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Development and Evaluation of a Method to Measure Traction on Turfgrass Surfaces

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ABSTRACT: Traction, as it relates to field quality, involves the athlete, studded footwear, and the turf. Traction involves two types of forces: those acting in a vertical manner that compress the turf and those that act horizontally and produce a shearing or tearing effect on the turf. The objectives of this research were to develop and evaluate an apparatus to measure the horizontal forces associated with traction, compare this apparatus with other devices routinely used to quantify traction, and examine how different turfgrass stand characteristics combine to influence traction.

An apparatus, termed PENNFOOT, was developed and field tested. PENNFOOT consists of a framework that supports a leg and foot assembly that can be used to measure both rotational and linear traction using different footwear under various loading weights. When we compared PENNFOOT to other traction measuring devices, the force values we obtained from different grass species and varying cutting heights provided low correlation values.

Experiments were conducted to determine the effect of turfgrass and soil conditions on traction of turf areas. Tall fescue and Kentucky bluegrass provided the highest traction values whereas perennial ryegrass and creeping red fescue provided the lowest. Higher linear traction values occurred with lower cutting heights.

Although more work is needed on the turf and soil characteristics that influence traction, the PENNFOOT with its versatility seems appropriate for traction evaluation.

KEYWORDS: playing fields, traction, sports fields, sports injuries, turfgrass, athletic footwear, shoes, cutting height, Kentucky bluegrass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), creeping red fescue (*Festuca rubra* L.), tall fescue (*Festuca arundinacea* Schreb.)

Although the public demand for high-quality athletic fields is growing, researchers and field managers find it difficult to quantitatively evaluate quality characteristics of an athletic field. Athletic field surface quality can be defined as the suitability of a surface for a particular sport as measured (or perceived) in terms of the important interactions between the playing surface and the player and/or a ball. An athlete interacts with a playing surface in two ways: through impacts with the surface; and through player-to-shoe-to-surface interactions associated with footing. Various terms have been used interchangeably to describe how a foot wearing a cleated shoe reacts with an artificial or natural turf. These terms include gripability, shear strength, friction, abrasion, and traction.

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Bell, et al. [*1*] proposed that the term "traction" should be used only when footwear containing studs, spikes, or cleats are in contact with a turf.

When a body slides on another body, the force tangent to the contact surface that resists the motion of one body relative to another is defined as friction [*2*]. The coefficient of friction is defined as the ratio of the maximum frictional force to the normal force between the two surfaces. These terms are generally associated with two smooth, rigid surfaces. The irregularities associated with cleated footwear and the disturbance in the turf surface created by the cleats, negate the application of the properties associated with friction. In order to describe the resistance properties associated with cleated footwear, variations of friction testing procedures had to be developed.

As with friction, traction can be divided into linear (translational) or rotational traction. Gramckow [*3*] assessed linear traction by measuring the force required to pull a weighted plate with four protruding cleats across a turf surface. Similarly, Milner [*4*] pulled a cleated shoe across a turf and used an Instron tensile test machine to measure the forces required to initiate and maintain motion. ASTM has established a Standard Test Method for Static Coefficient of Friction of Shoe Sole and Heel Materials (F 489-77) in which shoes are placed on a table on which different walking surfaces are mounted. The table is then moved linearly to determine the force exerted at the sole surface interface.

Rotational traction studies have received more attention than linear studies. Torg, et al. [*5*] measured the relative amounts of torque necessary to statically release various shoes on both artificial and natural turf. The shoes were weighted and torque was applied and measured with a torque wrench. Henderson [*6*], Rogers, et al. [*7*], and Rogers and Waddington [*8* ,*9*] measured traction with a field shear test apparatus, Type 1B, Eijkelkamp Equipment, Giesbeek, The Netherlands. This device consisted of twelve 1.0 and 2.0 cm-long steel fins attached to a disc. The researchers measured the maximum shear resistance of a turf by pressing the fins into the ground and then turning a handle equipped with a torque scale. Bostingl, et al. [*10*] measured rotational traction on both natural and artificial turf. Their machine consisted of a frame that housed a synthetic leg and foot assembly. They measured the force at the shoe-surface interface during a simulated tackle to the lower leg. The researchers generated a rotational force by swinging a weighted pendulum that struck a horizontal shaft connected to the leg. The peak torque at the shoe-surface interface was measured by two polarly mounted strain gages on the leg. Canaway [*11*] developed an apparatus for routine measurement of playing surface traction that consisted of a steel disc into which football cleats were secured. A centrally located shaft was attached to the disc and loaded with weights. The apparatus was dropped on to the turfgrass from a few centimeters and the torque required to tear the turf was measured with a torque wrench. This device was later modified by Winterbottom [*12*], and has been used in numerous studies [*13–15*].

In a review of the validity of methods used to evaluate the traction characteristics of a playing surface, Nigg [*16*] stated that since friction or traction resistance depends on the characteristics of both surfaces involved, traction tests provide relevant information only when appropriate shoe soles are used, and when the actual vertical force (loading weight) applied is similar to that applied by athletes. His review presents data from tests done to evaluate various artificial turf surfaces. The results demonstrated that by increasing the vertical force applied to the shoe-surface interface, the horizontal force needed to create linear movement of the shoe increased at varying rates for five artificial turf surfaces. One surface provided the least horizontal resistance of the surfaces tested at a vertical force of 280 N while providing the greatest resistance of the surfaces when tested at 770 N. Nigg [*16*] concluded that using vertical forces lower than those created by an actual athlete may lead to erroneous conclusions.

In this study we sought to develop a device that would measure both the linear and rotational traction on natural turfgrass and meet the requirements for valid traction evaluation set forth by Nigg [*16*]. We wanted to compare our device to other instruments used routinely to quantify traction on natural turfgrass, and examine how different turfgrass species, mowing height, and vertical force combine to influence traction on athletic field turf.

Procedures

Construction of Testing Apparatus

The testing apparatus that we developed (PENNFOOT) is shown in Fig. 1. PENNFOOT consists of two frames, an inner and an outer frame. The inner frame supports a centrally located collar through which the leg-shoe assembly passes. A set screw in the collar holds the leg in an elevated position when measurements are not being made. We constructed the shorter outer frame around the bottom portion of the inner frame in order to lift and transport the inner frame and leg-shoe assembly. The tires and rims shown in Fig. 1 are connected to this outer frame. Angle iron uprights on each corner of the outer frame provide support to the inner frame during transport.

The leg-shoe assembly consists of a solid (3.81-cm-diameter) steel rod with a ball-and socket assembly just below the centrally located collar and a cast aluminum foot pinned on the lower end. The extreme top portion of the leg (above collar), can be loaded with weights to exert various vertical forces.

The simulated aluminum foot was cast from a size 10 foot mold (Fig. 2). Two holes located on top of the foot are used for connection with the leg. The first hole located toward the toe allows the heel to be raised off the ground thus distributing the weight on the ball of the foot. This positioning of the foot was used for all measurements reported in this paper. The second hole can be used to place the entire sole in contact with the turf and distribute the weight evenly across the sole. We used two football shoes (Nike, Inc., 150 Ocean Dr., Greenland, NH) in this research. Shoe I is a hightop with a molded sole that has 18 triangular studs (12-mm long) around the perimeter of the sole and 35 smaller studs (9-mm long) in the center. Shoe II is a lowcut studded shoe with 12 cylindrical studs, each 12-mm long by 11 mm in diameter. A third shoe used in one test is a smooth leather soled shoe.

We generated the horizontal traction forces and the force required to lift the internal frame with an Energy HP-100 hand pump (Energy Mfg. Co., Inc. Monticello, IA) with a 20.7 MPa pressure limit. The rotating horizontal force is created by two model HTB-1R pistons (Air & Hydraulic Power, Inc. Wyckoff, NJ), that are mounted horizontally on angle iron 38.1 cm above the ground as measured with the machine in position to take a measurement (Fig. 3). These pistons have a bore of 2.54 cm and a stroke of 5.08 cm. We connected a strike plate to the simulated leg for the pistons to push against. A lower collar around the simulated leg prevented it from tilting while the rotational force was applied. A protector scale on this collar was used to determine how far the leg had rotated from the starting position. We applied a lubricant around the collars and on the ball-and-socket joint to minimize friction.

We created the linear force using one model HTB-1E pulling piston with a bore of 5.08 cm and a stroke of 5.08 cm (Fig. 4). We mounted the piston on the bottom of the internal frame with the pulling rod 7.3 cm above the ground when the machine was in position to take a measurement. The end of the pulling rod was pinned to a bracket mounted on the heel of the foot. We measured the distance traveled by the foot using a dial indicator. The pistons

FIG. 1—*PENNFOOT traction measuring device.*

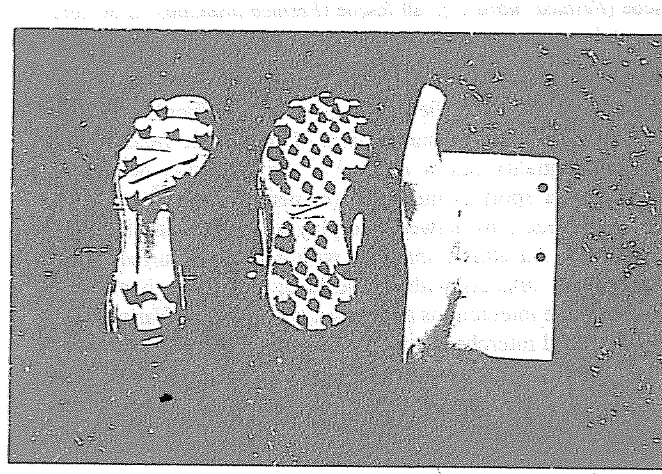

FIG. 2—*Shoe II (studded), Shoe I (Molded) and cast aluminum foot used with PENNFOOT traction-measuring device.*

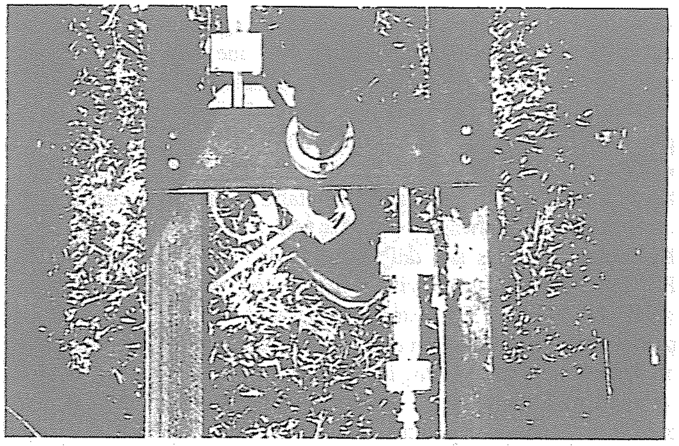

FIG. 3—*Rotational measurement setup (from above) for the PENNFOOT.*

used to create the tractional forces came equipped with return springs that reset the pistons when pressure was alleviated. We removed these springs to prevent unnecessary opposing forces. The force to rotate or pull the leg-shoe assembly when suspended in the air was 100 kPa.

Raising or lowering the internal frame is accomplished by two model HTB-1R pistons mounted vertically at opposite ends of the internal frame. The end of the piston rods rest on the external frame; therefore, when we applied pressure, the internal frame would lift up and could slowly be lowered by releasing the pressure. A 15.2-cm Noshok C-X60SSSB10 6.9 MPa liquid-filled pressure gage was connected directly to the pump to monitor the pressure being applied to the pistons. A selector valve allowed us to direct pressure to either the pistons that created the horizontal forces or to the pistons that raised or lowered the internal frame.

Operating Procedure

1. We weighted the leg-shoe assembly to arrive at a particular loading weight and secured the selected shoe on the simulated foot, which was attached using the forward hole to obtain a "toe" stance.
2. We situated the machine over the desired location and reset the pistons. We then lowered the internal frame slowly while holding up the heel until the toe came in contact with the turf. At this point the set screw, holding the top portion of the leg assembly, was released allowing the leg-shoe assembly and weights to act independently from the internal frame. This procedure allowed us to place rather than drop the weighted assembly onto the surface.
3. The selector valve was turned to connect either the rotational or linear pistons to the hand pump. For a rotational measurement, one person operated the pump and monitored the pressure gage. A second person watched the foot and indicated when the shoe first started to move and observed the linear distance traveled or the degrees rotated by the foot. Pressure readings were recorded at initial movement and at 10, 20, 30, and 40° of rotation or at every 0.635 cm of linear travel.
4. The last step in the procedure was the conversion of pressure to N and Nm for linear and rotational measurements, respectively. We determined linear forces (N) by multiplying the effective area of the pulling piston (20.26 cm^2) with the amount of pressure read from the gage. Rotational forces (Nm) were determined by calculating the moment of rotation. The moment of rotation is force multiplied by a lever arm, which for the PENNFOOT was the strike plate (81 mm).

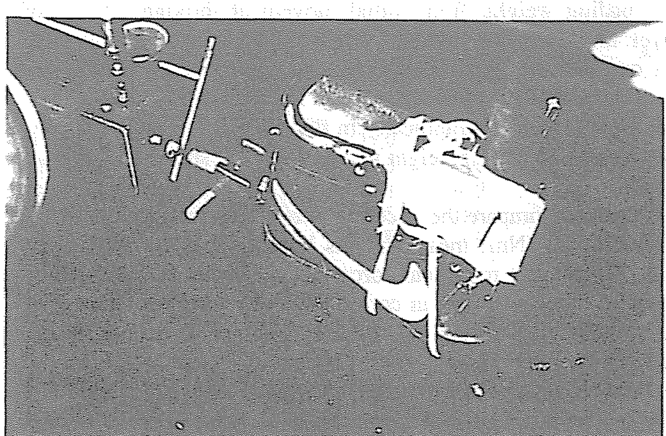

FIG. 4—*Linear measurement setup for the PENNFOOT.*

The standard deviation of the mean of four PENNFOOT measurements was determined by measuring both linear and rotational traction values using a loading weight of 116 kg and Shoe II. Measurements were made on a piece of 100% Anso crush-resistant nylon carpet 762 MEA #74172 Rack Sequence: L18 (Galaxy Carpet Mills, Inc. Chatsworth, GA) that we cemented to a 0.5 in.-thick (1.27 cm) piece of particle board. We calculated a standard deviation using peak traction values. Peak rotational traction measurements averaged 32.2 Nm and had a standard deviation of 0.7. Peak linear traction measurements averaged 1589 N and had a standard deviation of 35.

The numbers determined for tractional characteristics for both linear and rotational traction are to be used for comparative purposes only. Attempts to calculate a coefficient of traction from these data should not be made. We developed this machine to study the turfgrass with respect to traction, and although this machine represents an improvement when compared to other turfgrass testing machines, it was not designed to simulate actual human foot movements. Close approximations of actual foot movements with respect to traction have been accomplished by Lloyd, et al. [*17*] in artificial turf traction tests by attaching a piece of artificial turf to a piezoelectric load cell and then performing traction tests. This system is not feasible for natural turfgrass.

Measurements of Species, Cutting Height, and Loading Weight Effects on Traction

The objectives of this study were to determine the effects of grass species, cutting height, and loading weight on traction and to compare rotational to linear traction using the PENNFOOT. We measured traction with the PENNFOOT on plots located at the Joseph Valentine Turfgrass Research Center, University Park, PA in September 1991. The soil type was Hagerstown silt loam (17% sand, 62% silt, and 21% clay). We established four grass species, Aspen Kentucky bluegrass (*Poa pratensis* L.), Penn State 222 experimental perennial ryegrass (*Lolium perenne* L.), Pennlawn creeping red fescue (*Festuca rubra* L.), and Arid tall fescue (*Festuca arundinacea* Schreb.), in August 1990. The experimental design was a split plot (cutting height), split block (loading weight) design with three replications. We divided each species plot (5.49 by 6.10 m) into three cutting height subplots (1.83 by 6.10 m) for heights of 3.8, 5.1, and 6.4 cm. We split the blocks by loading weights (59.9, 73.9, 88, and 102 kg). The 59.9 kg loading weight was not used for rotational measurements. All measurements were made on dry turf using Shoe I.

We characterized the turfgrass stand characteristics by extracting three 81 cm^2 by 2-cm deep plugs from each subplot. Above-ground biomass and tiller density were determined using the procedure described by Lush [18]. We determined the below-ground biomass by first washing the soil from the roots and then determining the percent organic matter using ASTM Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils (D 2974-87). At the time traction measurements were being made, we extracted four smaller plugs (2.4 cm^2 by 1.5-cm deep) from each subplot in order to measure soil water content.

Comparison of Traction Testing Methods

In order to make a direct comparison between the PENNFOOT and the Field Shear Test Apparatus used by Rogers and Waddington [9], we measured traction with the shear vane across all species and cutting heights at the times of both the linear and rotational PENNFOOT measurements in the previous study. The shear vane (Fig. 5) consists of 12 fins welded at right angles to a cutting head (7.0-cm diameter). We pressed the shear vane into the surface using foot pressure. The foot was removed and torque was applied manually by turning the opposite handles in the same direction and the maximum torque (Nm) was read from the calibrated gage on top of the apparatus. We recorded the averages of four measurements and then correlated rotational and linear PENNFOOT data with the shear vane results.

In a second comparison, we compared the PENNFOOT with the shear vane and the device developed by Canaway and Bell [19] (Apparatus A). We constructed a replica of Canaway and Bell's device for use in this research (Fig. 5). The device was loaded with weightlifting weights to obtain an overall loading weight of 47.8 kg. To measure traction, we held the apparatus so that the support bars were the same height as the cross bars on the cart. The apparatus was then released and allowed to fall a standard height of 60 mm. To obtain a measurement we turned the two-handled torque wrench and recorded the maximum torque. Traction values were measured in August 1992 on the species plots to determine how the three machines responded to differences in species and cutting height. We took four measurements per plot for each method. The PENNFOOT was equipped with Shoe II with studs similar to those on Apparatus A, and was tested using a loading weight (47.6 kg) close to the loading weight with Apparatus A. We correlated all methods against one another and against tiller density, above-ground biomass, and below-ground vegetation.

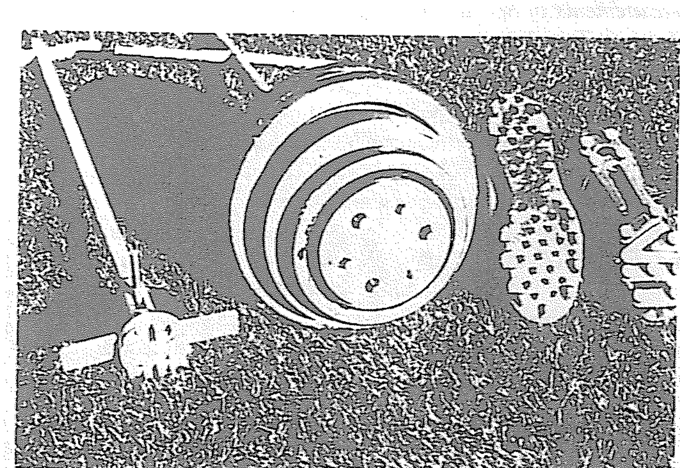

FIG. 5—*Cleat patterns for the shear vane, Cannaway and Bell's apparatus, Shoe I, and Shoe II.*

In a third comparison of these methods, we selected areas to provide a greater range of traction values than we obtained on the species plots. We took traction measurements on bare soil (firm but not compacted), a thinned turf stand (about 60% turf cover), compacted turf roadway (about 75% turf cover), and noncompacted Kentucky bluegrass and tall fescue plots (100% turf cover). The PENNFOOT was used with Shoe II and two loading weights (47.6 and 102 kg). We tested Apparatus A by using the standard procedure of a 60-mm drop height and by placing the apparatus on the turf without dropping it. We incorporated this second method to create an initial contact similar to that of the PENNFOOT, and to see if placing Apparatus A on the surface provided results different from the standard procedure.

Characterization of Species Using Smooth Sole Footwear

Measuring traction using PENNFOOT with athletic footwear, Apparatus A, and the shear vane may negate the often observed slipperiness differences among turfgrass species. In an attempt to determine species differences in slip, we measured rotational traction using the PENNFOOT equipped with a smooth, leather-soled shoe on the 5.1-cm cutting heights for each species on the "species plots."

Statistical Analysis

We used four PENNFOOT traction measurements to characterize the traction of each subplot in the experiments. We analyzed the mean values of the measurements using analysis of variance. The least significant difference (lsd) at the 0.05 level was calculated when the F ratio was significant at the 0.05 level. Linear correlation coefficients were determined between traction values and the turfgrass stand characteristics.

Results and Discussion

Effects of Species, Cutting Height, and Loading Weight on Rotational and Linear Traction

As we pulled or rotated the shoe sole, the tractional forces associated with natural turfgrass increased. Linear traction forces increased sharply, for the variables grass species, cutting height, and loading weight, from initial movement through 2.5 cm of travel, increased slightly to 3.8 cm, and then decreased slightly to 5.1 cm. Rotational forces responded similarly and the peak occurred around 40°. Traction values for the loading weight variable are represented graphically in Figs. 6 and 7. Traction values for species and cutting height main effects are shown in Tables 1 and 2.

We cannot compare the tractional forces observed for linear (N) and rotational (Nm) measurements because they have different units. To convert rotational forces to N, we must measure the radius of the sole that is in contact with the turf, but because of the irregular cleat pattern this distance can not be defined easily. As Nigg [16] and Harper, et al. [20] stated, linear and rotational forces should not be of the same magnitude; however, in this study, although we could not directly compare the units of measurement for rotational and linear forces, the traction values at 30° and 3.8 cm of travel were highly correlated ($r = 0.94$) over all main effects.

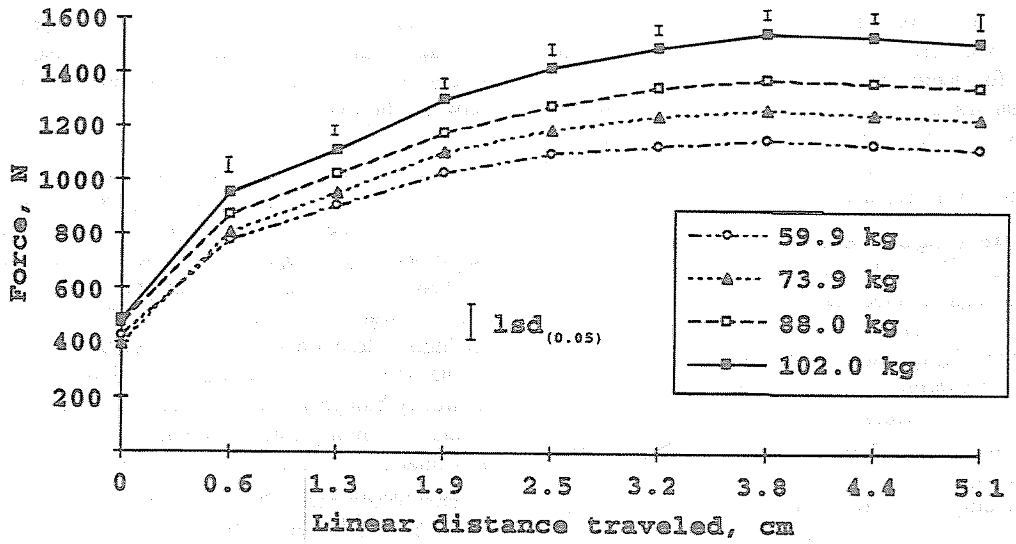

FIG. 6—*Mean linear traction forces for loading weights across grass species and cutting heights.*

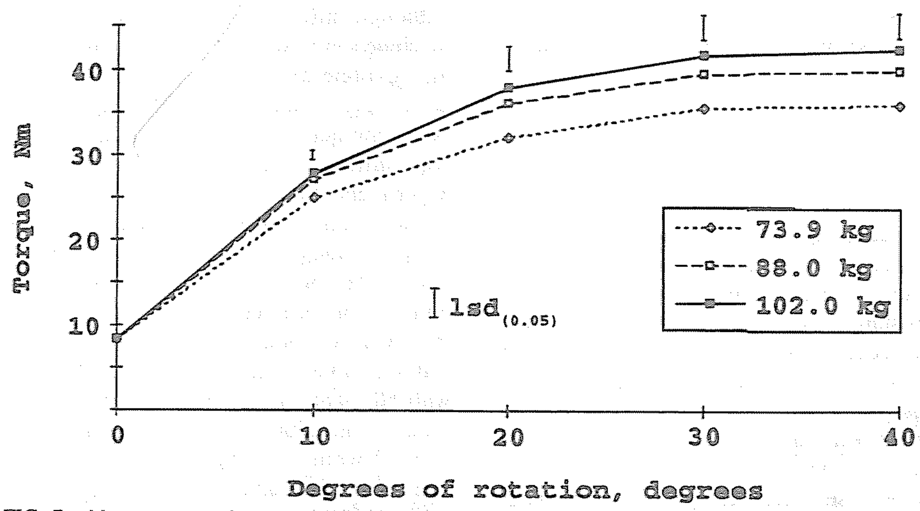

FIG. 7—*Mean rotational traction forces for loading weights across grass species and cutting heights.*

TABLE 1—*Mean traction values for the designated variables obtained from rotational measurements using Shoe I in September 1991.*

Variable	Degrees of Rotation				
	Initial	10	20	30	40
Species	Nm				
Tall Fescue	8.3	27.9	37.4	40.9	41.3
Kentucky Bluegrass	8.3	27.3	36.6	40.4	40.7
Perennial Ryegrass	8.2	25.8	34.2	38.0	38.4
Red Fescue	8.2	25.5	33.8	36.6	37.3
lsd (0.05)	NS[a]	0.8	1.0	1.4	1.2
Cutting Height, cm					
	Nm				
3.8	8.3	26.9	35.6	39.3	39.8
5.1	8.2	26.7	35.7	39.2	39.8
6.4	8.3	26.3	35.1	38.4	38.7
lsd (0.05)	NS	NS	NS	NS	NS

[a]NS = not significant at the 0.05 level.

TABLE 2—*Mean traction values for the designated variables obtained from linear measurements using Shoe I in September 1991.*

Variable	cm of Travel								
	Initial	0.6	1.3	1.9	2.5	3.2	3.8	4.4	5.1
Species	N								
Tall Fescue	443	868	1025	1197	1301	1375	1418	1408	1396
Kentucky Bluegrass	442	863	1017	1178	1288	1362	1417	1404	1387
Perennial Ryegrass	453	851	984	1129	1215	1274	1312	1303	1282
Red Fescue	432	828	975	1115	1186	1211	1208	1176	1151
lsd (0.05)	NS[a]	NS	NS	NS	68	66	72	82	91
Cutting Height, cm									
	N								
3.8	445	856	1004	1171	1274	1338	1371	1348	1317
5.1	438	849	1002	1157	1250	1306	1341	1326	1309
6.4	446	852	993	1137	1218	1273	1305	1294	1285
lsd (0.05)	NS	NS	NS	17	20	26	33	36	NS

[a]NS = not significant at the 0.05 level.

Species—Traction values for tall fescue and Kentucky bluegrass were not significantly different from each other but were significantly greater than for perennial ryegrass and red fescue at 2.54 to 5.08 cm of linear travel and at 10 to 40° rotation (Tables 1 and 2). Perennial ryegrass traction values were only significantly greater than red fescue at 30° rotation (Table 1) and between 3.81 to 5.08 cm of linear travel (Table 2).

Cutting Height—We found differences due to cutting height only for linear measurements. The 3.8 and 5.1-cm cutting heights had significantly greater traction values than the 6.4-cm cutting height from 1.90 through 3.81 cm of travel. Traction values for the 3.8-cm cutting height were significantly greater than those for the 5.1-cm cutting height at 2.5 through 3.2 cm of travel (Table 2).

Traction increased with increasing loading weight and significant differences in traction occurred at each increment of distance or rotation after initial movement occurred (Figs. 6 and 7). As with species and cutting height treatments, the forces associated with initial movement were not significantly different.

Loading Weight—Traction increased with increasing loading weight and significant differences in traction occurred at each increment of distance or rotation after initial movement occurred (Figs. 6 and 7). As with species and cutting height treatments, the forces associated with initial movement were not significantly different.

Comparison of Methods

Comparison of Rotational and Linear Traction with Shear Resistance—Using the shear vane, we measured the shear resistance on the species plots at the same time as we measured traction in the previous study. Shear resistance was not significantly correlated with rotational and linear traction. The correlation coefficients for rotational and linear traction versus the shear vane were $r = 0.30$ and $r = 0.18$ (both nonsignificant), respectively. We compared rotational, linear, and shear resistance measurements with tiller density, above-ground biomass, and below-ground vegetation in an attempt to find a basis for these differences (Table 3). The shear vane significantly correlated with below-ground vegetation while PENNFOOT did not. The shear vane seems to measure primarily the shear resistance of the soil and below-ground vegetation, probably because we force the fins of the apparatus through the turf and into the soil prior to making a measurement. The PENNFOOT, however, rests on the turf surface with depth of penetration being a function of soil moisture, turf density, shoe sole properties, and loading weight. We speculate that if we test the two methods on a very moist turf and soil environment, the correlation coefficient between the two methods may increase.

Comparison of Three Machines Tested on Four Grass Species and Three Cutting Heights—During the following growing season (1992), we tested the species plots using the PENNFOOT (rotational, 47.6 kg), Apparatus A, and the shear vane. PENNFOOT showed little separation among grass species and no separation among cutting heights using Shoe II (Table 4). Tall fescue provided the highest traction values at all positions measured.

The shear vane provided separation among all species with Kentucky bluegrass providing the most traction, but we found no separation among cutting heights (Table 4). Kentucky bluegrass is a rhizomatous species and the rhizomes (underground stems) no doubt contributed to the higher shearing forces associated with the species. With Apparatus A, traction on red fescue was significantly higher than on tall fescue, Kentucky bluegrass, and perennial ryegrass (Table 4). Using Apparatus A, traction was significantly greater at a cutting height of 3.8 cm than at 6.4 cm (Table 4). Although differences among species measured by an individual machine were small, all three machines detected a different species as providing the highest traction. A negative correlation existed between Apparatus A and PENNFOOT ($r = 0.81$) for grass species $\times$ cutting height means. The results indicate that these machines were differentially affected by turf under the conditions of this experiment. Neither Apparatus A ($r = 0.07$) nor PENNFOOT ($r = 0.02$) correlated well with the shear vane.

In this study the separation among species with rotational traction was less pronounced than in 1991. The possible factors contributing to this difference are different shoe type, characteristics of the stand (root biomass, tiller density, and above-ground biomass), and soil water content. Apparatus A had low correlation values with all plant characteristics. PENNFOOT's r values for below-ground vegetation and above-ground biomass decreased from 1991 to 1992 while tiller density r values increased (Tables 3 and 5). The shear vane had a higher correlation coefficient ($r = 0.93$) for below-ground vegetation in 1992 compared to $r = 0.77$ in 1991.

TABLE 3—*Correlation coefficients (df = 10) for PENNFOOT traction across all loading weights, grass species, and cutting heights versus the shear vane and for the machines versus below-ground vegetation, verdure, and tiller density for measurements taken September 1991.*

Treatments	PENNFOOT Rotational at 40°	Shear Vane	Below Ground Vegetation	Above Ground Biomass	Tiller Density
PENNFOOT Linear at 3.81 cm (shoe)	0.94[b]	0.18 NS[a]	0.55 NS	0.21 NS	−0.48 NS
PENNFOOT Rotational at 40° (shoe)		0.30 NS	0.57 NS	0.41 NS	0.30 NS
Shear Vane			0.77[b]	0.50 NS	−0.26 NS

[a]NS = not significant.
[b]= significant at 0.01 level.

TABLE 4—*Mean traction values for grass species across all cutting heights, and mean traction values for cutting heights across all species for measurements taken with shoe in August 1992.*

Variable	Apparatus A	Shear Vane	PENNFOOT (47.6 kg) at 40°
Species		Nm	
Red Fescue	25.3	18.1	14.5
Tall Fescue	23.1	15.8	16.4
Perennial Ryegrass	22.2	11.5	15.8
Kentucky Bluegrass	22.1	22.1	16.3
lsd (0.05)	1.4	1.3	0.9
Cutting Height, cm		Nm	
3.8	23.8	17.0	15.7
5.1	23.1	16.8	15.6
6.4	22.6	16.8	15.9
lsd (0.05)	1.0	NS[a]	NS

[a]NS = not significant.

TABLE 5—*Correlation coefficients* (df = *10) between the three machines across grass species × cutting heights and for the machines versus below-ground vegetation, verdure, and tiller density for measurements taken in August 1992.*

	Apparatus A	Shear Vane	Below-Ground Vegetation	Above-Ground Biomass	Tiller Density
PENNFOOT Rotational at 40° (shoe)	−0.81[b]	0.02 NS[a]	0.29 NS	0.10	−0.66
Apparatus A		0.07	−0.17	−0.32	0.29
Shear Vane			0.93	0.33	−0.10

[a]NS = not significant.
[b]= significant at 0.01 level.

Data from this study do not support the feasibility of calculating a coefficient of traction as defined by Canaway and Bell [*19*]. Besides the irregularities associated with the cleated sole and turf/soil surface, we found that the force required to initiate foot movement was always smaller than the force required to maintain movement. We would expect the opposite result if the properties governing friction applied to traction measurements. Higdon and Stiles [2] stated that for any given pair of surfaces with the same normal force, the kinetic friction will be less than the maximum static friction. Therefore, to apply the concept of a friction coefficient to traction, the force required to initiate movement of the foot should have been the largest force measured.

In order to determine what each machine is actually measuring, we suggest a detailed study utilizing a greater range of traction values in which the relative effect of various factors affecting each machine can be ascertained.

Comparison of the Five Methods to Measure Traction on Soil and Different Turf Densities—We designed this comparison to obtain a greater range of traction values for the various machines than we obtained previously. On the five areas tested, we obtained greater ranges of values with the PENNFOOT and shear vane than with Apparatus A (Table 6). With each method traction was greater with tall fescue, Kentucky bluegrass, and thinned turf than bare soil; however, full turf of tall fescue and Kentucky bluegrass gave greater traction than thinned turf only with the PENNFOOT and shear vane. Both the light and heavy-weighted PENNFOOT showed least traction on the compacted turfgrass roadway. The differences among methods on this compacted area appeared to be a result of differential penetration. Correlation between different machines was low, although high correlation occurred between the light and heavy-weighted PENNFOOT and between both procedures used with Apparatus A (Table 7). Correlation improved between PENNFOOT and Apparatus A when we placed rather than dropped Apparatus A, and the shear vane correlated better with Apparatus A when the drop procedure was used.

In the previous study where turf conditions were optimum across all the species, the three methods did not show much difference among species except the one that provided the highest traction values. In this study however, the three machines varied from one another, indicating that they are probably measuring something different; that is, soil and turf differentially affect the force required to rotate these devices. As mentioned in the results of the second study in 1991, the shear vane was thought to measure the shear resistance of the soil and below-ground vegetation rather than traction. Rogers [*21*] found with the shear vane that shear resistance increased with increasing bulk density. Apparatus A, using the standard drop procedure, had the highest correlation with the shear vane ($r = 0.66$). Both the shear vane and Apparatus A depicted the compacted turf roadway as providing relatively high traction. This result would indicate that Apparatus A is also measuring the shear resistance of the soil because the apparatus is initially dropped, allowing the studs to penetrate through the turf and into the soil.

Another possible explanation of the differences between Apparatus A and the PENNFOOT is the design of the machines. In order to measure the moment of torque, the forces acting on an object must be rotated about a central axis. We noticed that Apparatus A had a tendency to pivot during a measurement, displacing the center of the apparatus about 2.5 cm from the original starting position. It appeared that the pivoting occurred around one stud that remained stationary, while the others shifted.

Characterization of Grass Species, Using Smooth Sole Footwear

Using the PENNFOOT equipped with leather sole footwear, we were able to detect the often-observed differences in slipperiness among grass species. The mean rotational forces for grass species across the 5.1-cm cutting height and both the high (102.0 kg) and low (59.9 kg) loading weights were 17.4, 15.8, 15.1, and 12.2 Nm for perennial ryegrass, Kentucky bluegrass, tall fescue, and red fescue, respectively. The lsd (0.05 level) was 1.3 Nm. Thus, the data show that perennial ryegrass provided more "grip" than Kentucky bluegrass, tall fescue, and red fescue. Loading weight was also significant, as in previous studies. A loading weight of 102.0 kg induced an average traction/frictional force of 18.9 Nm while the 59.9-kg loading weight had an average force of 11.3 Nm. The species × loading weight interaction was not significant. Although this study confirmed the slipperiness of grass species, this type of

TABLE 6—*Mean traction values for the three machines and their procedures for measurements taken on bare soil and different turf densities in August 1992.*

Traction	PENNFOOT 102.0 kg (shoe)	PENNFOOT 59.9 kg (shoe)	Apparatus A Dropped	Apparatus A Not Dropped	Shear Vane
			Nm		
Tall Fescue	27.7	15.8	20.0	17.0	17.0
Kentucky Bluegrass	22.9	14.2	19.0	16.0	23.0
Thinned Turf Stand	21.2	13.3	20.0	17.0	15.0
Bare Soil	18.7	11.0	17.0	13.0	10.0
Compacted Turf Roadway	17.5	10.2	21.0	16.0	22.0

TABLE 7—*Correlation coefficients* (df = *10) between machines and their methods for measurements taken on bare soil and different turf densities in August 1992.*

Treatment	PENNFOOT (40°) 59.9 kg	Apparatus A Dropped	Apparatus A Not Dropped	Shear Vane
PENNFOOT (40°) 102.0 kg, shoe	0.97[b]	0.14 NS[a]	0.55 NS	0.10 NS
PENNFOOT (40°) 59.9 kg, shoe		0.11 NS	0.59[c]	0.12 NS
Apparatus A Dropped			0.84[b]	0.66[c]
Apparatus A Not Dropped				0.55 NS

[a]NS = not significant.
[b]= significant at 0.01 level.
[c]= significant at 0.05 level.

testing procedure is not adequate for athletic field characterization due to cleated footwear worn by athletes.

Summary and Conclusion

Player safety on athletic fields is a very important issue. Traction as it relates to field safety involves the athlete, cleated footwear, and the turf. The variability among grass species and cultural practices associated with athletic fields may provide the largest influence on traction; however, these conditions have not been well documented.

In this study, we wanted to develop an apparatus to measure traction on natural turfgrass; determine how different cutting heights, species, and loading weights influence traction on athletic field turf; and compare our device with others used to measure traction.

The PENNFOOT traction-measuring apparatus allows us the flexibility to measure both linear and rotational traction, change the amount of loading weight on the foot, and change the footwear that is in contact with the turf. The hydraulic system used to create tractional forces and the leg-and-shoe assembly are essential components of this apparatus. The frames, however, could be more compact and lighter as long as the apparatus does not move during a measurement.

The development and testing stages of the PENNFOOT provided useful information concerning traction. We found traction values increased as degrees of rotation or linear increments increased. Treatments did not affect forces at initial movement for linear and rotational measurements. Most significant differences among treatments occurred at 2.54 to 5.08 cm for linear traction and at 30 and 40° for rotational traction. Thus other increments could be neglected in data collection. If only the highest traction value is desired and if the distance or rotation point of this value is not of concern, one person could operate the PENNFOOT.

Comparing our traction results with the properties of static and kinetic friction, we concluded that a coefficient of traction as proposed by researchers in the past does not exist under these test conditions and should not be calculated.

The trends for both linear and rotational measurements were very consistent across all variables tested, and indicate that maximum tractional forces will occur at 3.2 cm for linear traction and 40° for rotational traction. It should be noted that even though 40° provided the highest traction values, separation among grass species, cutting height, and loading weight occurred at 30° for rotational measurements.

Grass species, cutting height, and loading weight affected traction, although the effects were not always the same for rotational and linear traction. Traction values for tall fescue and Kentucky bluegrass were not significantly different from each other but were significantly greater than perennial ryegrass and red fescue at 2.5 to 5.1 cm of linear travel and at 10 to 40° rotation. Differences in cutting height were obtained only for linear measurements, with lower cutting heights providing greater traction. Traction values increased as loading weight increased.

Comparisons of PENNFOOT to other traction-testing machines on different species, cutting heights, and different turf densities resulted in low correlations. We proposed that the other traction measuring apparatuses were not measuring the same variables as the PENNFOOT; however, we believe that the PENNFOOT, more than the other devices, is measuring characteristics of the turf that relate to traction as experienced by a player.

More work is needed on turf and soil characteristics that influence traction and on the geometry of traction-testing machines. When this information is obtained, we can determine the appropriateness of the different machines. At present, it seems important to make traction measurements using methods that approximate the type of traction (linear or rotational), loading weight, footwear, and contact with the turf surface that are similar to real conditions.

Ideally, results with instrumentation will correlate with players' assessments of traction. Such comparisons need to be made in future research. The results of this research are based on the conditions used in the various experiments. Different shoe designs and differing environmental factors such as soil texture, soil water content, surface wetness, thatch, and other vegetative characteristics may have a strong influence on future results.

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