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FRICTIONAL AND TRACTIONAL CHARACTERISTICS
OF VARIOUS SHOE-SURFACE INTERFACE COMBINATIONS
ON WET AND DRY NATURAL AND ARTIFICIAL TURF

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Thomas E. Mallette

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Sally E. Nogle
Major professor

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FRICTIONAL AND TRACTIONAL CHARACTERISTICS OF VARIOUS SHOE-SURFACE INTERFACE COMBINATIONS ON WET AND DRY NATURAL AND ARTIFICIAL TURF

By

Thomas Eric Mallette

A THESIS

Submitted to
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Abstract

FRICTIONAL AND TRACTIONAL CHARACTERISTICS OF VARIOUS SHOE-SURFACE INTERFACE COMBINATIONS ON WET AND DRY NATURAL AND ARTIFICIAL TURF

by

Thomas E. Mallette

The debate over the safety of athletic competition on artificial compared to natural turf has continued since the first artificial surface was installed. The current research attempted to compare the amount of force required to move selected athletic shoes across artificial and natural grass surfaces under wet and dry conditions.

Testing included the use of a portable apparatus termed the PENNFOOT. The PENNFOOT was able to accommodate weight up to 300 pounds, test various shoes, and be transported to different locations. PENNFOOT was used to test the shoe-surface interface of selected athletic footwear that would be utilized on both wet and dry artificial and natural turfs.

Results showed that there are significant differences in the force required for movement between various shoe-surface interface combinations. Throughout all experiments, the shoe-surface interface combinations on artificial turf required more force to move the selected footwear across the surface compared to the natural grass combinations.

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CHAPTER 1

INTRODUCTION

The first artificial surface for athletic use was installed in 1964 (Levy, Skovron, & Angel, 1990). The development of artificial surfaces has initiated an ongoing debate over the safety of synthetic playing surfaces. Recently, the war of words has increased against the use of artificial playing surfaces in American football. Several professional football franchises have converted their artificial surfaces to natural grass in response to the players' criticism about playing on the artificial surfaces. The participants in American football have long complained of the hardness of the artificial surfaces, the increased incidence of abrasions, and most importantly, the athletic shoe "sticking" to the surface. Previous studies (Ekstrand & Nigg, 1989; Torg & Quedenfeld, 1971) have shown that with an increase in traction there is an increase in injury rates. Many players have blamed the artificial surface for the injuries they have sustained and not the game itself.

Researchers (Adkinson, Requa, & Garrick, 1974; Baker & Bell, 1986; Bostingl, Morehouse, & Niebel, 1975; Bramwell, Requa, & Garrick, 1972; Canaway & Bell, 1986; Dick, 1992; Ekstrand & Nigg, 1989; Keene, Narechania, Sachtjen, &

Clancy, 1980; Powell & Schootman, 1992; Nigg & Segesser, 1988; Stanitski, McMaster, & Ferguson, 1974; Torg & Quedenfeld, 1971; and Torg, Quedenfeld, & Landau, 1974) have used various methods to study differences between artificial and natural surfaces. These methods have included prospective studies (Adkinson et al.; Bramwell et al.; Keene et al.; and Torg & Quedenfeld, 1971) and retrospective studies (Dick; Keene et al.) that examined injury rates on natural grass compared to artificial turf. A study by the National Football League Players Association (NFLPA, 1994) surveyed athletes on their perceptions of participating on natural grass compared to artificial surfaces. Additionally, studies have used apparatuses to simulate the shoe-surface interface in order to make comparisons between natural and artificial surfaces (Andreasson, Lindenberger, Renstrom, & Peterson, 1986; Bostingl et al.; Bowers & Martin, 1975; Canaway & Bell; Culpepper & Niemann, 1983; Torg et al; and Torg, Stilwell, & Rogers, 1996).

Although many types of research have been completed, the results have been conflicting. The prospective and retrospective studies of high school, college, and professional football injuries, overall, have shown differences in injury rates while participating on artificial surfaces when compared to natural surfaces (Adkinson et al., 1974; Bramwell et al., 1972; Keene et al., 1980; and Torg & Quedenfeld, 1971). Bramwell and colleagues, and Keene and colleagues found that there are higher injury rates on natural grass compared to artificial surfaces. Adkinson et al. found injury rates to be significantly higher on AstroTurf (AstroTurf Industries, Dalton, GA) than on natural grass. There is strong evidence, however, of an increase in minor injuries such as contusions and abrasions on artificial surfaces (Bostingl et al., 1975; Bowers & Martin, 1975; and Keene et al.). Through the years athletes' perceptions of playing on artificial surfaces have gone from good to bad. The last few years have produced an even greater negative impression when it comes to athletic participation on artificial surfaces (King, 1993; NFLPA, 1994). This may be partly due to representatives of the news media, who make unsubstantiated claims after an athlete is injured on artificial turf. The results of studies investigating the shoe-surface interface have been inconsistent, likely due to the number of different methods, apparatuses, and surfaces tested (Andreasson et al., 1986; Bostingl et al.; Bowers & Martin; Culpepper & Niemann, 1983; Middour, 1992; Torg et al., 1974; and Torg et al., 1996).

Researchers who have studied the shoe-surface interface have concentrated on the frictional components or traction of the shoes interacting with the surface. Friction can be defined as a force that opposes motion or impending motion and is expressed in terms of its coefficient (u). The coefficient of friction is the ratio of the frictional (tangential) force to the vertical (normal) force applied.

In the athletic setting, two types of friction have been studied: sliding friction, and static friction. Sliding friction was the focus of this study.

Need for the Study

Past studies (Andreasson et al., 1986; Bostingl et al., 1975; Bowers & Martin, 1975; Culpepper & Niemann, 1983; Middour, 1992; Torg et al., 1974; and Torg et al., 1996) of the shoe-surface interface have tested variables such as different artificial playing surfaces, frictional differences between natural and artificial surfaces, and the differences in various footwear on natural and artificial surfaces. Additional study involving the shoe-surface interface should be completed due to the inconsistent results of previous studies. The inconsistent results may have been due, at least in part, to the dissimilar methods and apparatuses used in these studies. Many of the apparatuses developed to test the shoe-surface interface were constructed for use in laboratories making them unusable to test actual and natural surfaces.

The current study was different from other studies because it involved the use of a portable test apparatus, the PENNFOOT, that could be moved to the desired surface to be tested. Unlike past studies where plots of natural grass or turf were secured under the test apparatus, the PENNFOOT can be transported to an actual playing surface. Other benefits of the PENNFOOT were that it could accommodate normal loads up to 300 pounds, simulating a potential vertical load on an athlete's foot, and it could test any size 10 shoe.

Purpose of the Study

The profession of athletic training deals with the prevention of potential injuries. More must be understood about the shoe-surface interface in order for the athletic training profession to make safety recommendations to the football community about playing surfaces and footwear used for practice and competition. The goal of this research was to determine differences in the frictional component of the shoe-surface interface by testing various footwear on wet and dry artificial and natural surfaces. Past researchers have hypothesized that the higher the frictional or tractional coefficient (u) the higher the injury rate (Andreasson et al., 1986; Bostingl et al., 1975; Culpepper & Niemann, 1986; Nigg & Segesser, 1988; and Torg et al., 1974). Bostingl and his colleagues stated, "the shoe-surface combinations that develop the highest torques present the greatest possibility that a player will sustain a knee injury" (p. 127). Culpepper and Niemann stated "a shoe-turf interface demonstrating a higher release coefficient indicates a greater interlocking of the cleats with the turf. The greater the interlocking of the cleats with the turf, the greater the risk of torque related injury to the knee or ankle" (p. 387). Torg and colleagues developed a scale determining the safety of athletic shoes based on the shoes release coefficient (r= Force/Weight). An attempt was made to correlate findings of the present study's findings to Torg and colleagues' release coefficient scale. Based on the conclusions of the current study, safety recommendations can be made regarding the safest shoe to be worn on a particular playing surface and playing condition.

Research Hypotheses

This study included four separate experiments. These experiments involved the testing of various combinations of the shoe-surface interface. Each study warrants its own hypothesis.

Experiment 1. Frictional Characteristics of the Reebok Dry Rat on Dry AstroTurf Compared to the Tractional Characteristics of the Reebok Vicious on Dry Natural Grass.

This study tested footwear that could be worn on natural and artificial surfaces under normal, dry conditions. It was hypothesized that the Reebok Dry Rat, a shoe developed for AstroTurf, would have a higher coefficient of friction than the Reebok Vicious, which was developed for natural grass use. This hypothesis was based on the idea that the grass shoe would be able to break through the root zone and slide through the surface while the artificial turf shoe would "stick" to the surface, the artificial turf shoe would "stick" to the surface, yielding a higher coefficient of friction.

Experiment 2. Frictional Characteristics of the Reebok Wet Rat on Wet AstroTurf Compared to the Tractional Characteristics of the Reebok Vicious on Wet Natural Grass.

As in Experiment 1, this study tested footwear that would normally be used on a particular surface and condition. The Reebok Wet Rat was developed for use on wet AstroTurf and the Reebok Vicious was developed for all types of natural grass conditions. It was hypothesized that the Reebok Vicious would have a higher coefficient of friction based on the shoe's ability to dig into the natural grass surface. The Reebok Wet Rat on wet AstroTurf would not have the ability to penetrate the surface and would slide more easily across the surface, yielding a lower coefficient of friction.

Experiment 3. Frictional Characteristics of the Reebok Dry Rat and the Reebok Wet Rat on Dry AstroTurf Compared to the Frictional Characteristics of the Reebok Dry Rat and Reebok Wet Rat on Wet AstroTurf.

The shoes in this experiment were both developed for use on artificial surfaces. The Reebok Wet Rat was developed for use on wet artificial surfaces and the Reebok Dry Rat on dry artificial surfaces. It was hypothesized that the Reebok Wet Rat would have a higher coefficient of friction on both wet and dry AstroTurf than the Reebok Dry Rat on wet and dry AstroTurf. The Reebok Wet Rat contained a rubber studded outsole with multiple cleat projections for increased grip on a wet playing surface. Therefore, the Reebok Wet Rat should require more force to move the shoe across a wet and dry artificial surface than the Reebok Dry Rat which contained a flat surface similar to a basketball shoe.

Experiment 4. Tractional Characteristics of the Reebok Vicious and the Reebok Pit Bull on Dry Natural Grass Compared to the Reebok Vicious and the Reebok Pit Bull on Wet Natural Grass.

The shoes tested in Experiment 4 were both developed for use on natural grass surfaces regardless of condition. It was hypothesized that the frictional coefficients of the Reebok Vicious and Reebok Pit Bull would be similar on both wet and dry natural grass, e.g., not significantly different from each other. This hypothesis was based on the premise that both shoes were developed for the same surface regardless of condition.

Limitations of the Study

Limitations of this study included the fact that shoe types from only one manufacturer were used in the collection of data so the results apply only to the single shoe manufacturer's athletic footwear. Due to uncontrollable circumstances the data collected on natural grass had to be performed in a indoor research facility rather than on an actual athletic playing surface. A final limitation of the study was the test apparatus itself. The PENNFOOT was unable to accommodate enough weight to simulate the vertical forces an athlete produces at the shoe-surface interface while running and/or cutting during an athletic competition which could be six or more times body weight. Secondly, the PENNFOOT was not biomechanically correct in relation to hip, knee, and ankle movements associated with dynamic running and cutting activities. Finally, the PENNFOOT could only accommodate a size ten athletic shoe, the apparatus was unable to test other size footwear.

Significance of the Study

The increasing number of athletes participating in sports on both artificial and natural surfaces results in an increasing number of athletic injuries to participants. This study was conducted to answer just one of the many questions in regards to injury prevention. The ability to determine the appropriate shoe to use on various surfaces and surface conditions would greatly increase the ability of athletic trainers to recommend the safest shoes for a particular surface.

Definitions

Coefficient of sliding friction- the ratio of the sliding frictional force to the normal force (McNitt, 1994).

Coefficient of static friction- the ratio of the static frictional force to the normal force (McNitt, 1994).

Force- an action capable of accelerating an object; force= mass x acceleration, presented in units of Newtons (N), (Hay, 1985).

Friction- the force distribution at a surface of contact between two bodies that prevents or impedes sliding motion between two bodies (Culpepper & Niemann, 1983).

Sliding friction- the friction developed by one object moving across another (Hay, 1985).

Sliding traction- the ratio of the sliding tractional force to normal force in relation to cleated footwear (Bell, et al., 1986; McNitt, 1994).

CHAPTER 2

Review of the Literature

The review of literature will be divided into four sections. The first section contains a discussion of forces and friction and the procedure for calculating the coefficient of friction and traction; the second section contains a history of artificial surfaces; the third section contains a review of retrospective surveys as well as player perceptions of playing surfaces; and, a final section provides a review of past research involving various apparatuses to test the frictional and tractional components of the shoe-surface interface.

Forces and Friction

In order for the athletic shoe to slide across an athletic playing surface, a force must be exerted to overcome the static frictional or tractional characteristics of the two surfaces. The pushing or pulling effect that the musculoskeletal system has and which causes movement of the shoe across the surface is termed force (Hay, 1985). Two types of force exist in this situation, horizontal force and vertical force. The horizontal force is the force necessary to move the shoe across the surface while the vertical or normal force is the downward force acting upon the body and the shoe. The unit of force is expressed as Newtons (N) and can be described in terms of the acceleration the force produces (Hay, 1985).

As the musculoskeletal system initiates force to move the shoe across the surface, another force (termed friction) acts to oppose the motion and this force (Hay, 1985). In this case, friction is present at the shoe-surface interface. As the shoe attempts to move across the surface, a static frictional force must be overcome in order for movement to take place. Bell, Baker, and Canaway (1985) defined the term "friction" as applying to smooth soled footwear and the term "traction" to having studs, cleats, or spikes to provide extra grip. Canaway (1978) described how the forces act in walking with smooth footwear.

> In walking, the horizontal forces applied by the foot are opposed by the frictional forces which provide "grip". When these frictional forces are small, the surface is experienced as slippery. While the foot is in contact with the ground, the values of both the horizontal and vertical forces change rapidly due to such factors as vertical movement of the body, the walker propelling himself/herself forward, etc. If the horizontal force produced by the body exceeds the maximum frictional force, the foot slips.

Horizontal forces can be divided into sliding and rolling friction. Rolling friction can be described as the friction encountered between a ball and the playing surface, while sliding friction is the friction developed by one object sliding across another. In this research, the purpose was to study sliding friction or the shoe sliding across the playing surface. When the shoe is in contact with the surface, it is being acted upon by two forces: one, the weight of the athlete; and the other, a supporting force exerted by the floor. Under the action of these forces, the shoe has no tendency to slide across the floor and thus there is no frictional force acting to oppose movement. If the athlete initiates muscular contraction to move the shoe across the surface or is acted upon outside forces (e.g., a tackler), the shoe will tend to slide. It is only at this point that friction will act in opposition to this tendency (Hay, 1985). To measure the frictional components of the movement of the shoe across the surface, a coefficient of friction is calculated. The coefficient is the ratio of the frictional force (the amount of force required to move an object across a surface) and the vertical force applied. The frictional coefficient can be calculated as follows :

$$u = \frac{Fh}{Fv}$$

As stated previously, friction applies to smooth soled footwear and the term traction applies to shoes having studs, cleats or spikes. Bell and co-workers (1985), stated that in the case of traction, there is not a well established law, but similar principles apply. Thus coefficients of traction can also be calculated. Both friction and traction coefficients can be considered in terms of either the force required to initiate motion or the force required to maintain motion once started. The coefficients of friction and traction are referred to as "static" and "dynamic" coefficients for the two situations, respectively (Baker et al., 1985).

Historical Perspectives of Artificial Surfaces

The first artificial surface was installed in the fieldhouse of the Moses Brown School in Providence Rhode Island in 1964 (Levy et al., 1990). Although the first artificial surface installed was for athletic competition, the development of the surface was for different reasons.

It was concluded after the Korean War that rural recruits were in better physical condition than urban recruits (Levy et al., 1990). It was conjectured that the primary reasoning for the difference in physical condition was a lack of suitable play areas for urban children. In 1960 the Ford Foundation created the Educational Facilities Labatory (EFL). The EFL's main objective was the development of rooftop playgrounds for the urban setting. From the work of the EFL and several other companies, the first ChemGrass field was installed in the Moses Brown first ChemGrass field was installed in the Moses Brown fieldhouse. The artificial surface was the first of its kind and it is still in use today.

In 1965 the Astrodome in Houston, Texas was completed as a multi-use facility. The ceiling of the dome was constructed of skylights, but it was soon discovered that the glare from the skylights would blind the outfielders. The skylights were then painted causing the natural grass to die. Monsanto AstroTurf (3M, St. Paul, MN) was laid over the floor and the first artificial surface was in place for professional athletics (Levy et al., 1990). By 1980, over 300 fields in the United States and abroad had been installed with Astroturf.

The market for artificial athletic surfaces grew with the popularity of the surfaces. Several companies developed their own versions of artificial surfaces. Tartan Turf (3M; St. Paul, MN), PolyTurf (American Bilt-rite; Wellesley, MA), Omniturf (Sportec; Kenmore, NY), and Poligras (Adolff Company; West Germany) all presented products to the market. Today, AstroTurf (AstroTurf Industries Inc.; Dalton, Georgia) is the most widely used artificial surface in the United States (Levy, et al., 1990).

Prospective and Retrospective Studies of Playing Surfaces

Several prospective and retrospective studies as well as player perception surveys in regards to participating on natural and artificial turf have been conducted. A problem that has been encountered with such studies is the inconsistencies of playing surfaces tested. An artificial surface may include several different brands of turf, differences in age of the surface, and differences in underpadding. The natural grass may incorporate different species of grass; and the type, soil compaction, and moisture content of soil may vary. Even though the inconsistencies exist, many research articles have been published since 1970 in this area.

In 1970, Bramwell et al. conducted a prospective survey of 26 high school teams in the Seattle area. Prior to the start of the season, questionnaires were sent to team officials whose teams play on both artificial and natural surfaces. Data were collected on 228 varsity football games involving over 1,350 varsity players, and 139 time loss injuries. It was found that injury rates were higher on artificial surfaces than on natural grass. However, the only injury differences encountered between surfaces was due to the footwear used. On the artificial surfaces, shoes with multiple molded short cleats were used, and on natural grass, shoes with longer cleats were used. Overall, 77 injuries occurred in 148 games on grass fields for a rate of 0.52 injuries per game compared to 62 injuries in 80 games on artificial surfaces for a rate of 0.76 injuries per game. The incidence of "serious" injuries, defined as missing two or more games, were virtually identical on the two surfaces. The authors also concluded that the injury rates on the artificial surfaces were higher when the surface was dry and suggested the possibility that tractional characteristics rather than impact qualities of the turf should be investigated as a higher priority.

Adkinson and colleagues (1974) followed up the previous study with an injury survey of 73 high schools in the Seattle and Spokane, Washington areas as well as the Portland, Oregon area. Combined, data were collected for 660 varsity football games. Four hundred and twenty four of the games were played on natural grass and 236 were played on artificial surfaces. The artificial surfaces included AstroTurf and Tartan Turf. There was no attempt to standardize the natural grass fields other than the requirement that the field be covered with turf at the beginning of the season. For all the surfaces, 349 time-loss injuries were reported, 218 of which occurred during the 424 games played on natural grass giving an injury rate of 0.51 injuries per game. The AstroTurf fields accounted for 116 injuries in 183 games with an injury rate of 0.63 injuries per game. The Tartan Turf fields accounted for 15 injuries in 53 games for an injury rate of 0.28 per game.

Adkinson and colleagues (1974) concluded that the injury rate on AstroTurf in a dry condition was significantly higher than on wet AstroTurf. A wet surface was identified as an artificial playing surface that was watered down with a hose prior to competition. Injury rates on the Tartan Turf differed significantly from those on grass and Astroturf. The injury rates were significantly lower on the Tartan Turf than on both grass and AstroTurf. A higher incidence of injuries occurred on the Tartan Turf when the surface was wet compared to when it was dry. The conclusions indicated that the type of playing surface influences the rate of injuries sustained, but no attempt was made to define whether the injury was due to the shoe-surface interface or to the impact qualities of the playing surface.

Keene et al. (1980) attempted to remedy the problem of collecting data on different brands of artificial turf by sending questionnaires to former varsity football players at the University of Wisconsin. The University had used Tartan Turf since 1966. Questionnaires were sent to all former players who competed between 1960 and 1973. Two hundred thirty-five of 450 athletes returned the questionnaires. The Tartan Turf was not installed until 1966 so all players prior to that time practiced and played on grass. The natural grass was only described as being extremely well kept and covered throughout the season. The questionnaire included items relating to the type and severity of the injury, field type and condition, and several other variables. Participants indicated if the injury that they sustained occurred while they played on either natural grass or on the Tartan Turf.

Overall, the research showed that there were significantly more serious sprains and torn ligaments occurring on natural grass than occurred on the Tartan Turf. Conversely, there were also significantly more minor injuries on the Tartan Turf than on the grass. The findings were similar to those of Adkinson et al. (1974) who also found lower injury rates on Tartan Turf compared to natural grass.

Nigg and Segesser (1988) attempted to correlate the findings of previous retrospective and prospective research. Thirty-two studies discussing the association of injuries with playing surfaces were analyzed. The data were divided into two categories of injuries, (severe and not severe), and three sites of injuries (general, knee, and others). The data were compared for injury frequency using three separate categories that included 10 percent more injuries on artificial than natural surfaces, about the same number on each surface, and at least 10 percent less injuries on artificial than on natural grass. Several results that were found directly related to the artificial compared to natural surface debate. The fields with artificial turf were reported to have more non-severe injuries than fields with natural grass. It was also speculated that severe injuries were about as frequent on artificial turf as on natural grass. Finally, higher injury rates were found when the shoe-surface interface had a higher frictional value.

Powell and Schootman (1992) conducted an epidemiological study of knee injuries that occurred in the National Football League (NFL) between 1980 and 1989. The study focused on the rate of injury for natural grass and AstroTurf surfaces as well as the risk factors of player position and the type of play. During the years of the study, the athletic trainers for each NFL club collected the data used in the study. Data were recorded on a day-to-day basis and reported regularly to the research office. Injuries that were considered reportable included any brain concussion that caused cessation of participation of the athlete for observation, any fracture, and any injury that caused the athlete to miss practice or a game throughout two participation days after the onset. Other factors that were recorded included the exposure rate and the type of surface that the practice or game was played on. Throughout the ten years of the study, the number of participants was counted for each practice or game, but final data analysis regarding injuries that occurred during games was used to study the relationship between the type of surface and the occurrence of knee sprains. Four different surfaces were studied, including natural grass, AstroTurf, Superturf (Superturf Inc, Dallas, TX) and Tartan Turf. Of the artificial surfaces, only 7.5 percent of the injuries occurred on the Superturf and Tartan Turf so the study was limited to comparing injuries that occurred on AstroTurf and natural grass surfaces.

Results of the study included 10,326 game-related injuries on all surfaces. During the 10 years of the study, 19.3 percent of the players suffered more than one knee sprain, 3.1 percent injured the same side more than once and 1.4 percent injured the opposite knee. The general injury rate for all the knee sprains was 0.21 per game. The knee sprain injury rates for natural grass was 0.20 and 0.22 per game for AstroTurf. While indicated as significant, the estimated etiologic fraction projected only 6.2 percent of the reported knee sprains to be attributable to playing on AstroTurf. It was concluded that there was an increased risk for knee sprains under certain conditions, such as player position, and type of play performed on the AstroTurf. The researchers recommended that further research include a study of the shoe-surface interface as well as player height, weight, and other specific factors that occur at the time of the injury.

Since 1982, the National Collegiate Athletic Association (NCAA) has been researching injury trends in intercollegiate athletics. The NCAA developed the Injury Surveillance System (ISS) in order to provide current and reliable data on injury trends (Dick, 1992). Injury data were supplied by athletic trainers to the ISS from 10 to 15 percent of the NCAA institutions. In order for the injury to be reportable, the athlete must have received an injury in an intercollegiate practice or game, required medical attention from the institution's athletic trainer or physician, and restricted physical activity for at least one day. Some limitations of the ISS were that institutions were randomly selected on a volunteer basis reflecting both a geographical and divisional distribution, and the accuracy of the submissions by the institutions' athletic trainers. One of the results of this ongoing study is a comparison of injury rates on natural and artificial turf. However, the institutions selected for participation in ISS may not represent an even distribution of playing fields with natural and artificial turfs.

ISS results for the 1981-1988 football season indicate that no significant differences occurred in injury rates on artificial and natural turfs. Another conclusion reported in the survey was that offensive backs and receivers were more likely to sustain injuries on artificial turf, while linebackers and defensive backs were more likely to sustain injuries on natural turf.

As of September 1993, 56 Division I NCAA institutions played their home football games on natural grass while 51 institutions played their home games on artificial turf (Berg, 1993). In the National Football League (NFL), 14 teams play on artificial turf and 16 teams play on natural grass. Only four teams in the last 10 years have converted back to natural grass. Several other teams are considering a switch to natural grass because of player preference.

Many NFL players have called for an end to artificial turf for many years. Players' concerns have been passed onto the public through popular sports magazines. Peter King, a column writer for Sports Illustrated, has written about the perceptions and complaints of football players about playing on artificial turf. King's most recent article (1993) relating to artificial turf, lists players who were injured on artificial surfaces, but there is no mention of players who sustained similar injuries on natural grass.

In a survey conducted by the National Football League Players Association in 1994, 13 questions were asked in relation to player perceptions about competing on grass and artificial turf. Overwhelmingly, NFL players chose to play on natural grass in all categories including factors such as temperature, and wet and dry conditions. Ninety-three percent of the players responding believe that artificial turf is more likely to contribute to injury.

The fact that past studies have been inconclusive in determining which type of surface contributes to injury shows the importance of further research in this area, particularly since players are clearly dissatisfied with artificial turf. The following portion of the literature review will be devoted to past research in the area of the shoe-surface interface, including testing apparatuses, and the results of such research.

Shoe-Surface Interface

An important aspect of the game of football is the relationship between the frictional qualities of the shoe and the surface. On natural turf, traction results from both the cleat-surface friction as well as the cleat penetration of the surface. On artificial turf, traction is mainly the result of the shoe surface to playing surface friction in which both the qualities of the shoe and the surface are important (Bowers & Martin, 1975). The tractional characteristics of the shoe- surface interface must be sufficient to satisfy the requirements of the game under the conditions in which it is played, permitting the players to stop and start quickly and to cut sharply (Merritt & Thomson, 1978). Excessive shoe-surface traction, however, has been identified as an important casual factor in the incidence in knee and ankle injuries (Bonstingl et al., 1975; Bowers & Martin; Torg & Quedenfeld, 1971; and Torg et al. 1974).

Several studies (Andreasson et al., 1986; Bonstingl et al., 1975; Bowers & Martin, 1975; Canaway & Bell, 1986; McNitt, 1994; Middour, 1994; Torg & Quedenfeld, 1971; Torg et al., 1974; and Torg et al., 1996) have concentrated on the relationship between the shoe-surface interface and injuries. A summary of past shoe-surface interface studies can be found in Table 1.

In the earliest research involving the shoe-surface interface, Torg and Quedenfeld (1971) studied the effect of

Table 1.
Summary of Shoe-Surface Studies.

Study	Apparatus	Surfaces(s)	Location(s)	Condition(s)	Footwear	Findings
The Shoe-Surface Interface and its Relationship to Football Knee Injuries. (Torg et al., 1974)	Assay device	Natural grass Dirt AstroTurf Tartan Turf Poly-Turf	Football field Baseball Field Laboratory Laboratory Laboratory	Wet and dry Dry Wet and dry Wet and dry Wet and dry	Three classes: conventional soccer type experimental	Release coefficients varied depending on the condition of the surface and the shoe used on the surface.
Torques Developed by Different Types of Shoes on Various Playing Surfaces. (Bostingl et al., 1975)	Weighted pendulum	Natural grass AstroTurf Tartan Turf Poly-Turf	Wooden pallet Artificial surfaces bonded to heavy plywood	Dry	11 shoe types: included swivel shoe, multicleated soccer-type shoe, non-cleated basketball-type shoe, and a conventional ¾- inch football shoe	The amount of torque developed at the shoe-turf interface is dependent on several factors, including the type of shoe, weight, and the player stance.
Cleat-Surface Friction on New and Old AstroTurf. (Bowers & Martin, 1975)	Crank tower	AstroTurf, new and old	New AstroTurf was tested in laboratory setting, old was tested on actual playing surface	Wet and dry for both surfaces.	1. Riddell 78, poly-urethane screw on type cleat 2. Riddell 391, red-molded urethane sole (slightly worn) 3. Riddell 391, (very worn) * Note- cleats were removed from shoe and attached to cleat platform	With use and exposure AstroTurf undergoes physical changes resulting in cleat-surface friction changes. Also cleat wear of the shoe most commonly used on AstroTurf, the Riddell 391, has little effect on friction.
An Investigation of the Shoe-Turf Interface Using Different Types of Shoes on Poly Turf and AstroTurf: Torque and Release Coefficients. (Culpepper & Niemann, 1983)	Modified Workbench with torque wrench	AstroTurf Poly Turf	Laboratory Laboratory	Wet and dry	1. Adidas- soft molded nonconventional shoe with 54 cleats 2. Black Puma- a soft molded soccer-type shoe with 23 cleats 3. White Puma- a soft molded nonconventional shoe with many "button" type cleats 4. SA 63 Spotbilt- a semi-soft molded soccer-type shoe with 15 cleats 5. VK 22 Spotbilt- a semisoft molded nonconventional shoe with multisized, square-triangular shaped cleats	Any given shoe demonstrates different shoe-turf characteristics on different surfaces and different shoes demonstrate different shoe-turf characteristics on any given surface condition.
Torque Developed at Simulated Sliding Between Sport Shoes and a Artificial Surface. (Andreasson et al., 1986)	Circulating disc with aluminum leg and foot	Poligrass	Laboratory	Dry	25 different artificial and natural turf shoes including: running, tennis, and soccer shoes	The physical distribution of the sole at the heel and toe, as well as the material of the shoe, is of great importance for the torque developed.

Table 1. (cont'd)
Summary of Shoe-Surface Studies

Study	Apparatus	Surfaces(s)	Location(s)	Condition(s)	Footwear	Findings
Technical Note: An Apparatus for Measuring Traction and Friction on Natural and Artificial Turf. (Canaway & Bell, 1986)	Studded disc with torque wrench	N/A	N/A	N/A	N/A	Canaway and Bell describe an apparatus that they developed, an actual study was not described.
Development and Evaluation of a Method to Measure Traction on Turf-Grass Surfaces. (Middour, 1994)	PENNFOOT	Natural grass	Actual surfaces	Dry	Nike- conventional football shoe Nike- multicleated football shoe	The coefficient of traction that has been proposed by previous researchers does not exist and should not be calculated.
The Effect of Ambient Temperature on the Shoe-Surface Interface Release Coefficient. (Torg et al., 1996)	Assay device	AstroTurf	Actual playing surface	Dry	1. Flat-soled basketball-style turf shoe 2. Three multistudded turf shoes 3. Natural grass soccer-style shoe	Release coefficients differ both within and among models across a range of turf temperatures.

shoe type and cleat length in relationship to the incidence and severity of injuries in high school football players. The Philadelphia Public High School and Catholic High School Leagues participated in this study and all data collected occurred on natural grass. There was no attempt to characterize the fields that were used in this study in regards to soil type, percent turf cover, or the type of turf. In 1968 the Public High School League wore conventional football cleats and in 1969 the Catholic League wore the conventional football cleats. In 1969 the Public School League switched to soccer style cleats which consisted of a molded sole and fourteen 3/8-inch cleats. In 1970 both leagues wore the soccer style cleats. Through out the duration of the study all knee injuries were documented. Results of the study indicated a large decrease in both the incidence and the severity of knee injuries in both leagues when the players wore the soccer style or multicleated shoe. Torg and Quedenfeld recommended that the conventional football shoe be condemned and only shoes with a molded bottom (minimum 14 cleats per shoe, minimum cleat diameter of 1/2 inch, and a maximum cleat length of 3/8 inch) be used for football.

In a later study by Torg et al. (1974) a test apparatus was developed to correlate the clinical findings of the study performed in the Philadelphia Public and Catholic High Schools. The assay device was developed to measure the amount of torque necessary to release an engaged shoe-surface interface. The device consisted of a prosthetic foot mounted on a loaded stainless steel shaft. The load could be changed and it was equally distributed on the forefoot and the heel. A force was applied to a torque wrench and measurements of the torque necessary to release or pivot the loaded shoe were taken. Various shoes and load combinations were tested. The researchers used the equation r= Force/Weight, where r= the release coefficient for a given shoe-surface combination, Force= the torque, and Weight= the axial load. A table was designed which classified the tested shoes based on their release coefficient into a specific category. The categories included "not safe", "probably not safe", "probably safe", and "safe". The researchers concluded that the release coefficient varies with the number, length, and diameter of the cleats as well as with the type of surface (natural or artificial), and condition of the surface (wet or dry). The conventional football cleat was found not to be safe on grass while the molded soccer type shoe was found to be safe on all surfaces.

In 1996, Torg et al. used the same assay device and procedure to evaluate the effects of temperature changes on shoe-surface (AstroTurf) release coefficients. Results showed that release coefficients differ between shoe type and turf temperature. The average release coefficient for all shoes combined was 0.41. The release coefficient increased 19.4 percent between artificial turf temperatures of 52 and 110 degrees F. Thus, an increase in temperature combined with cleat design and shoe material was shown to affect the shoe- surface interface frictional components and potentially increases the risk of injury. Based on Torg et al. 's (1974) previous table of shoe release coefficient classification, only the flat soled shoe tested would be termed "safe" or "probably" safe at all five turf temperatures tested. It was also concluded that an increase in turf temperature, combined with the shoes characteristics and sole materials, affects the shoe-surface interface friction and potentially places the athlete's knee and ankle at risk of injury.

In 1983, torque and release coefficients were studied by Culpepper and Niemann. A test apparatus was designed similar to those used in previous studies (Torg et al., 1974; Torg et al., 1996). The test apparatus was designed to simulate the shoe-turf system. A workbench was modified to accommodate a steel shaft that had a prosthetic foot attached at the bottom. Force was applied to a torque wrench which was built on top of the shaft. Weights were then applied to the shaft in 20-pound increments. Five shoes were tested on new and old Poly Turf, and new AstroTurf. All three surfaces were tested under wet and dry conditions. Results indicated that a shoe-surface interface with a higher release coefficient indicated a greater locking of the cleats within the turf. Based on a previous scale (Torg et al., 1974) the release coefficients calculated in this study indicated that all shoes tested on all surfaces both wet and dry were either "safe" or "probably" safe. Final conclusions indicated that any given shoe on any given surface demonstrates unique shoe-surface characteristics.

Bonstingl et al. (1975) used a laboratory apparatus to simulate the shoe-turf system. A weighted pendulum was released and a simulated player's leg received a torque similar to that of a real life condition. The apparatus was used to study various shoe-surface combinations which included 11 types of shoes, three artificial surfaces and natural grass. The grass was encased in wooden pallets, three years old, and consisted of an extensively developed structure in approximately one inch of soil. The testing also included two different weights and two football player stance positions. Results showed that the conventional 8-studded football cleat developed significantly more torque on natural grass than any other shoe tested including those tested on artificial surfaces. It was also concluded that the amount of torque developed at the shoe-surface interface is dependent on many factors including the type of shoe, playing surface, weight and player stance. With the exception of a swivel shoe, all of the footwear developed 70 percent more torque in a foot stance position than in a toe stance position. Torque was also affected by player weight. As player weight increased, the torque developed between the shoe-surface interface increased.

In a study by Bowers and Martin (1975), alterations in the shoe-surface friction of AstroTurf were evaluated in association with use and exposure. An apparatus constructed for testing was described as a crank tower which pulled a platform with cleats on the bottom across the surface. The platform was loaded with weights and pulled across the surface. The pulling friction force was recorded by a load ring onto a chart recorder. Three types of cleats were tested along with different weights. Surfaces tested included five-year-old AstroTurf, which was located outside, and new AstroTurf, which was the same age as the five year-old turf, but was stored inside and protected from sun and moisture. The new AstroTurf was tested in a laboratory setting. It was concluded that as AstroTurf ages and is subjected to use and exposure, it goes through physical changes which alter its mechanical properties. Thus, changes in the frictional components of the shoe-surface interface may result as well as a diminished impact absorption capacity. It was also found that different footwear on the new and old surfaces have different frictional characteristics. Three types of cleats tested included slightly worn urethane cleats, very worn urethane cleats, and slightly worn poly-urethane cleats. The urethane cleats, which were described as the most commonly used shoe on AstroTurf, produced less friction on the used turf under both wet and dry conditions than on the unused and unexposed turf. The poly-urethane cleat showed greater friction under the same turf conditions (wet and dry).

In an attempt to simulate torques developed by a shoe sliding on turf, Andreasson and his colleagues (1986) constructed an apparatus which could measure simultaneously the torque and the frictional force developed as a shoe slid on a surface. The apparatus was used to test 25 different shoes on an artificial surface. The artificial surface was placed on a circular rotating disc which was driven by a electric motor and whose velocity could be varied between one and five m/s. This variation was meant to simulate the change in velocity from walking to running. The circulating disc and the test leg were placed in a frame and the test leg was suspended above the disc from a moveable carrier. The disc and the leg had the ability to be tilted. The test leg was made of aluminum pipe with attached strain gauges which could measure the torque as well as the flexional stress. The different shoes were tested on Poligrass. The vertical force was kept constant at 241 N and was not increased to prevent failure of the measurement leg. Results indicated that the physical makeup of the shoe as well as the weight dispersed throughout the shoe is of great importance for the torque developed. The frictional force of the shoe-surface interaction was independent of the interval speed tested. The researchers believed, based on their results, that it is possible to manufacture a shoe that gives zero torque while sliding. It was recommended that when more than one type of material used on the sole of the shoe that the material should be evenly distributed throughout the heel and toe sole so that a correct balance is achieved.

Canaway and Bell (1986), attempted to improve on a previous apparatus which was designed in 1975 to measure traction and friction on natural and artificial surfaces, respectively. The original apparatus consisted of a steel disc 15 cm in diameter to which various football, rugby, and golf shoe surfaces could be secured. The disc was attached to a shaft and was loaded with weights. The apparatus was dropped to the turf to ensure stud penetration and the force required to tear the turf was measured with a torque wrench. Other discs were able to test artificial shoe surfaces on their respective playing surface. Many drawbacks were encountered with the original apparatus. It was found that complications arose when calculating the coefficient of traction because the studs were at different distances from the center of the disc. The apparatus was also very awkward to move as well as to operate. The biggest drawback was variations in results depending on who was operating the test apparatus. The new apparatus developed in 1986 by Canaway and Bell replaced the use of weights with a spring that was compressed to a standard length dependent on the operator's height. A drawback to this new system is that the amount of compression of the spring must be constant for each measurement to insure accuracy. The spring was very sensitive to changes in its length so it was only suitable on level surfaces which excluded natural grass from being tested with this apparatus. Canaway and Bell developed their apparatus further and went back to the original method of using standard weights to supply the vertical force onto the surface.

The new apparatus could be used to measure traction relating to the traditional football cleat. The cleats would be arranged equidistant from the center of the disc. Other discs with an artificial sole surface could also be used to test artificial surfaces. The apparatus had the ability to be mounted onto a trolley for ease of transportation and to standardize the drop distance to 60 mm. The disc was then turned and the amount of torque required to tear the turf or move the sole from the surface in the case of artificial surfaces was measured using a two-handled torque wrench. From the values of the torque wrench, the friction and traction coefficients could be calculated.

In 1992, Middour developed a new traction measuring device based on Bonstingl et al.'s (1975) frame and leg assembly device for measuring traction and friction. The apparatus termed PENNFOOT was designed to measure both linear and rotational traction. The PENNFOOT, a portable test device, had the ability to measure various surfaces and conditions, test various shoes, and accommodate various weights (McNitt, 1994). Middour used the PENNFOOT to test the effects of species and cutting height of grass, and loading on rotational and linear traction. Significant differences were shown in relation to traction and species of grass, cutting height, and loading in both the rotational and linear measurements.

Summary

Several testing apparatuses have been developed to test both traction and friction. Many of the studies using these apparatuses have failed to solve the question of which surface is safer, artificial or natural. Culpepper and Niemann (1983) tested AstroTurf and Poly Turf with their device while Torg et al. (1996) studied release coefficients with increases in temperature on AstroTurf.

Several studies had drawbacks. Canaway and Bell (1986) and Bowers and Martin (1975) used a circular disc with the desired cleat to be tested attached to the bottom of the disc. A limitation to this method is that testing does not include "real life" situations. Torg et al. (1974), Bonstingl et al. (1975), and Andreasson et al. (1986), all used testing apparatuses that measured friction or tractional characteristics on plots of artificial or natural turf. In some cases the piece of turf was glued or stapled to plywood and then the surface was tested. This presents a problem in relating the findings to real-life situations.

Middour (1992) explained that the PENNFOOT was not developed to simulate a real life situation, but many factors involved in the testing did represent real-life situations. The PENNFOOT had the ability to test linear or rotational forces, various shoes, and various surfaces in the real life setting due to the ability of the PENNFOOT to be transported, as well as use a variety of different weights.

Overall, the research in the area of the shoe-surface interface is not complete. Many questions remain, especially with respect to comparing artificial and natural surfaces. This study included the use of the PENNFOOT apparatus in order to compare traction and friction values of selected athletic shoes on natural and artificial surfaces in the hope that some of the many questions in this area could be answered.

CHAPTER 3

METHODS

The methods have been divided into three sections: an explanation of the materials used in data collection including the PENNFOOT test apparatus and the shoes used for testing; a section on the procedures for operation of the PENNFOOT; and a section on the techniques used for data collection with the PENNFOOT test apparatus.

Description of the PENNFOOT Test Apparatus

The description of the PENNFOOT includes an overview of the frame assembly, the player leg and foot assembly, and the hydraulic system assembly. The following description was adapted from Middour (1992) and McNitt (1994).

The PENNFOOT consists of two frames, an internal and an external frame (Fig. 1,a). The internal frame was built to allow the leg assembly to reach the ground, decrease overall weight, and make transferring the desired amount of weight easier. The external frame was built around the internal frame to facilitate lifting the weighted foot. The internal frame is able to slide up and down on the external frame. At the top of the internal frame is a collar (Fig. 1,a) centrally located in which the leg-shoe assembly (Fig. 1,a)

slides. The leg-shoe assembly can be locked to the internal frame by adjusting a set screw (Fig. 1,a) mounted on the collar. When the set screw is loosened, the weights (Fig. 1, a) and the leg-shoe assembly act independent of the internal frame. The PENNFOOT is made portable by two tires attached at the rear of the apparatus and one tire mounted on the front of the apparatus
(Fig. 1, a).

The player leg (Fig. 1, a) consists of a solid steel rod (3.81 cm diameter) the upper end of which has a simulated ball and socket assembly to imitate the human hip joint. The lower end of the leg assembly is pinned to a cast aluminum foot (Fig. 1, b) which imitates the human ankle joint. The vertical load is applied above the ball and socket joint by circular weights. The leg assembly itself has a weight of the total vertical load equals 33.7 kg plus the weight that is added.

The simulated foot is made of aluminum and casted from a size 10 foot mold. The leg assembly is pinned to the aluminum foot (Fig. 1, b), allowing the heel to be off the ground and all weight dispersed onto the ball of the foot. The molded foot has the ability to be fitted with most size 10 shoes.

The hydraulic assembly (Fig. 1, b) used to create the horizontal forces and to lift the internal frame was powered by an Energy HP-100 hand pump (Energy MFG.Co., Inc. Monticello, IA). The linear horizontal force was created by a HTB-1E pulling piston which was mounted on the bottom of the internal frame. The pulling rod was 7.3 cm above the ground when the internal frame rested on the ground, and the end of the rod was pinned to a bracket mounted on the heel of the foot. To measure the distance traveled by the foot, a dial indicator (Fig. 1, b) was used.

A liquid-filled pressure gauge (Fig. 1, b) was connected directly to the pump to monitor the pressure being applied to the pistons. The pressure gauge had a range of zero to 600 psi. Raising or lowering the internal frame was accomplished by two vertically mounted pistons that would lift the internal frame. The frame could also be lowered slowly by releasing the pressure.

Description of Footwear

Four shoes (Fig. 2) were used in this study, two shoes tested on each surface. Shoe I was a standard 7-studded cleat with 1.27 cm length x 1.90 cm diameter cone-shaped studs (Reebok Viscous, Reebok International; Stoughton, MA). Shoe II was a standard synthetic turf shoe with a flat surface (Reebok Dry Rat, Reebok International; Stoughton, MA.). Shoe III consisted of a hard rubber molded, multicleated grass shoe which contained 15 triangular and nine pyramid shaped, multi- sized rubber cleats (Reebok Pit Bull Mid II, Reebok International; Stoughton, MA.). Shoe IV, developed for wet synthetic surfaces consisted of a rubber studded outsole which contained 60 (.63 cm) rubber

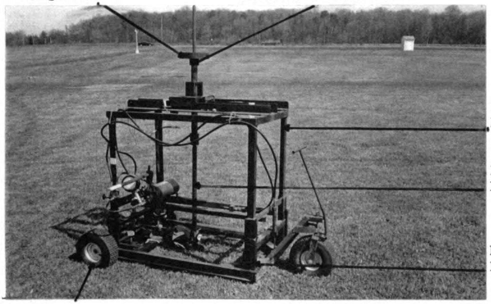
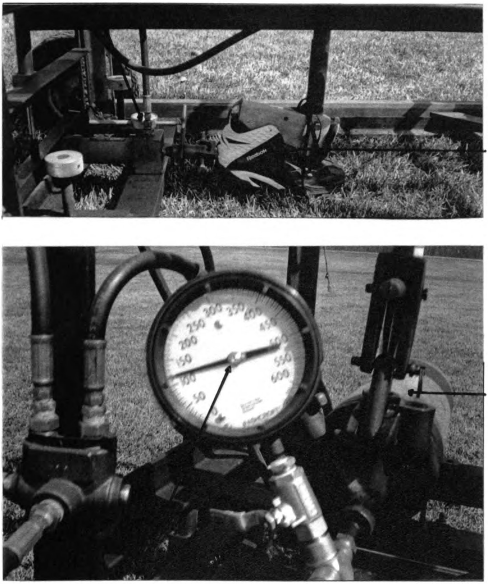


Figure 1, (a). PENNFOOT Traction Measuring Device.

Dial Indicator

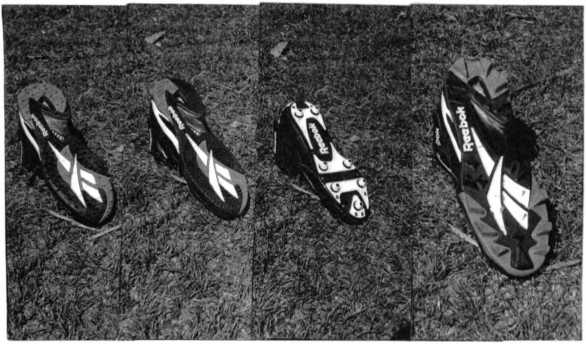
Cast
Aluminum
Foot



Hydraulic
Assembly

Pressure Gauge

Figure 1,(b). PENNFOOT Traction Measuring Device, cont.



(a) (b) (c) (d)

Figure 2. Athletic Footwear. (a) Reebok Wet Rat, (b) Reebok Dry Rat, (c) Reebok Vicious, and Reebok Pit Bull.

cleats (Reebok Wet Rat, Reebok International; Stoughton, MA.). All shoes were obtained in January 1996 from the football equipment room at Michigan State University, and were the styles used by the Michigan State football team for the 1995-96 football season.

Procedure for Using the PENNFOOT

The procedure for collecting data, using the PENNFOOT, was adapted from Middour (1992) and McNitt (1994). The procedure was as follows:

1. The selected shoe was secured on the simulated foot and the leg-shoe assembly was weighted to achieve the desired loading weight.

2. The machine was situated over the desired surface to be tested and the piston(s) used to create the horizontal force was reset. This was accomplished by pulling out the piston manually until the dial indicator read zero. The internal frame was then lowered slowly. When the toe of the shoe touched the surface, the set screw holding the top portion of the leg assembly was released, allowing the leg- shoe assembly and weights to act independent of the internal frame. This allowed placement rather than dropping of the shoe on to the surface.

3. In order to record a measurement, two people were required to operate the machine. One person operated the pump which caused linear movement of the foot parallel to the surface. A second person watched the dial indicator.

Nine pressure readings were taken, one every 0.635 cm starting at 1.27 cm and ending at 5.08 cm of linear travel.

4. The final step of the procedure was to convert psi values to N. This was accomplished by calculating the product of the effective area of the pulling piston ($3.14\ in^2$) and the amount of pressure (psi) to force (lb). The amount of force (lb) was then converted to SI units by the ratio of 1 lb:4.45 N. Combining the steps, multiplying psi by 13.97 converted the psi value directly to N.

The PENNFOOT was used in four separate experiments testing various surfaces, conditions, and shoe types. The objective of each experiment was to determine the differences in the frictional/tractional components of the respective shoe on the respective surface and surface condition. The following is a list of the four experiments performed:

Experiment 1. Frictional Characteristics of the Reebok Dry Rat on Dry AstroTurf Compared to the Tractional Characteristics of the Reebok Viscous on Dry Natural Grass.

Experiment 2. Frictional Characteristics of the Reebok Wet Rat on Wet Astroturf Compared to the Tractional Characteristics of the Reebok Viscous on Wet Natural Grass.

Experiment 3. Frictional Characteristics of the Reebok Dry Rat and Reebok Wet Rat on Dry AstroTurf Compared to the Reebok Dry Rat and Reebok Wet Rat on Wet AstroTurf.

Experiment 4. Tractional Characteristics of Reebok Viscous and Reebok Pit Bull on Dry Natural Grass Compared to the Tractional Characteristics of the Reebok Vicious and Reebok Pit Bull on Wet Natural Grass.

Data Collection

Data collection using the PENNFOOT required both operators to be accurate and efficient in their specific task. Prior to actual data collection a pilot study was performed. The pilot study included four different locations on dry AstroTurf with two types of artificial surface footwear. The pilot study was concluded when both operators of the PENNFOOT felt comfortable with their tasks for data collection. For all experiments, data were collected during the second week in January, 1996. All measurements for frictional characteristics were collected at the Duffy Daugherty indoor football facility on the campus of Michigan State University. The AstroTurf was eight years old at the time of data collection and was protected from extreme temperature, light, and moisture. Data collection for tractional characteristics of natural grass was performed on a grass plot (which measured approximately 3 m by 4 m) at the Hancock Indoor Turfgrass

Research facility which is associated with the Department of Crop and Soil Sciences at Michigan State University. The grass plot consisted of Poa pratenus, Lolium perenne, and Poa supina. The grass species within the plot was a representation of a typical grass athletic field in the midwest region of the U.S., but the physical characteristics within the plot did not represent the conditions of a typical athletic field in relation to soil compaction, wear patterns, and percent cover. On an actual playing field these physical characteristics can change from the beginning to the end of the season.

The artificial and natural surfaces were tested in the same manner. Two locations were tested on each surface in order to obtain an average of the surface being tested and to take into account wear patterns. The locations on the grass plot consisted of two random areas within the plot for each experiment. For AstroTurf, one test site was outside the hash marks on the 50 yard line which was considered an "unworn" surface. The other location considered a "worn" area was inside the hash mark on the 20-yard line. These locations were chosen because Cockerham (1989) concluded that 78 percent of football field traffic is concentrated on 7 percent of the field. High traffic concentration is located between the hash marks and between the 20-yard lines.

At each location, a two by two foot square was marked off using athletic tape. Prior to data collection surface hardness and surface temperature were taken at each field and plot location. Surface hardness was collected using a Clegg Surface Hardness Tester. The Clegg is used to measure maximum deceleration of a compaction hammer which hits the surface when dropped from a fixed height (Bell, Baker, & Canaway, 1985). Surface temperature was recorded using a Barnett Thermocuplet. Surface hardness and temperature was not accounted for in the data analysis. Surface hardness and temperatures values for each experiment are located in Appendix A.

Testing consisted of four trials within the marked squares. The procedure for data collection was as previously described. After each trial, the PENNFOOT was moved within the marked square for the next trial. All testing with PENNFOOT was completed with 90.67 kg of vertical load. This load was chosen to simulate the body weight of a collegiate skill position football player and no attempt was made to simulate the forces of a skill position player while running and cutting. The 90.67 kg of vertical load was a combination of the weight of the leg assembly (33.7 kg) and circular weights (56.97 kg). Trials on the wet surfaces were consistent with those taken on the dry surfaces. On both surfaces 2.8 liters of water was evenly distributed within the marked square. Through trial and error on the AstroTurf, it was determined that 2.8 liters of water adequately saturated the playing surface. When the water was distributed onto the AstroTurf there was no standing water, but the surface was saturated. To simulate the same amount of rainfall on the grass plot, 2.8 liters of water were also used on the natural surface. The wet surfaces were tested immediately following application of the water to the surface. A dry surface, was characterized as a surface with no standing water and no dampness to the touch. Soil moisture content was not considered in the classification of a dry natural surface. A sample data sheet used for the data collection can be found in Appendix A.

Data Analysis

Data collected were analyzed using the SPSS 6.1.3 statistical program. Data were coded for the SPSS program and included the following: experiment (1-4), surface (1-2), condition (1- 2), footwear (1-4), displacement (1-8), trial (1-4), and force (N). A analysis of variance (ANOVA) was run for each experiment with a confidence level of 95 percent ($p< 0.05$). To analyze experiment 1 and 2, an one-way ANOVA with a simple factorial was selected. Data analysis for experiments 3 and 4 included a two-way ANOVA with a general factorial. The dependent variable for all experiments was force which was calculated from the original force values (N) collected. The factor for each experiment was footwear. Surface condition was also included as a factor in experiments 3 and 4.

CHAPTER 4

RESULTS

Chapter four will provide results for each of the experiments conducted. Findings will be presented in ANOVA tables as well as graphically. For each experiment, force values collected through all trials are located in Appendix B. Overall, the shoe-type, playing surface, and surface condition had statistically significant effects ($p<0.05$) on the frictional/tractional forces required to move the shoes at the shoe-surface interface. The following will document the results for each of the four experiments:

Experiment 1. Frictional Characteristics of the Reebok Dry Rat on Dry AstroTurf Compared to the Tractional Characteristics of the Reebok Vicious on Dry Natural Grass.

The objective of this study was to determine whether there is a significant difference in the frictional components between the shoe-surface interface on natural grass and AstroTurf using standard footwear for the respective playing surface. It was hypothesized that the Reebok Dry Rat would require more force to move across the AstroTurf than the Reebok Vicious would require to move across the natural grass. The hypothesis was based on the idea that the Reebok Vicious would be able to break through the root zone and slide through the surface while the Reebok Dry Rat would "stick" to the surface, yielding a higher coefficient of friction. Significant differences in the force required to move the shoes across the surface were found [$F(1,126)= 25.02$, $p=.000$] (Table 2). For all distances, the Reebok Dry Rat required significantly more force for movement across the AstroTurf than was required for the Reebok Vicious across natural grass. The differences are shown graphically in Figure 3. The mean frictional values were shown to increase in a linear fashion from initiation of movement to 1.27 cm, values then remained relatively constant throughout the completion of movement (Fig. 3). The original hypothesis for experiment 1 was supported with the above results.

Experiment 2. Frictional Characteristics of the Reebok Wet Rat on Wet AstroTurf Compared to the Tractional Characteristics of the Reebok Vicious on Wet Natural Grass.

The objective of this study was to determine whether there is a significant difference in the frictional components between the shoe-surface interface on wet natural grass and wet AstroTurf using standard footwear for the respective playing surface. It was hypothesized that the Reebok Vicious would require more force to move across the surface based on the shoe's ability to dig into the natural grass surface. The Reebok Wet Rat on wet AstroTurf would

Table 2
Experiment 1: Analysis of Variance

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	973710.100	1	973710.100	25.023	0.000
Footwear	973710.100	1	973710.100	25.023	0.000
Explained	973710.100	1	973710.100	25.023	0.000
Residual	4902922.000	126	38912.080		
Total	5876632.000	127	46272.690		

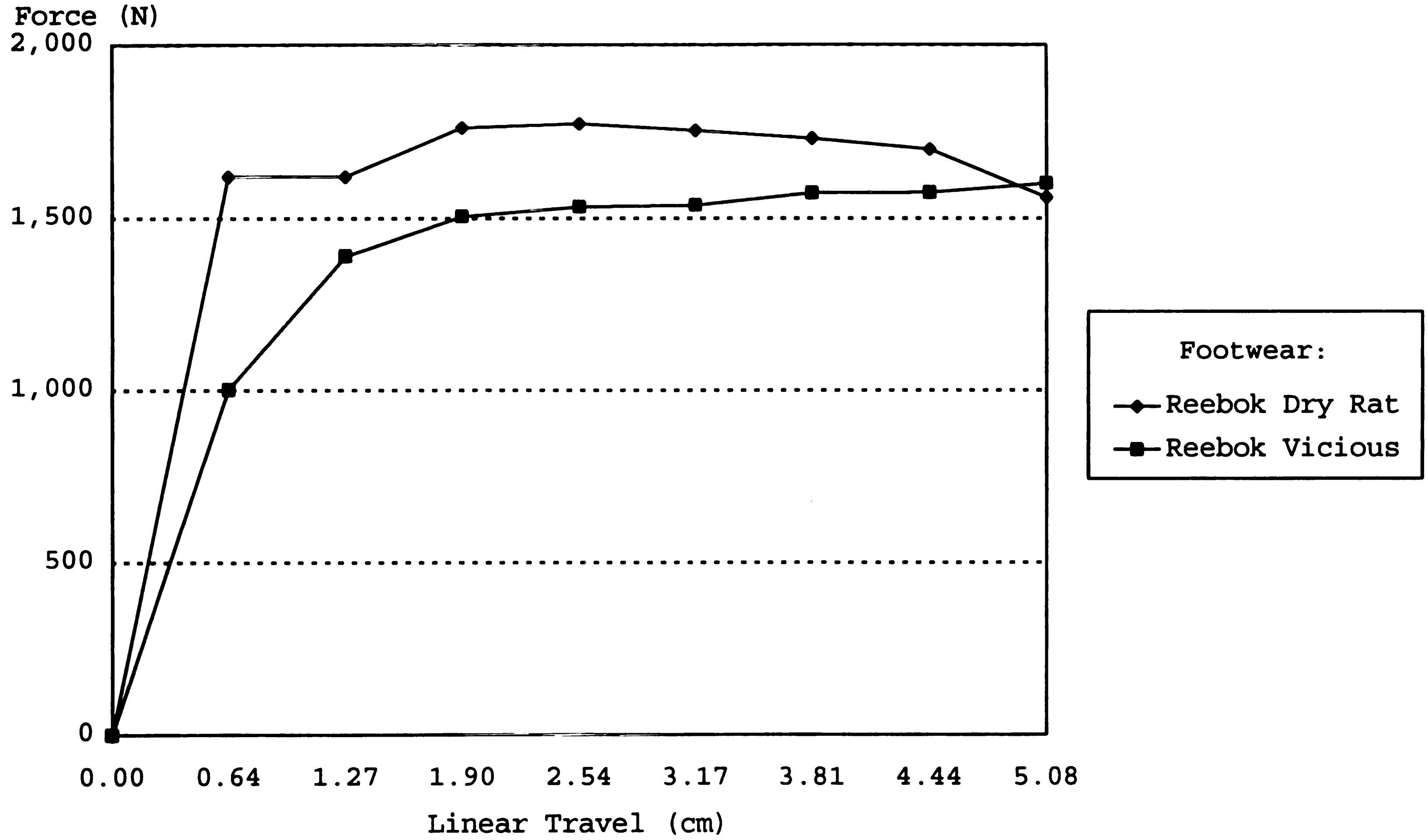


Figure 3. Mean force values of the Reebok Dry Rat on AstroTurf compared to the Reebok Vicious on grass. Experiment 1: dry condition.

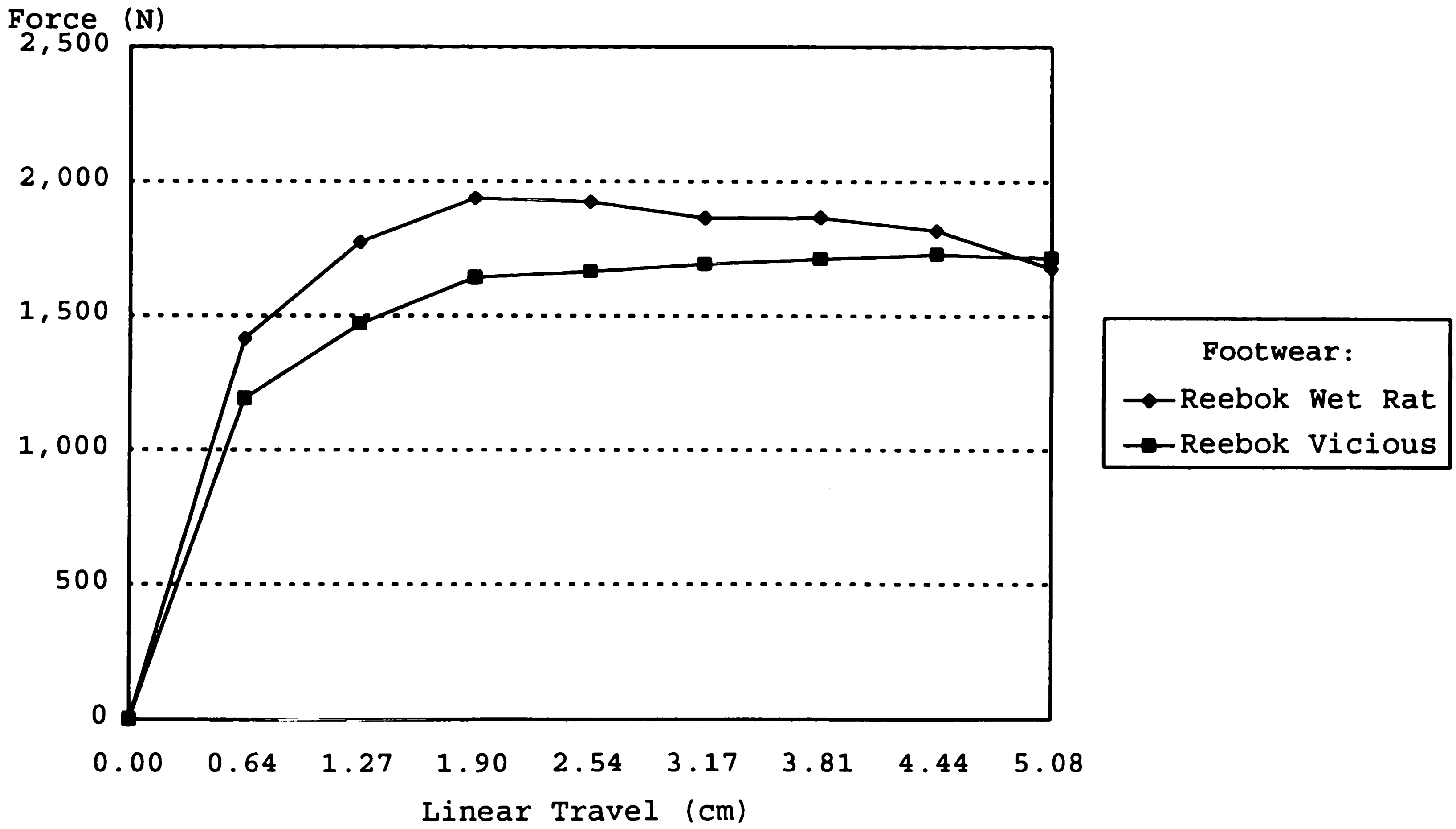
not have the ability to penetrate the surface and would slide more easily across the surface, yielding a lower coefficient of friction. Significant differences in the force required to move the shoe across the surface were found [F(1,126)= 32.70, p=.000] (Table 3). The Reebok Wet Rat required significantly more force (under all distances) for movement across the wet AstroTurf than the Reebok Vicious across the wet grass. The differences are shown graphically in Figure 4. The mean frictional values were shown to increase in a linear fashion from initiation of movement to 1.27 cm, values then remained relatively constant throughout the completion of movement (Fig. 4). Based on the results for experiment 2, the original hypothesis was not supported.

Experiment 3. Frictional Characteristics of the Reebok Dry Rat and the Reebok Wet Rat on Dry AstroTurf Compared to the Reebok Dry Rat and the Reebok Wet Rat on Wet AstroTurf.

The objective of this study was to determine whether there is a significant difference in the frictional components between the Reebok Wet Rat on wet and dry AstroTurf and the Reebok Dry Rat on wet and dry AstroTurf. The Reebok Wet Rat was developed for use on wet Astroturf while the Reebok Dry Rat was developed for use on dry AstroTurf. It was hypothesized that the Reebok Wet Rat would require more force for movement across the wet and dry AstroTurf than the Reebok Dry Rat. This hypothesis was

Table 3
Experiment 2: Analysis of Variance

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	1072014.000	1	1072014.000	32.708	0.000
Footwear	1072014.000	1	1072014.000	32.708	0.000
Explained	1072014.000	1	1072014.000	32.708	0.000
Residual	4129690.000	126	32775.320		
Total	5201704.000	127	40958.300		



<u>Figure 4</u>. Mean force values of the Reebok Wet Rat on AstroTurf compared to the Reebok Vicious on grass. Experiment 2: wet condition.

based on the premise that a shoe developed for increased grip on a wet surface (Reebok Wet Rat), would yield a higher coefficient of friction on a wet and dry surface.

Significant differences were found between force and footwear [F(1,255)= 70.34, p=.000] while the interaction between force and condition was found to be not significant [F(1,255)= 3.56, p=.060]. The interaction between the footwear and surface condition was also found to be not significant [F(1,255)=1.16, p=.282]. Complete results can be found in table 4. Based on the findings, there is a significant difference in the force required for movement of the Reebok Wet Rat and Reebok Dry Rat, but the difference is independent of surface condition. The results of experiment 3 are shown graphically in Figure 5. The Reebok Wet Rat required more force (under all distances) for movement across the wet and dry AstroTurf compared to the Reebok Dry Rat on wet and dry AstroTurf. The mean force values for the Reebok Wet Rat compared to the Reebok Dry Rat on wet and dry AstroTurf are consistently higher from initiation of movement to the completion of movement. The Reebok Dry Rat had the lowest mean force values on wet AstroTurf while the Reebok Wet had the highest on dry AstroTurf. The original hypothesis for experiment 3 was supported based on the results.

Experiment 4. Tractional Characteristics of the Reebok Vicious and Reebok Pit Bull on Dry Natural Grass Compared to

Table 4
Experiment 3: Analysis of Variance

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Within + Residual	8222401.30	252	32628.58		
Condition	116238.38	1	116238.38	3.56	.060
Footwear	2295035.63	1	2295035.6	70.34	.000
Condition by Footwear	37854.57	1	37854.57	1.16	.282
(Model)	2449128.57	3	816376.19	25.02	.000
(Total)	10671529.87	255	41849.14		

R-Squared = .230
Adjusted R-Squared = .220

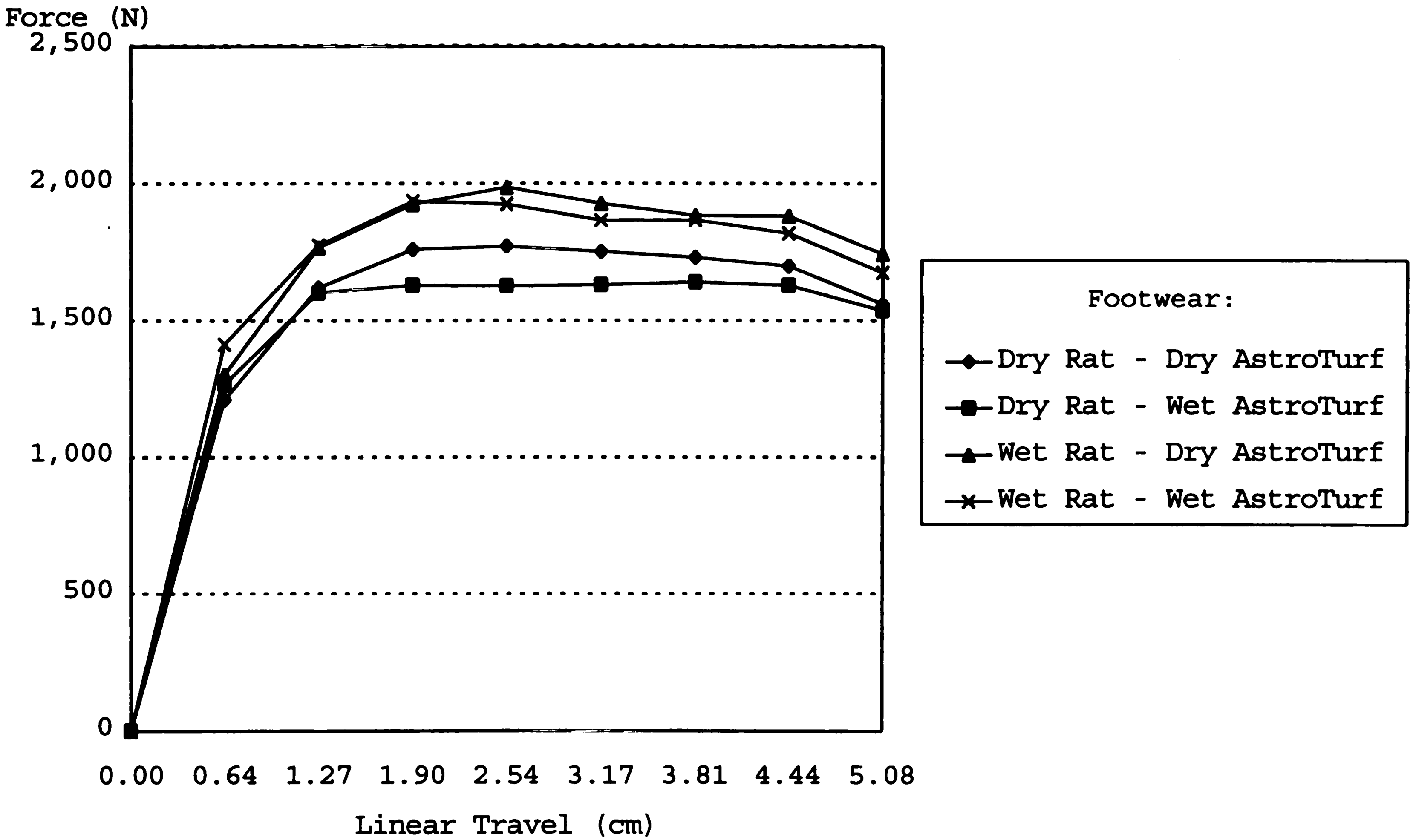


Figure 5. Mean force values of the Reebok Dry Rat and Reebok Wet Rat on Dry AstroTurf compared to the Reebok Dry Rat and Reebok Wet Rat on wet AstroTurf.

the Tractional Characteristics of the Reebok Vicious and Reebok Pit Bull on Wet Natural Grass.

The objective of this study was to determine whether there is a significant difference in the tractional components between the Reebok Pit Bull and Reebok Vicious on wet and dry natural grass. It was hypothesized that the force required for movement across the surface would be the same for the Reebok Pit Bull and Reebok Vicious because both shoes were developed for the same surface (natural grass) regardless of surface condition.

Significant differences were found between force and footwear [$F(1,255) = 7.56$, $p = .006$] and between force and surface condition [$F(1,255) = 4.71$, $p = .031$]. Significant effects were also found between the interaction of footwear and the surface condition [$F(1,255) = 13.27$, $p = .000$]. Complete results can be found in table 5. The differences are also shown graphically in Figure 6. Overall, the Reebok Pit Bull demonstrated higher force values compared to the Reebok Vicious. In relation to surface condition, the highest force values were collected when the natural grass was dry. The significant interaction between the footwear and surface condition is explained by the differences in force required for movement of the same shoe on wet and dry natural grass. As demonstrated graphically, the Pit Bull had higher force values on dry natural grass while the Vicious had higher values on wet natrural grass. Based on the results, the original hypothesis was not supported.

Table 5
Experiment 4: Analysis of Variance

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Within + Residual	9110564.80	252	36153.03		
Condition	170310.97	1	170310.97	4.71	.031
Footwear	273202.22	1	273202.22	7.56	.006
Condition by Footwear	479642.82	1	479642.82	13.27	.000
(Model)	923156.01	3	307718.67	8.51	.000
(Total)	10033720.81	255	39347.92		

R-Squared = .092
Adjusted R-Squared = .081

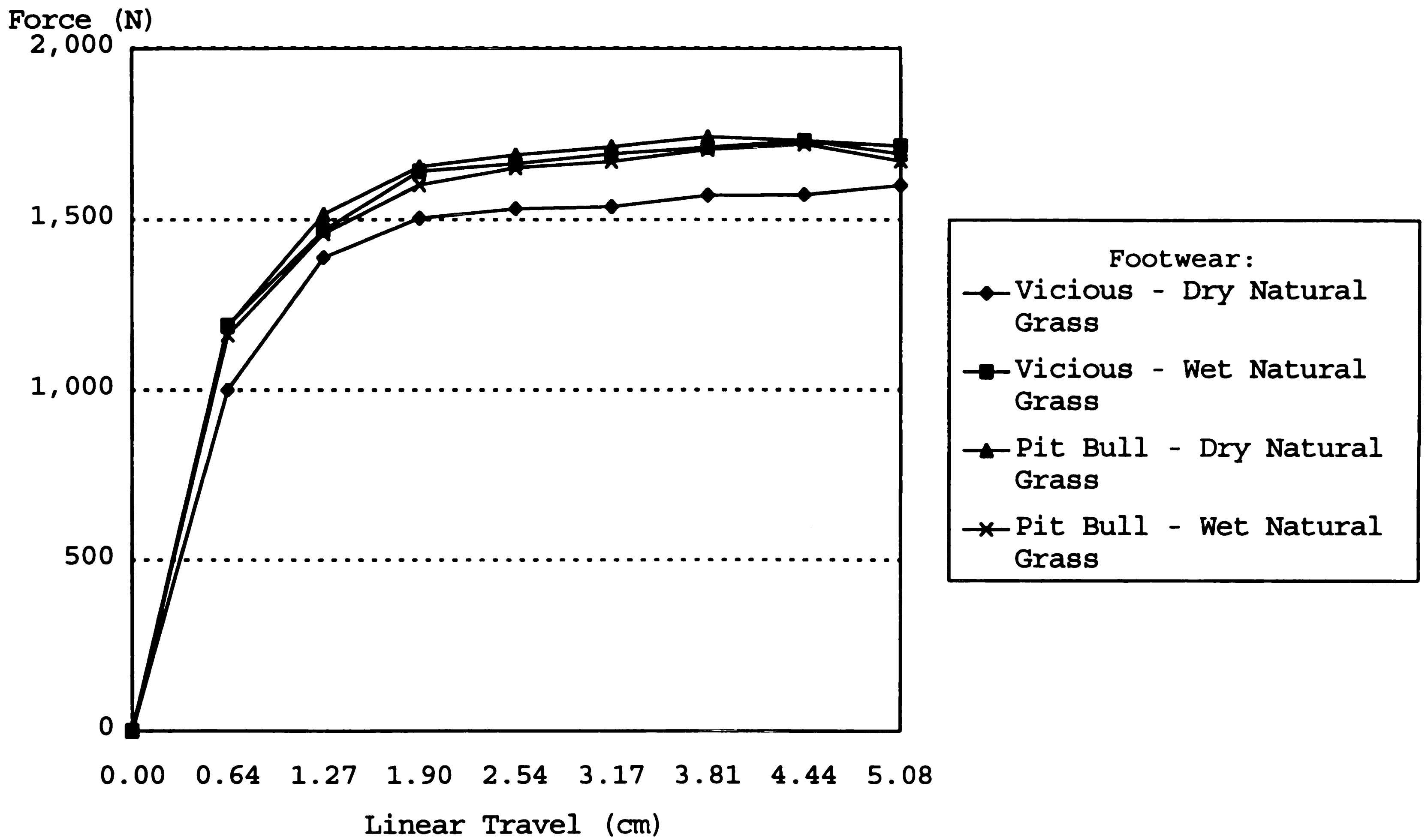


Figure 6. Mean force values of the Reebok Vicious and Reebok Pit Bull on dry natural grass compared to the Reebok Vicious and Reebok Pit Bull on wet natural grass.

CHAPTER 5

DISCUSSION

The results of each of the six experiments as well as a graphic description of the data were reported in the previous chapter. This chapter will discuss findings and observations across all experiments. Topics will include comparing results of the study to the original hypotheses and relating results of this study to previous studies. Through all experiments, the artificial surface footwear (Reebok Dry Rat and Wet Rat) produced higher force values compared to the natural grass footwear (Reebok Vicious and Pit Bull). The current study not only provided a comparison of artificial and natural turfs and footwear, but also two types of artificial turf and natural grass shoes against each other. The artificial turf shoes were designated "wet" or "dry" shoes, but on a given day an athlete may have on the "wrong" footwear for the surface condition (e.g., rain is expected so the athlete wears the "wet" condition footwear on a dry surface). This constitutes the reasoning behind testing artificial footwear designed for wet and dry conditions. The Reebok Wet Rat consistently showed higher force values compared to the Reebok Dry Rat. The two natural grass shoes, when compared to each other, yielded inconsistent findings. On dry natural grass, the Reebok Pit Bull had higher traction values compared to the Reebok Vicious on dry natural grass, while the Reebok Vicious demonstrated higher traction values compared to the Reebok Pit Bull on wet natural grass.

It was theorized that on a dry artificial surface, the Reebok Dry Rat would have higher frictional force values compared to the Reebok Vicious on natural grass. The premise was that the Reebok Vicious would be able to tear through the root zone, thus producing lower values. Results proved to be consistent with the hypothesis. During testing on the natural grass, an audible "tearing" of the natural grass was heard. On wet surfaces, it was theorized that the natural grass shoe would have the ability to penetrate the wet grass giving the grass shoe more traction than an artificial shoe, which does not have the ability to penetrate the artificial surface. The results showed the opposite. The Reebok Wet Rat obtained higher friction values on wet AstroTurf compared to the Reebok Vicious on wet natural grass.

Based on the findings of the dry and wet surface testing, it can be stated that the artificial surface footwear has higher coefficients of friction, under all artificial turf conditions studied when compared to the Reebok Vicious seven-studded natural grass shoe. No comparisons were made between the artificial turf footwear and the Reebok Pit Bull multicleated grass shoe.

Throughout all experiments, except experiment four involving wet natural grass, the shoe with the most projections offered a greater coefficient of friction regardless of surface. In a study by Torg and Quedenfeld (1971), it was found that increasing the cleat surface area, by increasing the number of cleats resulted in a decrease in both the incidence and severity of injuries. Torg and Quedenfeld's findings, although based on data collection on natural grass, do not relate to the current findings. This is due to the increase in friction and traction with an increase in the number of projections on both natural and artificial surfaces found in the current study. On a dry surface, the Reebok Wet Rat, designed for increased grip on a wet artificial surface showed greater values on both the wet and dry artificial surfaces. The Reebok Pit Bull, a multicleated natural grass shoe, also showed greater values on dry natural grass compared to the Vicious. The exception was on a wet natural grass surface. A comparison of both natural grass shoes on the wet natural grass showed virtually no difference in tractional values.

Results Comparison to Previous Studies

In the review of literature prior studies and their results were presented. Comparisons of the present study to earlier research will be made (Baker & Bell, 1986; Bell, Baker et al., 1986; Bostingl et al., 1975; Culpepper &

Niemann, 1983; Torg & Quedenfeld, 1971; Torg et al., 1974; and Torg et al., 1996).

The current study investigated sliding friction whereas some of the previous studies examined rotational friction (Bostingl et al., 1975; Culpepper & Niemann, 1983; Torg et al., 1974; and Torg et al., 1996). Many of the previous authors calculated release coefficients based on their data collection results (Culpepper & Niemann; Torg et al., 1974; and Torg et al., 1996). Torg et al. (1974), along with Culpepper and Niemann, explained that the coefficient of friction (u) can be expressed by the equation u= F/W, where F is the force required to move the object, and W is the weight of the object. The equation is used, according to Culpepper and Niemann, when relatively smooth and uniform surfaces are involved. However, the shoe-surface interface is not always smooth, especially in regards to natural grass. Therefore, a true coefficient of friction cannot be determined (Culpepper & Niemann; Middour, 1992). Both Torg et al. (1974) and Culpepper and Niemann (1993) described a release coefficient that could be calculated for the shoe-surface interface. The release coefficient was defined as: r= Force/Weight, where (r) is the release coefficient for a given shoe-surface combination. Based on the release coefficients, a scale determining the safety of a given shoe on a given surface was developed. Release coefficients that were considered "not safe" were 0.49 (0.55- 0.06) or greater. A shoe-turf combination with a release coefficient of 0.31 (0.28+0.03) or less is "safe". An attempt was made with the data from the current study to calculate the release coefficient and relate the findings to the scale of Torg et al. The current studies release coefficients and the Torg et al. scale did not correlate. For the current study, release coefficients ranged from a low of 7.19, which was the release coefficient for the Reebok Vicious on dry natural grass, to a high of 9.05, which was for the Reebok Wet Rat on dry AstroTurf. Differences in the release coefficients may be due to dissimilar methods e.g., Torg et al. examined rotational friction and the current study examined sliding friction. Therefore, no safety recommendations can be made for the current study based on the previous scale and equation.

Bell and colleagues (1986) summarized the results of several past studies (Bowers & Martin, 1975; Canaway, 1985; Garrick & LaVigne, 1972; and Stanitski et al., 1974) by comparing friction and traction values on natural and artificial turf. In an attempt to relate previous findings to the current study, a coefficient of friction and traction was calculated. The method of calculation of coefficients of friction and traction was as follows;

1. The average mean force value (N) for each shoe was calculated from the force tables (Appendix A).

2. The average mean force value (N) was converted to pounds per square inch (psi), by dividing the force value by 13.97.

3. The psi value was then converted to pounds (lbs) by multiplying the amount of pressure read from the gauge (psi) on the PENNFOOT, by the product of the effective area of the pulling piston 3.14 in^2 (Middour, 1992).

4. The lbs value was then divided by 200 which was the vertical (normal) load used throughout all experiments. To summarize, once the pound value was calculated (step 3), the coefficient of friction (u) was then calculated by the equation u= Force(lbs)/Weight(lbs).

The coefficients of friction and traction ranged from 1.61 for the Reebok Vicious on dry natural grass to 2.04 for the Reebok Wet Rat on dry AstroTurf. Coefficients of friction for artificial turfs were previously calculated (Bell et al., 1986) based on data collected by Bowers and Martin (1975), Garrick and LaVinge (1972), and Stanitski et al. (1974). Coefficients of traction for natural grass were also calculated by the same authors based on data collected by Canaway (1985), and Stanitski et al. (1974).

Coefficients of friction values on AstroTurf ranged from 0.93 to 1. 63 with three studs on a weighted plate (Bowers & Martin, 1975), 1.10 to 4.10 for a multicleated football shoe with 9.5 mm diameter cleats (Garrick & Lavinge, 1972), and 0.92 to 1. 54 using four types of training shoes with rubber or plastic molded shoes (Stanitski et al., 1972). Bowers and Martin, and Garrick and LaVinge both tested wet and dry conditions, but their results cannot be compared to because of the difference in footwear. Different footwear also can be associated with the inability to relate the coefficients of friction and traction from the current study to the previous study. Stanitski et al. did test shoes with a rubber sole whose coefficients of friction may relate to the current study. Stanitski and his colleagues found, as stated previously, coefficients of friction in a range from 1.16 to 1.34. Coefficients of friction for the current study on AstroTurf ranged from 1.73 to 2.04. Once again the differences most likely are due to the fact that a different apparatus and different shoes were utilized.

Coefficients of traction on dry natural grass derived from previous studies ranged from 0.91 to 3.06 when tested with six 15 mm x 12.5 mm diameter football studs on a circular disc (Canaway, 1985), and from 0.92 to 1.23 when tested with four types of rubber or plastic molded shoes (Stanitski et al., 1974). The current study found traction coefficients that ranged from 1.61 to 1.81 on dry natural grass. Previous studies did not test or calculate traction coefficients for wet natural grass. Differences also can be attributed to dissimilar apparatuses and the types of shoes tested.

As stated, an attempt was made to relate findings of the current study to previous findings. Torg and his colleagues' (1974) release coefficient scale did not correlate nor did other studies (Bell et al., 1986) that calculated coefficients of friction and traction. Modern footwear used for American football is unlike footwear tested in previous studies so comparisons are difficult. The current study attempted to utilize current footwear, as close to actual playing surfaces, and as human-like conditions as possible.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

A debate rages on over the safety of playing American football as well as other sports on artificial surfaces. An attempt was made to answer one of the many questions related to athletic injuries and artificial surfaces. The shoe-surface interface has been the topic of study for decades and should continue to be the focus of constructive research. An apparatus termed PENNFOOT was used to collect data in four separate experiments studying the shoe-surface interface. The device had the capability of testing actual playing surfaces, capacity to accommodate weight up to 136 kg (300 lbs), and the ability to test any desired size 10 shoe.

The four experiments included comparisons of footwear on dry artificial and natural surface conditions (Reebok Dry Rat and Reebok Vicious), as well as wet artificial and natural surface conditions (Reebok Wet Rat and Reebok Vicious). An investigation of the frictional differences of two shoes designed for artificial surfaces (Reebok Dry Rat and Reebok Wet Rat) on wet and dry AstroTurf was also completed. Finally, tractional comparisons of two natural grass shoes (Reebok Vicious and Reebok Pit Bull) on wet and dry natural grass were made.

Conclusions

Based on the results of this study the following conclusions can be made:

1. The coefficients of friction and traction at the shoe-surface interface vary depending on the shoe, surface, and surface condition.

2. Through all experiments, the artificial surface shoes showed higher coefficients of friction compared to the natural grass shoes, regardless of surface condition.

3. The Reebok Wet Rat had the highest friction values on dry AstroTurf, while the Reebok Vicious had the lowest values on wet natural grass.

Recommendations

1. It is recommended that artificial surface footwear such as the Reebok Wet Rat, designed for wet artificial surfaces, should not be worn on dry artificial surfaces.

2. Further research in this area should include the development of a biomechanically correct apparatus that can simulate the forces exerted by an athlete while running and cutting. Such an apparatus would be able to better investigate the forces at the shoe-surface interface. Also, this study only tested one brand of footwear. Further studies must also include various brands of footwear similar

to those used in this study, as well as various natural and artificial surface conditions.

As a result of further study by the sports medicine community and athletic shoe manufacturers, safety recommendations can be made to the athletic population regarding proper footwear for a given surface and condition. The usefulness of artificial surfaces will provide them a place in sports for a long time. It is the responsibility of the sports medicine community to develop a method to determine what footwear is safe for a given athletic surface so that the incidence and severity of athletic injuries can be reduced.

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APPENDICES

APPENDIX A

Table 6
Summary of Surface Hardness and Temperatures.

Experiment	Surface	Location	Hardness (G)	Temperature (F)
1	AstroTurf	unworn	49	58.6
1	AstroTurf	worn	57	59.3
1	Nat. Grass	1	44	52.8 (dry)
1	Nat. Grass	2	49	53.2 (dry)
2	AstroTurf	unworn	50	59.1
2	AstroTurf	worn	40	59.0
2	Nat. Grass	1	35	54.5 (wet)
2	Nat. Grass	2	36	54.5 (wet)
3	AstroTurf	unworn	56	58.6 (dry)
3	AstroTurf	worn	50	51.8 (dry)
3	AstroTurf	unworn	54	60.4 (wet)
3	AstroTurf	worn	45	59.7 (wet)
4	Nat. Grass	1	47	55.5 (dry)
4	Nat. Grass	2	45	59.7 (dry)
4	Nat. Grass	1	42	54.5 (wet)
4	Nat. Grass	2	42	54.5 (wet)

Table 7.
Sample data collection table.

EXPERIMENT #

NAME-

SURFACE-

FIELD LOCATIONS-

SURFACE CONDITION-

FOOTWEAR TYPE-

MANUFACTURER-

WEIGHT-

LOCATION-

PSI in "	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
PSI @ 0"				
PSI @ .25"				
PSI @ .50"				
PSI @ .75"				
PSI @ 1.00"				
PSI @ 1.25"				
PSI @ 1.50"				
PSI @ 1.75"				
PSI @ 2.00"				

APPENDIX B

Table 8
Force Values of the Reebok Dry Rat on Dry AstroTurf (Unworn Location)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1327.15	1327.15	1187.45	1327.15	1292.00	69.85
1.27	1536.70	1662.43	1676.40	1634.49	1627.00	62.99
1.90	1676.40	1676.40	1816.10	1816.10	1746.00	80.65
2.54	1676.40	1746.25	1746.25	1816.10	1746.00	57.03
3.17	1704.34	1746.25	1816.10	1634.49	1725.00	76.09
3.81	1676.40	1746.25	1816.10	1746.25	1746.00	57.03
4.44	1663.43	1788.16	1844.04	1676.64	1742.00	87.52
5.08	1536.70	1662.43	1606.55	1536.70	1585.00	60.89
					Average of All Mean Values (N):	1651.00

Table 9

Force Values of the Reebok Dry Rat on Dry AstroTurf (Worn Location)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1257.30	977.90	1187.45	1089.66	1127.00	121.45
1.27	1648.46	1606.55	1662.43	1536.70	1613.00	56.45
1.90	1802.13	1746.25	1816.10	1746.25	1777.00	36.74
2.54	1802.13	1830.07	1816.10	1746.25	1798.00	36.74
3.17	1746.25	1746.25	1844.04	1788.16	1781.00	46.33
3.81	1676.40	1634.49	1816.10	1746.25	1718.00	79.84
4.44	1676.40	1606.55	1746.25	1606.35	1658.00	66.92
5.08	1536.70	1536.70	1536.70	1536.70	1536.00	0.0

Average of All Mean Values (N): 1626.00

Table 10

Force Values of the Reebok Vicious on Dry Grass (Location 1)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	977.90	977.90	852.17	838.20	911.00	76.83
1.27	1327.15	1327.15	1257.30	1369.06	1320.00	46.33
1.90	1438.91	1397.00	1466.85	1536.70	1459.00	58.70
2.54	1466.85	1466.85	1536.70	1606.55	1518.00	66.87
3.17	1466.85	1522.73	1550.67	1606.55	1536.00	58.16
3.81	1522.73	1550.67	1606.55	1620.52	1574.00	46.15
4.44	1536.70	1564.64	1606.55	1662.43	1592.00	54.70
5.08	1564.64	1606.55	1606.55	1606.55	1595.00	20.95
					Average of All Mean Values (N):	1438.00

Table 11
Force Values of the Reebok Vicious on Dry Grass (Location 2)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1327.15	1047.75	1005.84	991.87	1092.00	156.53
1.27	1536.70	1466.85	1383.03	1452.88	1459.00	62.99
1.90	1550.67	1662.43	1466.85	1522.73	1550.00	82.25
2.54	1676.40	1536.70	1438.91	1536.70	1546.00	97.70
3.17	1536.70	1536.70	1536.70	1550.67	1539.00	40.32
3.81	1536.70	1606.55	1536.70	1606.55	1571.00	40.32
4.44	1606.55	1466.85	1550.67	1606.55	1557.00	66.01
5.08	1816.10	1536.70	1536.70	1536.70	1606.00	139.81
			Average of All Mean Values (N):			1490.00

Table 12
Force Values of the Reebok Wet Rat on Wet AstroTurf (Unworn Location)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1466.85	1522.73	1257.30	1341.12	1396.00	120.17
1.27	1802.13	1802.13	1802.13	1746.25	1788.00	27.94
1.90	1955.80	1955.80	1955.80	1885.95	1937.00	34.92
2.54	1941.83	1969.77	1913.89	1885.95	1927.00	36.07
3.17	1816.10	1899.92	1927.86	1816.10	1864.00	57.59
3.81	1816.10	1885.95	1885.95	1885.95	1867.00	34.92
4.44	1774.19	1816.10	1816.10	1885.95	1822.00	46.33
5.08	1676.40	1676.40	1676.40	1676.40	1676.00	0.0

Average of All Mean Values (N): 1784.00

Table 13
Force Values of the Reebok Wet Rat on Wet AstroTurf (Worn Location)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1397.00	1397.00	1536.70	1397.00	1431.00	69.85
1.27	1732.28	1732.28	1830.07	1746.25	1760.00	47.03
1.90	1955.80	1885.95	1969.77	1941.83	1937.00	36.74
2.54	1941.83	1955.80	1885.95	1941.83	1923.00	30.97
3.17	1955.80	1816.10	1885.95	1816.10	1868.00	66.87
3.81	1885.95	1885.95	1816.10	1885.95	1867.00	34.92
4.44	1816.10	1816.10	1816.10	1816.10	1816.00	0.0
5.08	1676.40	1676.40	1676.40	1676.40	1676.00	0.0

Average of All Mean Values (N): 1784.00

Table 14
Force Values of the Reebok Vicious on Wet Grass (Location 1)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1397.00	1243.33	1187.45	1117.60	1236.00	108.51
1.27	1676.40	1522.73	1466.85	1536.70	1550.00	89.08
1.90	1746.25	1606.55	1662.43	1606.55	1655.00	66.01
2.54	1746.25	1634.48	1662.43	1620.52	1665.00	56.31
3.17	1746.25	1634.49	1606.55	1676.40	1665.00	60.76
3.81	1760.22	1676.40	1648.46	1704.34	1697.00	47.71
4.44	1788.16	1704.34	1606.55	1690.37	1697.00	74.36
5.08	1746.25	1676.40	1606.55	1718.31	1686.00	60.76
				Average of All Mean Values (N):		1606.00

Table 15
Force Values of the Reebok Vicious on Wet Grass (Location 2)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1117.60	1117.60	1117.60	1229.36	1145.00	55.88
1.27	1397.00	1397.00	1536.70	1229.36	1389.00	125.73
1.90	1606.55	1550.67	1676.40	1676.40	1627.00	60.89
2.54	1606.55	1606.55	1690.37	1746.25	1662.00	68.43
3.17	1676.40	1648.46	1746.25	1816.10	1721.00	75.12
3.81	1676.40	1648.46	1746.25	1844.04	1728.00	87.14
4.44	1690.37	1676.40	1816.10	1885.95	1766.00	101.06
5.08	1676.40	1676.40	1816.10	1816.10	1746.00	80.65
					Average of All Mean Values (N):	1598.00

Table 16
Force Values of the Reebok Wet Rat on Dry AstroTurf (Unworn Location)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1243.33	1397.00	1271.27	1327.15	1309.00	67.84
1.27	1676.40	1816.10	1746.25	1816.10	1763.00	66.87
1.90	1746.25	2095.50	1955.80	1885.95	1912.00	145.40
2.54	1885.95	2123.44	1955.80	1885.95	1962.00	112.05
3.17	1885.95	2053.59	1955.80	1871.98	1941.00	83.04
3.81	1885.95	1955.80	1816.10	1844.04	1875.00	60.76
4.44	1816.10	1955.80	1816.10	1871.98	1864.00	66.01
5.08	1676.40	1955.80	1676.40	1676.40	1745.00	139.76

Average of All Mean Values (N): 1796.00

Table 17

Force Values of the Reebok Wet Rat on Dry AstroTurf (Worn Location)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1341.12	1327.15	1257.30	1257.30	1295.00	44.72
1.27	1802.13	1885.95	1676.40	1718.31	1770.00	92.92
1.90	1844.04	2137.41	1816.10	1955.80	1938.00	145.79
2.54	1955.80	2011.68	2067.56	2025.65	2014.00	46.15
3.17	1885.95	1955.80	1885.95	1941.83	1916.00	36.74
3.81	1871.98	1885.95	1941.83	1885.95	1895.00	30.97
4.44	1885.95	1899.92	1871.98	1955.80	1902.00	36.74
5.08	1676.40	1816.10	1746.25	1746.25	1746.00	57.03
				Average of All Mean Values (N):		1809.00

Table 18
Force Values of the Reebok Dry Rat on Wet AstroTurf (Unworn Location)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1257.30	1327.15	1187.45	1187.45	1239.00	66.87
1.27	1536.70	1606.55	1536.70	1536.70	1553.00	34.92
1.90	1606.55	1564.64	1606.55	1676.40	1613.00	46.33
2.54	1536.70	1592.58	1606.55	1676.40	1602.00	57.45
3.17	1536.70	1536.70	1606.55	1676.40	1588.00	66.87
3.81	1536.70	1536.70	1676.40	1704.34	1613.00	89.45
4.44	1536.70	1606.55	1564.64	1620.52	1581.00	38.47
5.08	1536.70	1536.70	1536.70	1536.70	1536.00	0.0
					Average of All Mean Values (N):	1540.00

Table 19
Force Values of the Reebok Dry Rat on Wet AstroTurf (Worn Location)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1285.24	1327.15	1327.15	1243.33	1295.00	40.12
1.27	1676.40	1662.43	1662.42	1606.55	1651.00	30.97
1.90	1676.40	1676.40	1606.55	1676.40	1648.00	34.92
2.54	1662.43	1606.55	1676.40	1676.40	1655.00	33.25
3.17	1746.25	1676.40	1620.52	1662.42	1676.00	52.27
3.81	1676.40	1662.43	1662.43	1676.40	1669.00	8.07
4.44	1746.25	1620.52	1676.40	1676.40	1679.00	51.48
5.08	1536.70	1536.70	1536.70	1536.70	1536.00	0.0
					Average of All Mean Values (N):	1601.00

Table 20

Force Values of the Reebok Pit Bull on Dry Grass (Location 1)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1117.60	1257.30	1187.45	1187.45	1187.00	75.96
1.27	1466.85	1536.70	1536.70	1522.73	1515.00	33.25
1.90	1676.40	1676.40	1662.43	1606.55	1655.00	33.25
2.54	1746.25	1676.40	1676.40	1662.43	1690.00	37.83
3.17	1746.25	1746.25	1676.40	1690.37	1714.00	36.74
3.81	1746.25	1732.28	1746.25	1746.25	1742.00	6.98
4.44	1746.25	1676.40	1760.22	1746.25	1732.00	37.83
5.08	1676.40	1676.40	1676.40	1746.25	1693.00	34.92
					Average of All Mean Values (N):	1616.00

Table 21
Force Values of the Reebok Pit Bull on Wet Grass (Location 1)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1187.45	1117.60	1159.51	1159.51	1155.00	28.79
1.27	1536.70	1466.85	1466.85	1466.85	1483.00	34.92
1.90	1606.55	1606.55	1606.55	1676.40	1623.00	34.92
2.54	1662.43	1676.40	1634.49	1704.34	1669.00	21.33
3.17	1676.40	1690.37	1662.43	1704.34	1683.00	18.03
3.81	1690.37	1704.34	1676.40	1774.19	1711.00	60.76
4.44	1746.25	1746.25	1662.43	1802.13	1739.00	57.59
5.08	1676.40	1676.40	1606.55	1676.40	1658.00	34.92

Average of All Mean Values (N): 1590.00

Table 22
Force Values of the Reebok Pit Bull on Wet Grass (Location 2)

Linear Displacement (cm)	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force Value (N)	SD
0.64	1327.15	1117.60	1117.60	1117.60	1169.00	104.77
1.27	1466.85	1410.97	1397.00	1466.85	1434.00	36.74
1.90	1536.70	1550.67	1550.67	1648.46	1571.00	51.64
2.54	1564.64	1634.49	1676.40	1690.37	1636.00	56.45
3.17	1606.55	1606.55	1676.40	1746.25	1658.00	66.87
3.81	1634.49	1676.40	1746.25	1746.25	1700.00	55.14
4.44	1676.40	1690.37	1746.25	1746.25	1714.00	36.74
5.08	1648.46	1676.40	1676.40	1746.25	1686.00	41.71
				Average of All Mean Values (N):		1571.00