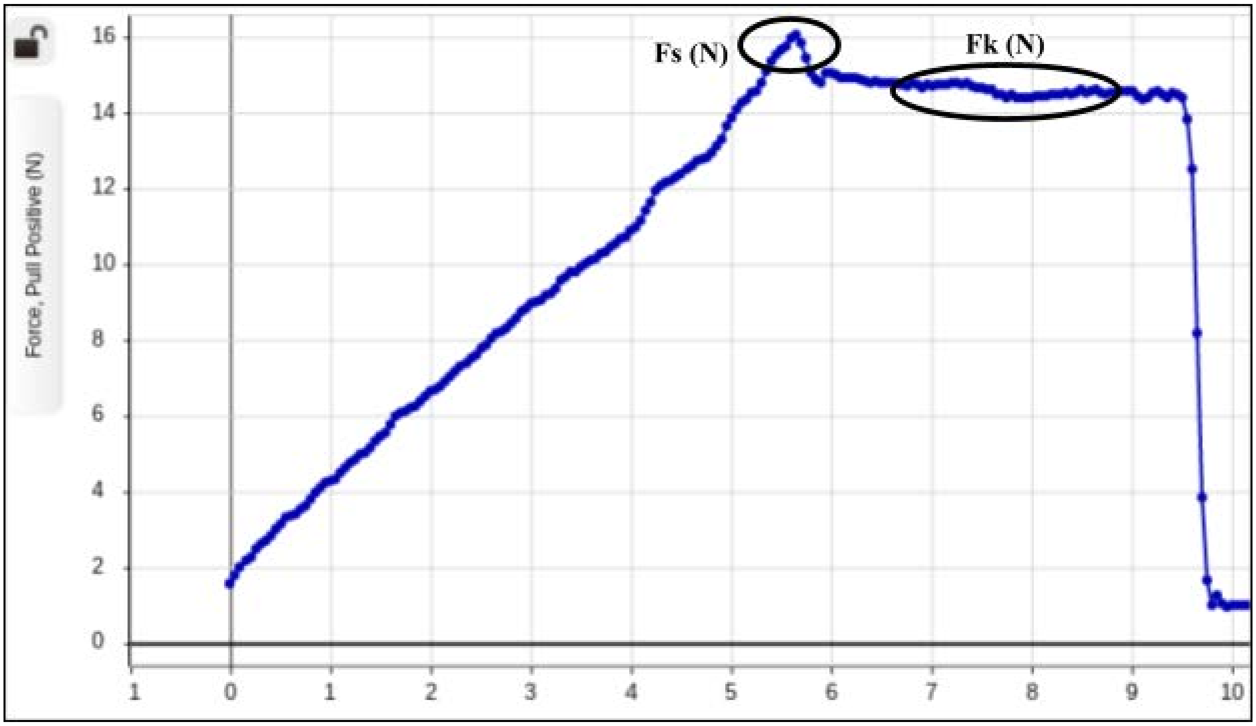

Figure 3, Example graph of frictional forces provided by Sparkvue software (Doyle, 2022)

After data collection is complete the normal force (F_N) was calculated for each shoe, taking into consideration the weight of the dumbbell as well as the weight of the shoe using the equation $F_N = mg$. This force, in Newtons, remains the same for each shoe once initially found by combining the mass of the shoe and weight, found using a digital scientific scale (m), and multiplying this by the force of gravity (g).

Using the normal force found previously for each shoe, divide the shoe-surface frictional force (both static and kinetic) by this number. Utilizing the equation $\mu = Ff/F_N$, the coefficient of friction was calculated and noted for each trial on every playing surface. This ratio of frictional force divided by the normal force, or the downward force exerted by the shoe on the surface due to gravity, enabled experimenters to determine the amount of friction existing between the outsole and the surface.

Statistical analysis was performed following data collection and calculations to further examine the effects of shoe-surface interaction on traction. T-tests were used to compare the mean values of the natural grass in relation to the average on artificial turf in the two locational comparisons. This type of analysis is used when analyzing whether there is a significant effect of a categorical independent variable on a numeric dependent variable. The dependent variable, a numeric value, was the μ of each shoe-surface. The independent variable, or the two groups being compared categorically, were grass and artificial turf playing surfaces. Other statistical variables were taken into account such as standard deviation, to determine consistency within each data set. All statistical tests were performed using DataClassroom with significance set at $p<0.01$ in all analyses.

Results:

All trials in this study were completed to the best ability of the experimenter in an attempt to increase accuracy. *Figure 4* compares the static coefficient of friction (μ□) on the grass playing surface at Hudson Falls High School's football field, to the μ□ on the artificial playing surface at Glens Falls High School's football/soccer field. The mean μ□ on the natural grass playing surface was found to be 1.249 (average standard deviation +/- 0.134) for all shoes, with the Nike Zoom exhibiting the highest average μ□ of 1.343. The lowest average μ□ was found in the Puma Axelions, with an average coefficient of 1.181. The mean μ□ on the artificial turf playing surface was found to be 0.809 (average standard deviation +/- 0.083) for all shoes, the Nike Air Zoom Pegasus exhibited the highest average μ□ of 0.866. Unlike the grass playing surface, the lowest average μ□ was found with the Nike Zoom with an average of 0.727.

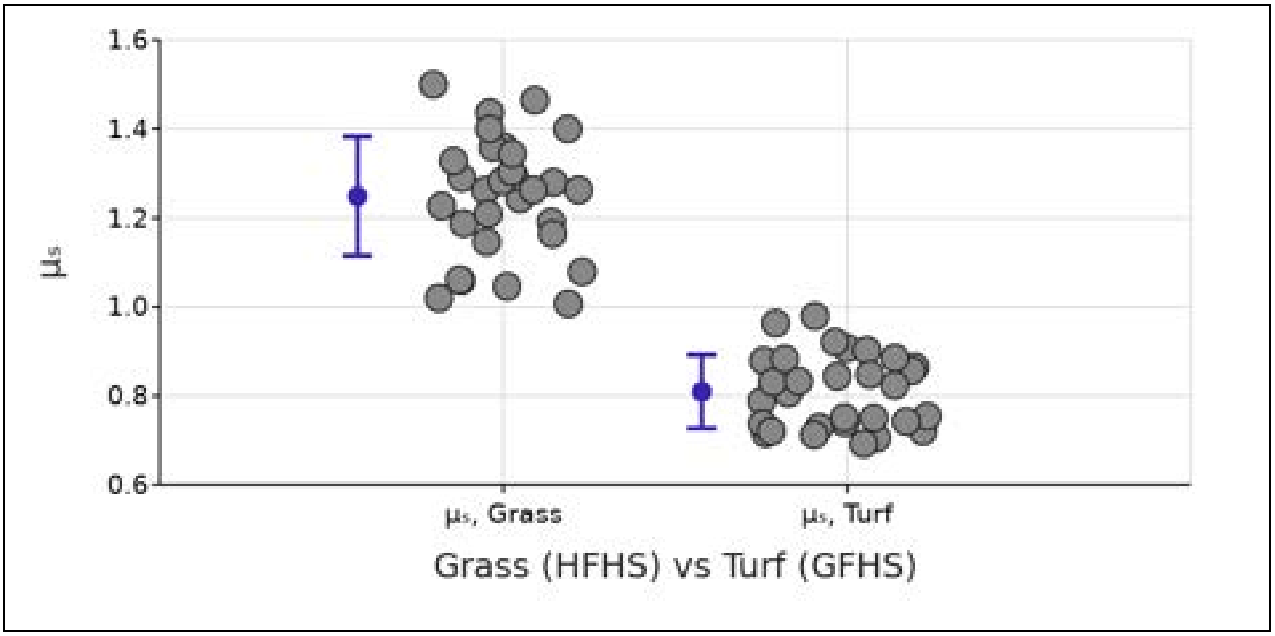

Figure 4, graph comparing μ_s on grass (HFHS) vs turf (GFHS) with descriptive statistics such as mean and standard deviation (Doyle, 2022)

Figure 5 analyzes μ_s on the grass playing surface at Hudson Falls High School compared to the μ_s on the artificial turf playing surface at the Glens Falls High School football field. The mean, or average, μ_s on the grass surface was found to be 1.148 (average standard deviation +/- 0.126) for all of the shoes, with the Nike Zoom again exhibiting the highest average of 1.245 again on the grass playing surface. The lowest average was found in the Puma Axelions, with an average μ_s of 1.059. The mean μ_s on the artificial turf playing surface was found to be 0.713 (average standard deviation +/- 0.072). The highest average was exhibited by the Nike Air Zoom Pegasus with an mean μ_s of 0.752 and the lowest average being found in the Nike Zoom with a mean μ_s of 0.640.

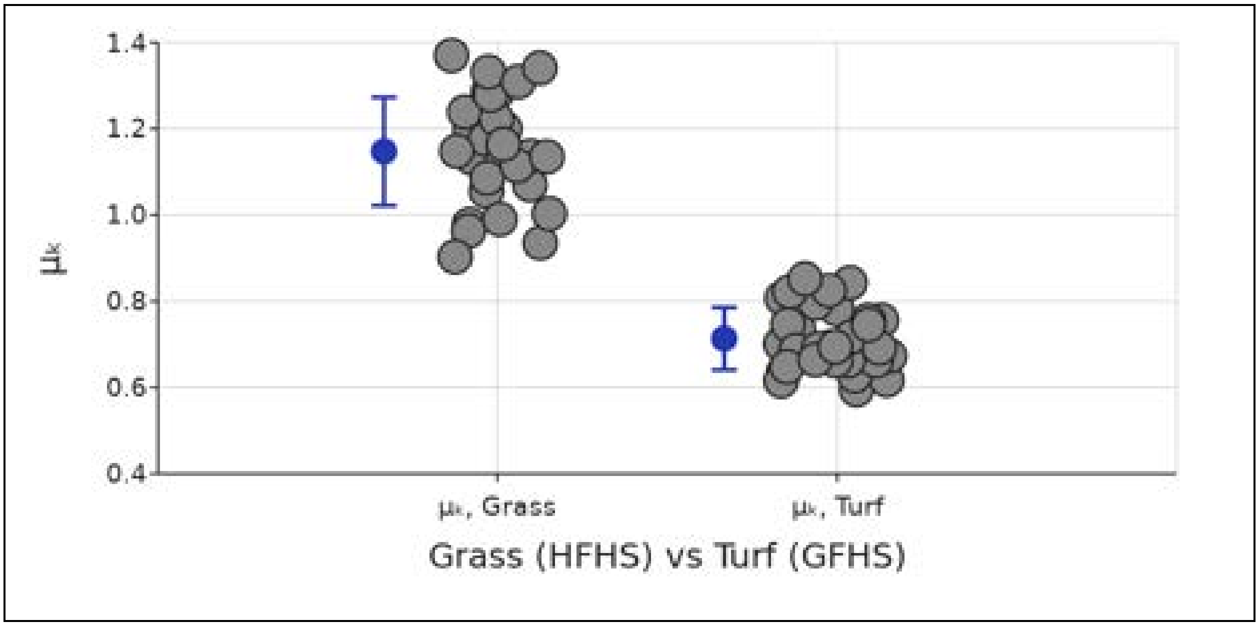

Figure 5, graph comparing μ□ on grass (HFHS) vs turf (GFHS) with descriptive statistics such as mean and standard deviation (Doyle, 2022)

After comparing both the *μ*□ *and* μ□ at the first two testing sites located at Hudson Falls High School (grass) and Glens Falls High School (turf) in New York, we move into the third and fourth sites located at Ocean City High School in New Jersey. *Figure 6* compares the two different playing surfaces found at Ocean City High School, the football field (turf) vs the practice football field (grass) analyzing *μ*□. The mean *μ*□ across all shoes on the turf playing surface was found to be 0.912 (average standard deviation +/- 0.105). The highest coefficient on average was found to be in the Nike Air Zoom Pegasus with a mean coefficient of 1.010. The lowest coefficient was found when testing the Nike Zooms with a mean *μ*□ of 0.859. On the natural grass playing surface, the practice football field, an average *μ*□ of 1.031 (average standard deviation +/- 0.107) was found. Again it was consistent that the Nike Air Zoom Pegasus had the highest *μ*□ of 1.152 on average. On the grass playing surface however the Puma Axelions had the lowest mean *μ*□ of 0.970.

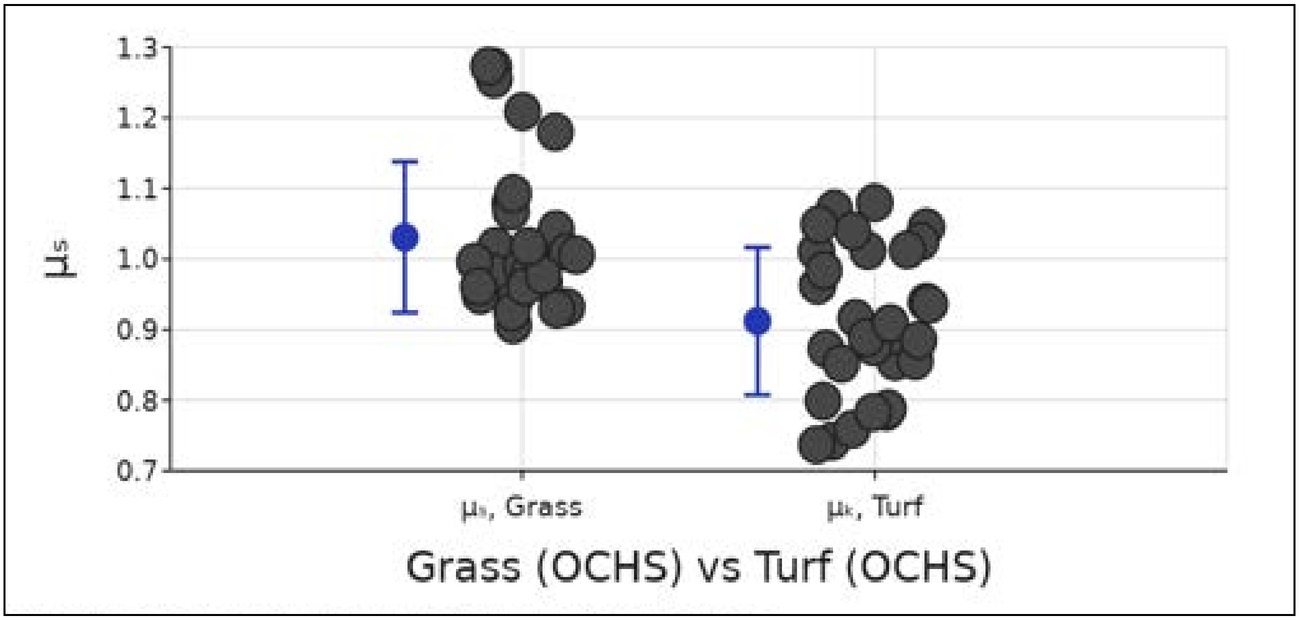

Figure 6, graph comparing μ□ at Ocean City High School, New Jersey, on the football field (turf) vs the practice football field (grass) with descriptive statistics such as mean and standard deviation of both surfaces (Doyle, 2022)

Lastly, *Figure 7,* analyzing the same location and same two testing sites, compares μ□ at both the grass and turf athletic playing surfaces at Ocean City High School. The mean μ□ at the turf football field was found to be 0.776 (average standard deviation +/- 0.075) across all three shoes that were tested. The highest μ□ on turf was found when testing the Nike Air Zoom Pegasus which had a mean μ□ of 0.820. The Puma Axelion showed the lowest μ□ on average with a mean of 0.742. On the natural grass practice football field a mean μ□ of 0.912 (average standard deviation +/- 0.111) was found. Consistent with the turf playing surface the Nike Air Zoom Pegasus resulted in the highest μ□ of 1.034 on average as well as the Puma Axelion leading to a μ□ of 0.846, the lowest of the three shoes being tested.

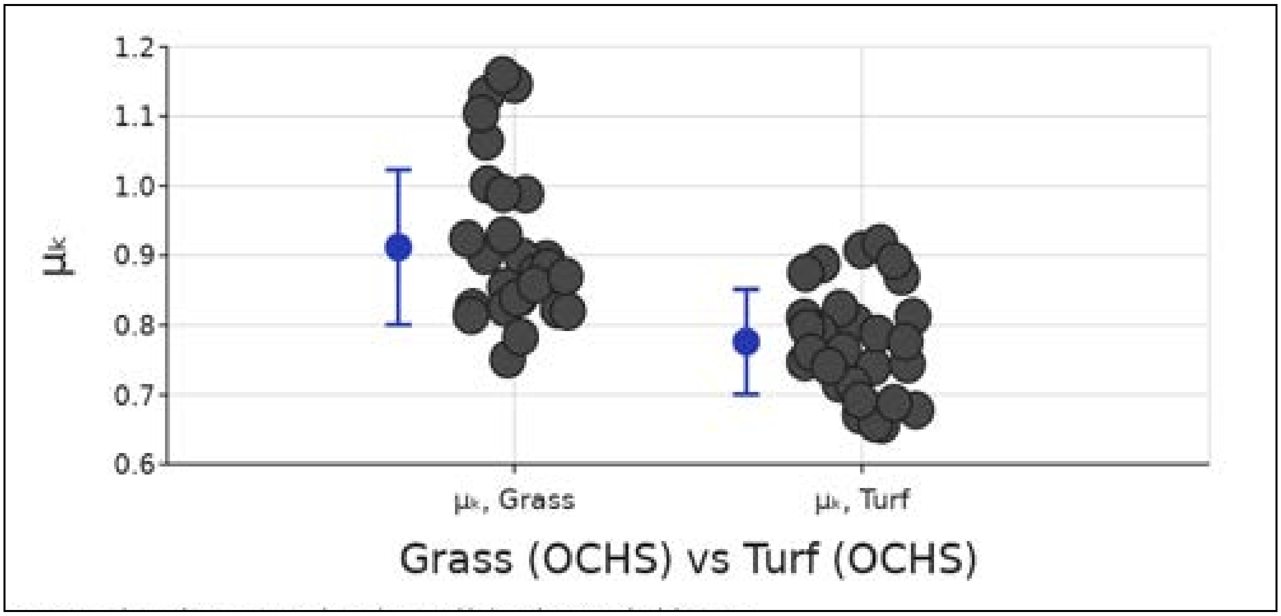

Figure 7, graph comparing the μ□ at Ocean City High School, New Jersey, on the football field (turf) vs the practice football field with descriptive statistics such as mean and standard deviation of both surfaces (Doyle, 2022)

Statistical values both basic and expanded were calculated using Data Classroom, an online interactive graph-driven statistical analysis website. For each playing surface comparison basic statistics were calculated including mean, standard deviation, and standard error mean for each individual dataset. Figure 8 shows these calculated statistics for the trials comparing Hudson Falls (grass) vs Glens Falls (turf) μ□ and *μ*□. The grass playing surface had a mean *μ*□ of 1.249 coupled with a mean μ□ of 1.148. The standard deviation of each dataset for the grass playing surface was 0.134 for *μ*□ and for μ□ the standard deviation was 0.126. The artificial turf playing surface, which had significant lower mean *μ*□ *of 0.809 and* μ□ of 0.713, was also closely statistically analyzed. The standard deviation of the μ□ and *μ*□ on the artificial turf surface at glens falls were significantly reduced when compared to those on the grass surface at Hudson Falls. The standard deviation of the *μ*□ *was 0.083 and* μ□ was found to be 0.072 .

Group	Mean	Std.dev	SEM
μ_s, Grass	1.249	0.1338	0.02443
μ_s, Turf	0.8093	0.0828	0.01512

Group	Mean	Std.dev	SEM
μ_k, Grass	1.148	0.1257	0.02294
μ_k, Turf	0.7133	0.07244	0.01323

Figure 8, Calculated mean, standard deviation, and standard error for trials conducted comparing μ_s and μ_k at Hudson Falls High School football field (grass) vs Glens Falls High School football/soccer field (turf) (Doyle, 2022)

The same basic statistical values were calculated for the grass vs turf comparison for trials taken at Ocean City High School. *Figure 9* shows these values in a table, showing mean values, standard deviation, and standard error mean again for these turf vs natural grass fields. The mean μ_s of 1.031 was found on the grass playing surface with a standard deviation for these values of 0.107. This same grass playing surface had a mean μ_k of 0.912 and a standard deviation of 0.111. The turf playing surface again in this instance exhibited a lower mean value for both μ_s (0.912) and μ_k (0.776). The standard deviation was also found to be lower on the turf playing surface with the standard deviations being 0.105 for μ_s and 0.075 for μ_k.

Group	Mean	Std.dev	SEM
μ_s, Grass	1.031	0.1069	0.01985
μ_k, Turf	0.9121	0.1045	0.01908

Group	Mean	Std.dev	SEM
μ_k, Grass	0.9119	0.1112	0.0203
μ_k, Turf	0.7761	0.07532	0.01375

Figure 9, Calculated mean, standard deviation, and standard error mean for trials conducted comparing μ□ and μ□ at Ocean City High School, football field (turf) vs practice football field (grass) (Doyle, 2022)

After calculations of these basic statistics, a T-test was conducted in order to test for a difference in numeric mean values between two different groups (grass vs turf). The test weighs the difference in the means between the two groups against the spread of the whole data around the mean. This determines whether or not a difference is statistically significant or a product of random chance. These T-tests found p values < 0.01 in all instances on all playing surfaces which can be interpreted to mean that there is a significant difference between groups as shown in *Figure 10*. Also shown in these tables is an example of T-score and degrees of freedom for both the Hudson Falls High School playing field and the Glens Falls High School playing field. In all instances values were significant and a difference between mean values comparing grass vs turf was found.

Degrees of Freedom (df)	T-Score	P-value	Interpretation of P
58	16	<0.01	A P-value of <0.01 means that the groups are different.

Degrees of Freedom (df)	T-Score	P-value	Interpretation of P
58	15	<0.01	A P-value of <0.01 means that the groups are different.

Figure 10, example values obtained from calculating a T-test for values obtained from Hudson Falls High School and Glens Falls High School, both showed p-values < 0.01 (Doyle, 2022)

Discussions and Conclusions:

The data pool showed higher frictional forces for both static and kinetic on the grass playing surface at all testing locations. This frictional force translates to μ□ and μ□ on both surfaces as well. At the first two testing sites, located in New York, HFHS showed an average μ□ of 1.249, a value that is shown to be significantly higher than the average on turf at GFHS (0.809). This was also consistent for the μ□ at both of these same testing locations. A mean μ□ of 1.148 was calculated on the grass playing surface and a mean μ□ of 0.713 was displayed on the turf playing surface. These values show a higher rate of available shoe-surface on the grass playing surface when compared to the turf playing surface in this instance. This shows that athletes could possibly gain traction, enhancing athletic maneuvers, possibly correlating to a reduced injury rate for athletes when on natural grass.

The average standard deviation across the HFHS grass playing surface was found to be 0.130, a value that is higher than the standard deviation calculated across the GFHS turf playing surface of 0.078. This standard deviation represents the average distance +/- away from the mean of the dataset. In this study a higher standard deviation could represent inconsistencies in the playing surface leading to a more spread out data set. This data shows that on the grass surface athletes could face more inconsistent results when performing athletic maneuvers when compared to turf, representing a possibility for more random loss of traction when performing in athletic events and practices. These results show that grass playing surfaces have higher frictional forces and μ when compared to artificial turf.

These results found on natural grass and artificial turf in New York were consistent with the second trials conducted at Ocean City High School (OCHS). Here an average μ□ of 1.031 was found on the grass field and an average of 0.912 was found on the artificial turf field. The μ□ on the grass practice field was found to be significantly higher than the average found on the turf game field. These values held consistent with the μ□ on both fields, as the grass surface had a coefficient of 0.912, a value greater than the 0.776 average discovered on the turf playing surface. These values, consistent to those recorded on the grass and turf fields in New York, show higher μ on the grass playing surface in comparison to the turf surface. Again the average standard deviation was also consistently higher on the turf surface, with an average of 0.090, compared to the average of .109 found on the grass surface. As previously stated, the higher standard deviation found on grass represents more inconsistencies when playing or practicing for athletes on grass fields compared to artificial turf fields.

Statistical analysis was calculated using a T-test, P-values < 0.01 were found across all playing surface comparisons. This shows a significance between the mean of the two groups, turf vs grass. This could suggest that there is a statistically significant difference for μ found on turf and grass playing surfaces.

While this study found that grass playing surfaces had higher rates of shoe-surface traction for athletes than artificial turf, there are other factors that need to be taken into account. Artificial turf offers other practical benefits such as reduced cost, easier maintenance, and more consistent traction for athletes. These benefits are to be taken into account when considering which playing surface to install alongside the amount of traction maintained by athletes on both surfaces.

All traction values obtained in this study can be influenced by extrinsic factors, such as rain, which can change the μ of any surface. This should be taken into account in further studies by testing the playing surface multiple times with varying conditions. More accurate results could have been obtained if more trials were conducted for each playing surface, with each new trial being on a different day to experience a vary in preliminary conditions. Pulls were done to the best of the experimenters ability however no human can maintain a perfect horizontal to the playing surface and pull the force sensor/shoe/weight across the surface at a perfectly constant rate. A solution to this could lie in robotics by possibly constructing an artificial machine that can maintain this constant, consistent pull. In this study it is found that a natural grass playing surface could potentially have a reduced injury rate during athletic events and practices in comparison to artificial turf. More studies should be conducted to study possible correlations between injuries and the shoe-surface μ.

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