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thesis entitled

THE FRICTION AND TRACTION CHARACTERISTICS
OF VARIOUS SHOE-SURFACE COMBINATIONS
WITH DIFFERENT VERTICAL LOADS

presented by

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has been accepted towards fulfillment
of the requirements for

Master's degree in PES

Major professor

Date 7/22/96

THE FRICTION AND TRACTION CHARACTERISTICS OF VARIOUS SHOE-SURFACE COMBINATIONS WITH DIFFERENT VERTICAL LOADS

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Physical Education and Exercise Science

1996

ABSTRACT

THE FRICTION AND TRACTION CHARACTERISTICS OF VARIOUS SHOE-SURFACE COMBINATIONS WITH DIFFERENT VERTICAL LOADS

By

Aric Jon Warren

The purpose of this study was to examine the shoe-surface interface of AstroTurf and natural grass using different footwear and varying vertical loads, and to measure the effects that these variables have on the coefficient of friction. It was hypothesized that AstroTurf produces more friction than natural grass and that a linear relationship exists between force and vertical load.

The PENNFOOT friction and traction testing apparatus was used to examine various shoe-surface interface combinations at different vertical loads. Testing was done using 4 Reebok football shoes on AstroTurf and natural grass at normal loads of 890, 1112.5, and 1335 Newtons.

The results showed that more friction was produced on AstroTurf than on natural grass. Also, the multicleated grass shoe provided more traction than the 7-studded, cleated shoe. Finally, a linear relationship exists between frictional or tractional force and vertical load.

ACKNOWLEDGMENTS

I would like to acknowledge the following individuals who helped make this research possible. I would first like to thank Andy McNitt, Pennsylvania State University, for the use of the PENNFOOT. Without his generosity this research would not have been possible.

I would also like to thank Jeff Monroe for providing me the opportunity to attend graduate school at Michigan State University. His encouragement and support have helped me to attain the best possible experiences during my education at Michigan State University.

My thanks is also given to Dr. John Rogers III, Dr. Eugene Brown and Dr. John Haubenstricker for their time devoted to reviewing this thesis. Their advice and patience were greatly appreciated. The advice from Dr. Marty Ewing and John Fitzpatrick was also very helpful.

Finally, I would like to thank Tom Mallette for his time and devotion in helping me with the data collection process. My thanks is also given to Bob Knickerbocker and Kevin Lartigue for the donation of the football shoes used in this study.

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CHAPTER 1: INTRODUCTION

Most outdoor sports are played on either natural grass or artificial turf. Unfortunately, injuries occur in sports regardless of the playing surface. A common belief in the public, which is projected by player bias and the media, is that artificial turf is responsible for more athletic injuries than natural grass (McCarthy, 1989). Typically, if an athlete is injured while playing on natural grass, the mechanism of the injury is usually blamed. On the other hand, injuries that occur while playing on artificial turf, are usually blamed on that surface.

Need for the Study

There are many different ways an athlete can become injured while performing his or her sport. These include player to player contact, player to equipment contact, player to surface contact, and improper traction between the shoe and the surface. In some instances, injury may result from too much traction in which the shoe does not break loose from the surface when a large shear force is applied. In other instances, there may be too little traction, resulting in injury due to slipping (Hamil & Knutzen, 1995). Traction-related injuries are dependent on many variables associated with the interaction between the shoe and the surface. The condition of the playing surface is one such variable. The relative wetness of the playing field can influence the amount of traction that an athlete has on the field (Culpepper & Niemann, 1983). Differences in temperature of the surface can also affect the amount of traction (Torg, Stilwell & Rogers, 1996). Other factors that affect shoe traction on playing surfaces are differences in the vertical (normal) load and shoe styles (Torg, Quedenfeld & Landau, 1974). The design of shoe soles, in combination with varying normal loads placed on them can produce different levels of traction on a surface. As a result, a debate among researchers remains unresolved between the safety of playing surfaces and the safest footwear for each surface. To help solve this debate, research needs to be conducted to determine which surface, under certain conditions, is the safest for play. The need to identify safe shoe-surface combinations is necessary for athlete safety. With this information, coaches, athletes, and athletic trainers can then select the safest shoe style for specific playing surfaces and field conditions.

Purpose of the Study

The purpose of this study was to examine the shoe-surface interface of artificial and natural surfaces under a variety of conditions and to measure the effects that these variables have on the coefficient of friction. The conditions tested were the differences in 4 shoe styles and the differences in the amount of vertical (normal) load placed on the surface. The dependent variable for this study was the force that was produced at the shoe-surface interface. The independent variables were the shoe styles, the amount of vertical load applied, and the type of surface.

Specific Aim of the Study

The specific aim of this study was to compare the friction and traction properties of natural grass and artificial turf using various shoe styles and vertical loads. This study was limited to only assessing the effect these variables have on linear friction.

Research Hypotheses

In Experiment 1, the traction properties of the Reebok Wet Rat and Dry Rat shoes were compared on dry AstroTurf with vertical loads of 890, 1112.5, and 1335 N. It was hypothesized that the Reebok Wet Rat shoe would exhibit more traction than the Reebok Dry Rat with the selected vertical loads.

In Experiment 2, comparision of the traction properties of the Reebok Pit Bull and Viscious shoes on dry natural grass with vertical loads of 890, 1112.5, and 1335 N were made. The hypothesis was that the Reebok Pit Bull shoe produces more traction than the Viscious shoe.

In Experiment 3, frictional differences between dry AstroTurf using the Reebok Dry Rat shoe and dry natural grass using the Reebok Viscious shoe at vertical loads of 890, 1112.5, and 1335 N were measured. It was hypothesized that more friction would be produced on AstroTurf using the Dry Rat shoe than on natural grass with the Viscious shoe at the three vertical loads.

Experiment 4 compared the friction differences between dry AstroTurf using the Wet Rat shoe at vertical loads of 890, 1112.5, and 1335 N and dry natural grass using the Pit Bull shoe at the same vertical loads. The hypothesis was that more friction would be produced on dry AstroTurf using the Wet Rat shoe than on dry natural grass using the Pit Bull at the three vertical loads.

Experiments 5 tested the Reebok Dry Rat shoe on dry AstroTurf at vertical loads of 890, 1112.5, and 1335 N. It was hypothesized that force increases linearly as vertical load increases.

Experiment 6 tested the Reebok Wet Rat shoe on dry AstroTurf at vertical loads of 890, 1112.5, and 1335 N. It was hypothesized that force increases linearly as vertical load increases.

Experiment 7 tested the Reebok Viscious shoe on dry natural grass at vertical loads of 890, 1112.5, and 1335 N. It was hypothesized that force increases linearly as vertical load increases.

Experiment 8 tested the Reebok Pit Bull shoe on dry natural grass at vertical loads of 890, 1112.5, and 1335 N. It was hypothesized that force increases linearly as vertical loads increases.

Research Plan

The data for the current study were collected using the PENNFOOT friction testing apparatus developed at Pennsylvania State University (Middour, 1992). The testing apparatus uses a system of hydraulic pumps to pull a weighted foot across a surface, measuring the amount of force required to produce movement at the shoe-surface interface. This apparatus can be used to simulate the linear friction of an athlete's shoe on natural and artificial surfaces using the various footwear at the selected vertical loads.

Limitations of the Study

It was assumed that the section of turf selected for testing was consistent in surface temperature and hardness. These factors may pose as possible limitations for the study. Other limitations include the age of the artificial surface, the dry surface condition, and only one brand of shoes was selected for testing. Also natural grass shoes were only tested on natural grass surfaces and no on AstroTurf. Likewise, the artificial turf shoes were only tested on AstroTurf and not on natural grass.

Significance of the Study

The significance of this study is that the findings may be used to aid in the awareness of potentially hazardous conditions that may predispose an athlete to injury. This information may also help answer questions regarding the shoe-surface interface; such as the possibility of increased risk for injury with an increase in vertical load, and also which shoe style on particular surfaces is safer for athletes. Furthermore, correct footwear can thus be selected under these conditions to help reduce the risk of severe injury.

DEFINITIONS

1. **Coefficient of friction:** The ratio of the magnitude of the maximum force of friction to the magnitude of the perpendicular force pressing the two surfaces together
2. **Force:** That which causes or tends to cause a change in a body's motion
3. **Friction:** The force that resists the sliding of one surface upon another
4. **Kinetic friction:** The friction that takes place once the two surfaces begin moving relative to each other
5. **Static friction:** The friction force generated between two objects before movement occurs
6. **Shoe-surface interface:** The point at which the shoe and surface interact
7. **Torque:** A turning or rotary force
8. **Traction:** The ratio of the tractional force to normal force in relation to cleated footwear
9. **Vertical load (normal load):** A force directed perpendicular to the surface

CHAPTER TWO: REVIEW OF LITERATURE

The literature reviewed for the current study has been divided into four segments: first, a section in which the history of artificial turf is described; second, the advantages and disadvantages of natural grass and artificial turf; third, injury rate comparisons between natural grass and artificial turf; and finally, a section in which the properties of friction and the literature pertaining to the shoe-surface interface are described.

History of Artificial Turf

Artificial turf was introduced to improve playground surfaces for city children. It was believed that falling on the traditional asphalt playgrounds could become a hazard to the children that play on them. The potential for injury, while playing on asphalt surfaces, inhibited city children from running and playing at full speed, making them less physically conditioned than children their own age from rural areas who played on grass playgrounds. In an attempt to increase the playability of school playgrounds, the first installation of artificial turf was at Moses Brown School in 1964, a school for boys in Providence, Rhode Island (Pine, 1991).

The first athletic stadium in which an artificial playing surface was installed was the Astrodome in Houston, Texas (Levy, Skovron & Agel, 1990). Initially, a grass field was nurtured from the light of the skylights. But, after complaints from the athletes of the glaring light, the skylights were painted over. The grass later died as a result. In 1966, the Houston Astrodome replaced the dying grass field with AstroTurf, an artificial surface made by Monsanto Commercial Products Company. By 1980, AstroTurf was installed on over 300 playing fields across the United States (Levy et al., 1990). The next artificial playing surface used to replace natural grass was Tartan Turf, manufactured by 3M. It was installed on university playing fields in Wisconsin and Tennessee but is no longer in production (Stanitski, McMaster & Ferguson, 1974). Other brands of artificial turf used on playing fields are PolyTurf, Omniturf, and Poligrass.

Advantages and Disadvantages of Natural Grass and Artificial Turf

No matter which surface is used, natural grass or artificial turf, both have distinctive advantages and disadvantages. The primary advantage of artificial grass is its ability to withstand the adverse weather conditions and still maintain its uniform playing surface. It can be used in domes where natural grass might not grow as easily as in an outdoor environment. Artificial turf can be used in climates in which conditions for natural grass to grow are limited. Artificial turf is ideal for areas with heavy rainfall and extreme cold and snowy weather. In areas with heavy rainfall, grass fields are more likely to be torn up with continual use. This can increase the cost of maintenance of the fields due to the divots caused by the softness of the surface. Another factor is the amount of activity on the field. Artificial turf can be used in schools that have high traffic levels due to the many sports that use the facilities (Roche, 1990). A natural grass field can not easily accommodate repetitive use and still maintain its function, whereas an artificial surface can withstand the daily practices of several teams and still remain in good condition for game day. Artificial turf can also extend the use of the facility by allowing owners to host various activities other than sporting events (Troy, 1977).

Although the use capabilities of artificial turf may exceed those of the grass fields, the playing quality of the artificial surfaces can decrease with age (Ryan, 1979). Bowers and Martin (1975) found that exposure to ultraviolet rays from the sun reduces the molecular weight of the turf fibers. This often causes the fibers to become brittle and flake off. Bowers and Martin (1975) also found that older artificial turf showed significantly less ability to absorb impact. The underpadding of the turf becomes flattened and leads to an increased hardness of the playing field. This can lead to a decrease in performance and the possibility of an increase in player-surface contact injuries.

According to George Toma (Roche, 1990), one of the biggest problems with artificial turf is surface temperature. Buskirk, Loomis, and McLaughlin (1971) found that there was a maximal difference of almost forty degrees Fahrenheit between artificial turf and grass temperatures. Torg, Stilwell, and Rogers (1996) found that an increase in the temperature of the artificial turf affects the shoe-surface interface friction and potentially places an athlete at risk of injury. Patrick and Barton (1972) found that turf temperature is higher at the surface on artificial turf than on natural grass. The lower surface temperature of natural grass compared to artificial turf is an advantage of natural grass. Another advantage of natural grass is the ability to absorb impact. As previously stated, the underpadding of artificial surfaces can become hard after prolonged use (Bowers & Martin, 1975), this is also the case with natural grass. Other advantages reported for natural surfaces include a lower rate of injury and also a decrease in the severity of injuries when compared to artificial turf (Bramwell, Requa & Garrick, 1972).

Injury Rate Comparisons of Natural Grass and Artificial Turf

As discussed earlier, injuries can occur from a variety of causes. The type of injury that is of primary concern, in the current study, is the surface related injury. Turf related injuries that result from player-surface contact and the non-contact injuries resulting from the turf itself have been studied. Researchers have studied the rates at which injuries occur on both natural and artificial playing surfaces. These studies have resulted in conflicting opinions concerning which surface produces more turf-related injuries.

Keene, Narechania, Sachtjen, and Clancy (1980) compared the injury rate between natural grass and Tartan Turf. They found that more serious sprains and torn ligaments occurred on grass than on the Tartan Turf. These results agree with those of Adkinson, Requa, and Garrick, (1974). Adkinson and his associates found that the highest injury rates occurred on AstroTurf followed by natural grass and Tartan Turf. Injury rates, including incidence of serious injury, were also found to be higher on AstroTurf than on natural grass (Bramwell et al., 1972).

Although injuries can occur on both surfaces, minor injuries such as skin abrasions and burns occur more often on artificial turf (Troy, 1977; Merritt & Thomson, 1978; Ryan, 1979). Bowers and Martin (1975) found that injuries to the great toe are more prevalent on artificial surfaces than on natural grass. The injury known as turf-toe is a sprain to the plantar capsule-ligament complex of the first metatarsophalangeal joint. Turf-toe occurs when the joint is forced into hyperextension due to the resiliency of the artificial turf (Bowers & Martin, 1975). An additional finding of Bowers and Martin (1975) is that traumatic prepatellar and olecranon bursitis occur more often on artificial surfaces.

According to Skovron, Levy, and Agel (1990), participation on an artificial surface is probably responsible for an increase in the risk of injury to the lower extremity. This agrees with the findings of Powell (1987) in which increased injury rates of the lower extremity were found in the National Football League (NFL) between 1980 and 1985. In a separate study of the knee injury rates in the NFL, Powell and Schootman (1992) found that there was a statistically significant difference between the higher AstroTurf injury rates for knee sprains compared to those for natural grass. They also found that overall there is a trend for AstroTurf to be associated with an increased risk for medial collateral ligament and anterior cruciate ligament injuries.

According to Epstein (1977), the National Football League Players Association (NFLPA) believes that artificial turf is responsible for many injuries, such as fractures, sprains, strains, and abrasions. In a more recent survey conducted by the NFLPA (1994), NFL players were asked a series of questions pertaining to their attitudes toward natural grass and artificial turf. A total of 93.4 percent of the players surveyed attributed higher rates of injury to artificial turf when compared to natural grass. Ninety-six percent also believe that artificial turf causes more soreness than natural grass. In addition, 91.5 percent of the NFL players surveyed believe that artificial turf is more likely than natural grass to shorten football careers. Even though most of the research suggests higher injury rates on artificial turf, some authors conclude that differences in injury rates do not exist between natural grass and artificial turf (Merritt & Thomson, 1978; Troy, 1977). A review of the NCAA Injury Surveillance System (1988) reveals that no significant differences were reported in football injury rates on artificial and natural turf between 1986 and 1988. Results showed that from 11 to 34 percent of all sports injuries may be turf related, but no significant differences were found for football.

Properties of Friction and the Literature Pertaining to the Shoe-Surface Interface

In order to understand what takes place between the shoe and the surface it interacts with, it is important to understand the concepts of force and friction. Hamill and Knutzen (1995) describe force as "any interaction, a push or pull, between two objects that can cause an object to accelerate either positively or negatively". According to Newton's principles of force, objects move when acted upon by a force greater that the resistance to movement provided by the object. Forces can produce motion, stop motion, acceleration, deceleration, or a change in the direction or movement of an object (Hamill & Knutzen, 1995).

Friction is defined as the force created between two contacting surfaces that tend to rub or slide past each other (Kreighbaum & Barthels, 1985). The force of friction is proportional to the normal force, or the force perpendicular to the surface. This is calculated by:

$$F = u N$$

where u is the coefficient of friction, F is the force of friction, and N is the normal force or the force perpendicular to the surface. The greater the coefficient of friction, the greater the interaction between the two surfaces. The point where the pulling force is at its maximum in which movement of the object has not yet begun is termed as the coefficient of static friction (Kreighbaum & Barthels, 1985). Kinetic friction is defined as the friction that takes place once the two surfaces begin moving relative to each other (Hamill & Knutzen, 1995).

Friction is an important factor in athletics. In many situations, athletes may try to either increase or decrease the coefficient of friction depending on the activity and conditions of the playing surface. Athletes wear particular shoe styles that can interact with the surface causing different coefficients of friction. For instance, some athletes prefer to wear cleated shoes to get better traction on the field, or to increase the amount of friction between the shoes and the surface. When the coefficient of friction is too small, between the shoe-surface interface, slipping can occur; but, when the coefficient of friction is too great, fixation of the foot on the surface may occur. When the shoe is fixed to the turf, injury to musculotendinous, ligamentous, bone, and cartilaginous structures may occur.

Several researchers have studied the shoe-surface interface and the differences in frictional components of natural and artificial surfaces. They have tested various shoe-surface combinations under a number of conditions. Many of the researchers have developed apparatuses to simulate shoe interaction with the playing surfaces.

Canaway and Bell (1985) developed an apparatus to measure friction and traction. It consisted of a steel disc in which football cleats could be secured. A shaft was centered through the disc with circular weights loaded on it giving it a total weight of 47.8 kg. The loaded apparatus was then dropped to the turf from a height of a few centimeters to ensure that studs penetrated the surface. A force was then applied to the shaft by a torque wrench to measure the amount of rotational friction present.

Several apparatuses were developed by other researchers for the purpose of studying turf friction. Andreasson, Lindenberger, Renstrom, and Peterson (1986) constructed an apparatus to measure the frictional forces and torque produced between the shoe and the surface. The apparatus consisted of a plot of artificial turf placed on a circular rotating disk driven by an electric motor. The speed of the disk could be varied to simulate walking and running speeds. The disk and a prosthetic test leg made of aluminum pipe were contained inside a metal frame. Vertical forces were applied by pneumatic cylinder pressure which varied from zero to 1000 N. Twenty-five different shoes were tested on the artificial Poligrass. They found that shoes made of polypropylene material gave a lower torque than shoes made of polyurethane and rubber-like soles. The increased shoe-surface interface friction of the rubber soled shoes was also found by Torg, Quendenfeld, and Landau (1974). Andreasson and colleagues (1986) also found that torque for sliding in the footstance position (foot in total contact with the surface) is lower than the torque produced when the foot is in the toestance position (only the ball of the foot in contact with the surface).

Bowers and Martin (1975) also developed an apparatus to test shoe-surface friction on new and old AstroTurf. They tested three cleats from three different shoes. The selected cleats were placed in a triangular shape on a platform loaded symmetrically with weights to produce a vertical load. The platform was pulled across the new and old AstroTurf using a crank tower assembly. A load ring recorded the frictional force. More weight could be added to the platform for re-testing at various vertical loads. The forces recorded were divided by three to obtain the friction forces produced per cleat. The results revealed that a linear relationship exists between the amount of frictional force produced and the vertical load. This finding was also confirmed by Torg et al. (1974); Andreasson et al. (1986); and Culpepper, Kurt, and Niemann (1983).

Another apparatus developed by Culpepper and his colleagues (1983) consisted of a prosthetic foot mounted on a steel shaft supported by a modified work bench. Vertical loads of ten to ninety pounds were applied to the foot with a force produced by a torque wrench. Culpepper and his associates tested five different shoes under wet and dry conditions on Poly-Turf and AstroTurf artificial surfaces. The results of the study showed that the shoe-surface interface demonstrating a higher coefficient of friction indicated a greater interlocking of the cleats with the playing surface. The more interlocking that occurs between the shoe and the surface the greater the risk of a torque-related injury to a knee and/or ankle joint. The authors also found that any given shoe can demonstrate different shoe-surface characteristics on different surfaces.

Bonstingl, Morehouse, and Niebel (1975) tested the effects that shoe type, vertical load, and stance position have on the shoe-surface interface. They tested eleven shoe types on three artificial surfaces and natural grass in the footstance and toestance positions. The artificial surfaces tested were AstroTurf, Tartan Turf, and Poly-Turf. The natural grass was about 3 years old and cut to a uniform height between 1 and 1.5 inches. Vertical load was applied using 170 and 200 pounds simulating two different player weights. The testing apparatus constructed was designed to simulate a torque delivered to a player's leg by a weighted pendulum. The two different weights were added to the drawn back pendulum and were then released. The impact from the released pendulum caused the prosthetic leg to rotate over a sample of the playing surface being tested. It was found that

70 percent more torque was produced in the footstance position than in the toestance position. This finding contradicts the results of Andreasson et al. (1986), in which torque was greater in the toestance position. Bonstingl and his colleagues (1975) also found that the torque produced at the shoe-surface interface was greater at the 200 pound vertical load than the 170 pound vertical load. Other findings in this study included: a) more torque with the seven-studded conventional style shoe on natural grass than any other shoe-surface combination; b) the non-cleated style shoe produced less torque on natural grass than on any of the artificial surfaces tested. The result of increased torque produced with an increase in vertical load agrees with that of Torg et al. (1974) Andreasson et al. (1986) and Culpepper et al. (1983), although no linear relationship between torque and vertical load was found.

In 1974, Torg et al. measured rotational movement using a prosthetic foot mounted on a loaded steel shaft. The system was designed so that the vertical load was equally distributed on the forefoot and heel. The load placed on the prosthetic foot was able to be changed. The force was applied using a torque wrench which was attached at the top portion of the steel shaft. The prosthetic foot was placed over a plot of the testing surface. The surfaces tested with the device were natural grass, AstroTurf, Tartan Turf, and Poly-Turf. Characterizations of these surfaces were not made. The shoe styles used in the study were a conventional shoe with seven three-quarter inch cleats and an all purpose "soccer style" shoe with 15 three-eighths inch cleat tips. The vertical load was varied from 25 and 150 pounds and was increased in 25 pound increments. They found that a linear relationship existed between the vertical load and force required to move the shoe when the two shoes were tested on the selected surfaces.

In another study by Torg and Quendenfeld (1971) the relationship between the use of the conventional seven-studded football shoe and knee injuries was assessed in Philadelphia Public and Catholic High School football leagues. They determined that foot fixation is dependent on the number and the size of the cleats on the football shoe. It was hypothesized that the fewer the number of cleats on the shoe and the smaller the cleat length and diameter, the smaller the surface area bearing weight. This smaller surface area of the cleats then produces a greater pressure that is transmitted through each cleat. It was also hypothesized that the longer cleats penetrated the surface to a greater depth. Thus a shoe containing a few long cleats will cause the foot to become fixed to the surface producing more injuries. According to Torg and Quendenfeld (1971), the conventional seven-studded football shoe creates foot fixation and the multicleated molded soccer style shoe greatly lessens the possibility of foot fixation. To test their hypotheses, Torg and Quendenfeld used the Philadelphia Public and Catholic High School Football Leagues. All knee injuries were recorded in 1968 in which the conventional seven-studded shoes were worn. In the 1969 season the molded sole shoes were worn and the total number of knee injuries were also recorded. In both leagues, all practices and games were conducted on natural turf. Their results showed that the incidence of knee injuries decreased when the players wore the shorter, multicleated molded soccer style shoe. The severity of injuries also decreased with the use of this shoe as opposed to the conventional seven-studded football shoe.

Using the results of the Philadelphia study (Torg & Quendenfeld, 1971), Torg, Quendenfeld, and Landau, (1974) developed a friction release coefficient (r) for shoe-surface interface combinations. The release coefficient is described as r where r = Force/weight. Torg et al. (1974) then assigned relative safety characterizations for each interface and established an overall risk criterion for each shoe style. Any shoe-surface combination with a release coefficient ranging from .49 to .55 is not safe and may result in more injuries. Release coefficients ranging from .40 to .49 are probably not safe. Likewise, release coefficients from .31 to .40 are probably safer than the shoe-surface combinations with a higher release coefficient. The safest shoe-surface combinations are those with a release coefficient of less than .30.

Torg et al. (1974) concluded that the conventional seven-studded football shoe is not safe on grass. Also, that the molded multicleated soccer style shoe with the wider diameter cleats is safe on all surfaces. This supports the original hypotheses that cleat length and diameter affect the amount of foot fixation that is experienced on the surface. This statement agrees with the work of Culpepper et al. (1983). Ekstrand and Nigg (1989) also agreed that the incidence and severity of knee and ankle injuries are significantly lower when using shoes with lower friction properties. Culpepper et al. (1983) suggest that a shoe-surface interface that demonstrates a higher release coefficient indicates a greater interlocking of the cleats with the surface, thus the greater the risk of a torque-related injury to the knee and/or ankle.

Summary

Several studies have been conducted to find out which surface, artificial or natural turf, is safer for athletes. Although these studies provide valuable information regarding the shoe-surface interface, they fail to come to a unanimous decision about which is the safest playing surface. Most of these studies contradict the findings of other researchers leaving this area of study inconclusive.

Powell and Schootman (1992) state that the type of shoe worn at the time of injury is of valuable importance. In addition, Torg et al., (1974) found a linear relationship between the vertical load placed on a shoe and the force required for movement to occur. Although these researchers have contributed to the study of the shoe-surface interface, additional research in this area is needed.

CHAPTER THREE: METHODS

The methods chapter of the current study has been divided into five sections: first, a section describing the PENNFOOT apparatus used to test shoe-surface traction differences; second, a description of the footwear and surfaces tested; third, the procedure for collecting data with the PENNFOOT; fourth, the procedures used for data collection; and finally, a description of the data analysis.

Description of the PENNFOOT test apparatus

The PENNFOOT test apparatus used for data collection was constructed at Pennsylvania State University. The description of the PENNFOOT was taken from Middour (1992) and includes an overview of the frame assembly, player leg and foot assembly, hydraulic system assembly, and measuring devices. A photograph of the PENNFOOT appears in Figure 1.

The PENNFOOT consists of two iron frames, an internal and an external frame. The internal frame was constructed to allow the leg assembly to reach the ground, decrease the overall weight of the apparatus, and make the transferring of loading weights easier. The second frame was constructed

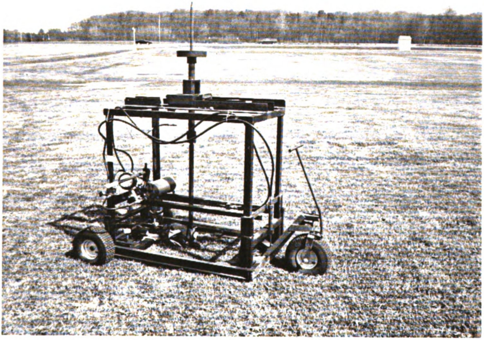

Figure 1. The PENNFOOT friction and traction testing apparatus.

around the outside of the internal frame. It was designed to encase the internal frame, which allows for vertical sliding of the internal frame, while the outer frame remains fixed. The external frame also allows for ease of lifting the weighted foot between measurements. The top portion of the internal frame contains a centrally located collar in which the leg-shoe assembly slides. A set screw located on the collar is used to lock the leg-shoe assembly in place during lifting and transporting of the apparatus. When the set screw is loosened, the leg-shoe assembly and the weights placed on it act independent of the internal frame and drop to the surface being tested. The external frame of the PENNFOOT has been mounted on wheels to make the apparatus movable. Two wheels are mounted on the rear of the apparatus and the third wheel is centered on the front. This makes for easy transportation of the apparatus to various testing sites.

The player leg assembly consists of a solid steel rod (3.81 cm diameter) of which the upper portion consists of a ball-and-socket assembly. This was made to simulate a human hip joint. The lower end of the leg assembly is pinned to a cast aluminum foot simulating a human ankle joint. The very top portion of the leg assembly (above the ball-and-socket) is capable of holding circular weights. The circular weights placed on top of the leg assembly provide the vertical load and simulate different player body weights. The leg assembly itself has a weight of 74.4 pounds (33.7 kilograms). Thus, the total vertical load is equal to the weight of the circular weights plus the weight of the leg-shoe assembly.

The simulated foot is made of aluminum from a size ten foot mold. The foot is pinned to the leg assembly allowing the heel to be off the ground and all the weight to be placed over the ball of the foot in the toestance position. The molded aluminum foot has the ability to be fitted with any desired shoe to be tested.

The hydraulic assembly used to create the horizontal (sheer) forces between the shoe and the surface and to lift the internal frame is generated by a Energy HP-100 hand pump (Energy MFG. Co., Inc., Monticello, IA). The linear horizontal force is created by a HTB-1E pulling piston. The piston was mounted on the bottom of the internal frame. The pulling rod is 7.3 cm above the ground when the internal frame rests on the ground. The rod end is pinned to a bracket mounted on the heel of the foot. The traveling distance of the foot, when pulled by the piston, is measured by a dial indicator in inches.

A liquid filled pressure gauge (Ashcroft Duragauge, Stratford, CT) is connected directly to the hydraulic hand pump to monitor the pressure being applied to the pistons. The pressure gauge has a range from zero to 600 psi. Raising or lowering the internal frame is accomplished by two vertically mounted HTB-1R pistons. The ends of the piston rods rest on the external frame. When pressure is applied, the internal frame is lifted. Once the pressure is released, the internal frame lowers and rests on the surface.

Footwear

The shoes used in the data collection were acquired from the football equipment room at Michigan State University. The shoes selected were the shoe styles used by the Michigan State Football team. Four shoes were used in the data collection (see Figure 2). Two shoe styles were used for natural grass testing and two shoe styles were selected for testing on artificial surfaces. Shoe I, developed for wet synthetic surfaces, consisted of a rubber studded outsole with approximately 1/8 inch length cleats (Reebok Wet Rat, 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 was a standard 7-studded, cleated, grass shoe with 1/2 inch length studs (Reebok Viscious, Reebok International; Stoughton, MA). Shoe IV consisted of a hard rubber molded, multi-cleated grass shoe with 15 triangular-shaped and 9 cone-shaped cleats (Reebok Pit Bull, Reebok International; Stoughton, MA).

All of the friction and traction measurements made on AstroTurf were collected at the Duffy Daugherty indoor football facility at Michigan State University. The AstroTurf was eight years old at the time of the data collection. Because it was a surface in an indoor facility, it has not been exposed to extreme temperatures, sunlight, and wetness. Data on natural grass was collected on a grass plot at the

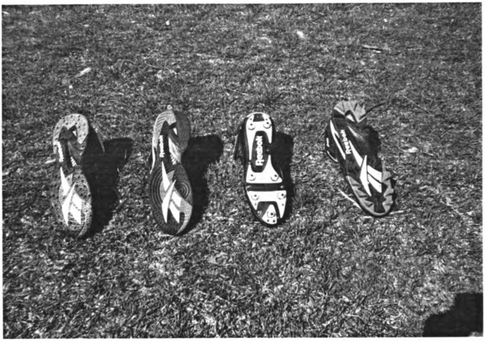

Figure 2. The 4 shoes used for testing friction and traction are, from left to right, a) the Reebok Wet Rat, b) the Dry Rat, c) Viscious, and d) Pit Bull.

Hancock Turfgrass Research Center at Michigan State University. The grass plot consisted of a combination of Kentucky bluegrass (Poa pratensis), perennial ryegrass (Lolium perenne), and Poa supina. The grass plot was grown in the indoor turfgrass research facility, so it too was also protected from extreme cold and hot temperatures. The grass had not been watered and the surface was dry for all measurements.

Procedures for collecting data with the PENNFOOT

The procedure for data collection was the same for both AstroTurf and natural grass measurements. Locations for experimentation were randomly selected for both surfaces. Once a location had been selected, the area for testing was marked off by a two foot square barrier using athletic tape. All of the measurements for each experiment took place within the selected two foot square barrier. Prior to data collection, surface hardness and surface temperature were assessed at each testing location (see Appendix, Table 26). Surface hardness was measured using a Clegg Impact Soil Tester (Clegg, 1978). This device measures the maximum or peak deceleration of the impact of the hammer as it hits the surface when dropped from a fixed height (Rogers & Waddington, 1992). Surface temperature was evaluated using a Barnett Thermocuplet. Testing consisted of four trials within the marked areas. To be certain that testing was not performed in the same place, the PENNFOOT was moved to another section within the marked area. This was done to provide an undamaged portion of the surface for each testing trial. Each experiment was performed at a new randomly selected location on the surface to be tested.

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. Then the leg-shoe assembly was weighted with circular weights to attain a particular loading weight, or vertical load.

2. The machine was situated over the desired surface to be tested and the pistons used to create the horizontal force were set. Setting the linear piston was accomplished by manually pulling the piston out until the dial indicator read zero. Once the piston had been set, the internal frame was lowered slowly. When the toe of the shoe made contact with the surface, the set screw holding the weighted leg assembly was released. This allowed the leg-shoe assembly and weights to act independent of the internal frame. This allowed for placement of the shoe on the turf rather than dropping of the shoe to the surface.

3. The measurement for linear traction required that two people operate the apparatus. One person operated the hydraulic pump which created linear movement of the foot. This person also read the pressure gauge and reported the readings in psi. The second person watched for initial

movement of the foot and read the dial indicator, monitoring the linear movement of the foot in inches. Eight pressure readings were recorded, one at every 0.25 inches (0.635 cm) starting at 0.25 inch (0.635 cm) and ending at 2.0 inches (5.08 cm) of linear travel.

4. The final step of the procedure was to convert psi values from the pressure guage to force (N). This was accomplished by calculating the product of the effective area of the pulling piston (3.14 inches squared) and the amount of pressure (psi) read from the pressure gauge. This step converts 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 will convert the pressure reading directly to N.

Prior to data collection several practice trials were performed on both artificial and natural surfaces. The operation of the PENNFOOT required training to be certain that it was operated correctly. Practice trials included proper reading of the gauges along with smooth operation of the hydraulic pumps. Data collection did not begin until both operators were comfortable and proficient at operating the PENNFOOT.

Methods for data collection

The objèctive of this study was to compare the friction and traction properties of natural grass and artificial turf using various shoe styles and increasing vertical loads. The PENNFOOT was used in eight experiments testing the effects that varying vertical loads and different footwear have on the friction and traction characteristics of the two surfaces.

In the following four experiments, testing was performed on natural grass and AstroTurf under dry conditions. This means that no moisture was observed on the surface during testing. The shoes used in these experiments were the shoes that would normally be worn on a particular surface during competition. Experiment 1 assessed the traction difference between the two shoe styles worn on artificial surfaces while Experiment 2 assessed the traction difference of the natural grass footwear. In Experiments 3 and 4, friction differences were measured between natural grass and AstroTurf using the appropriate footwear. Experiments 1 through 4 are as follows:

Experiment 1. Compare traction properties of the Reebok Wet Rat shoe to the Reebok Dry Rat on dry AstroTurf with vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N).

Experiment 2. Compare traction properties of the Reebok Pit Bull shoe to the Reebok Viscious shoe on dry natural grass with vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N).

Experiment 3. Compare shoe-surface frictional values of dry AstroTurf and the Reebok Dry Rat shoe with those of dry natural grass and the Reebok Viscious shoe at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N).

Experiment 4. Compare shoe-surface frictional values of dry AstroTurf and the Reebok Wet Rat with those of natural grass and the Pit Bull at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N)..

Experiments 5 through 8 assessed the effects that an increasing vertical load has on the friction properties of a particular surface. Experiments 5 through 8 are as follows:

Experiment 5. The Reebok Dry Rat was used on dry AstroTurf and tested at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N), respectively.

Experiment 6. The Reebok Wet Rat shoe was used on dry AstroTurf and tested at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N), respectively.

Experiment 7. The Reebok Viscious shoe was used on dry natural grass and tested at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N), respectively.

Experiment 8. The Reebok Pit Bull shoe was used on dry natural grass and tested at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N), respectively.

Data analysis

The data were analyzed using the SPSS statistical program. The data for all of the experiments were entered in a spreadsheet format and code numbers were assigned to the independent variables (shoes and weight). A 2 by 3 ANOVA test was performed for Experiments 1 and 2 to test the difference in the amount of force required to produce movement at the shoe-surface interface between the 2 shoe styles and varying vertical loads. Also a Tukey's highly significant difference (HSD) one-way analysis of variance test was performed for Experiments 1 and 2 to test for significant differences in the amount of force required to produce movement at the shoe-surface interface with the increase of vertical load. A 2 by 3 ANOVA was also used for Experiments 3 and 4 to test for differences in the amount of force required to produce movement at the shoe-surface interface on natural grass and AstroTurf with the varying vertical loads. In Experiments 3 and 4 the shoes used for testing were held constant in order to test the difference in friction between the two surfaces. In Experiments 5 through 8 a one-way analysis of variance was used along with Tukey's HSD test. These tests were used to find if a significant difference exists in the amount of force required to produce movement with an increase in vertical load and also to find out exactly where the difference occurs. Also, linear regression tests were used for Experiments 5 through 8 to find if force is dependent on the amount of vertical load placed on the shoes. For all experiments a significance level of 5 percent ($p < 0.05$) was established.

CHAPTER 4: RESULTS

The objective of this study was to determine and compare the friction and traction properties of the shoe-surface interface for various shoe styles on dry natural grass and AstroTurf under different normal load conditions. This was accomplished by performing eight experiments using the PENNFOOT friction testing apparatus.

In Experiment 1 the traction properties of the Reebok Wet Rat shoe were compared to those of the Reebok Dry Rat shoe on dry AstroTurf under vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N). It was hypothesized that the Reebok Wet Rat shoe would require a greater force to produce movement at the shoe-surface interface than the Reebok Dry Rat under the same vertical load conditions. The average mean forces of the Wet Rat were 1738, 1914, and 2156 N at the three vertical loads compared to the Dry Rat with average mean forces of 1609, 1754, and 1932 N at the same vertical loads (Table 1). The results of statistical testing showed a significant difference in the amount of force required to produce movement at the shoe-surface interface between the Reebok Wet Rat and Dry Rat shoes [$F(1, 192) = 38.761$, $p=.000$], favoring the Wet Rat shoe (Figure 3). There was also a significant difference in force with the increase in vertical

Table 1
Average Mean Forces of the Reebok Wet Rat, Dry Rat, Viscious, and Pit Bull at Vertical (Normal) Loads of 890, 1112.5, and 1335 N.

Shoe	Surface	Average Mean Force at 890 N	Average Mean Force at 1112.5 N	Average Mean Force at 1335 N
Wet Rat	AstroTurf	1738.88 (± 171.16)	1914.75 (± 203.75)	2156.28 (± 226.47)
Dry Rat	AstroTurf	1609.12 (± 206.67)	1754.25 (± 143.93)	1932.87 (± 176.70)
Viscious	Natural Grass	1438.12 (± 231.44)	1682.93 (± 278.55)	1833.94 (± 264.14)
Pit Bull	Natural Grass	1616.00 (± 187.50)	1831.65 (± 232.58)	2032.18 (± 262.13)

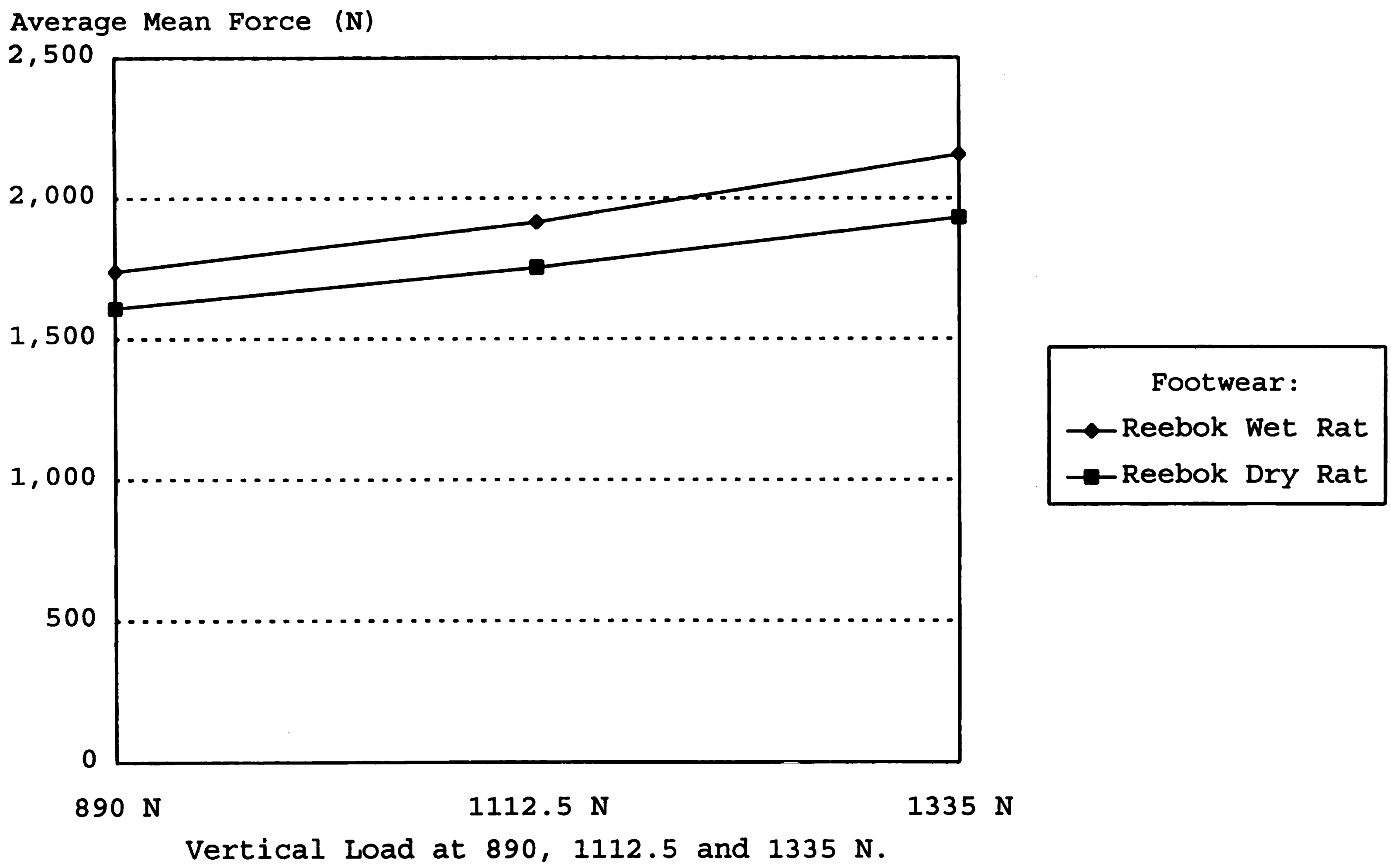

Figure 3. Traction properties of the Reebok Wet Rat and Dry Rat on dry AstroTurf at vertical loads of 890, 1112.5 and 1335 N.

load [F(2, 192) = 61.178, p=.000] (see Appendix, Table 14). Post hoc testing showed that a significant difference in force occurred between all vertical loads of 890 and 1112.5 N, 890 and 1335 N, and also 1112.5 and 1335 N. There were no significant shoe-vertical load interaction effects. Thus, the hypothesis for Experiment 1 was supported.

In Experiment 2 the traction properties of the Reebok Pit Bull shoe were compared to those of the Reebok Viscious shoe on dry natural grass under vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N). The hypothesis for Experiment 2 was that the Reebok Pit Bull shoe would require a greater force to produce movement at the shoe-surface interface than the Reebok Viscious at the selected vertical loads. The average mean tractional forces produced by the Pit Bull were 1616, 1831, and 2032 N at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N) compared to the Viscious with average mean forces of 1438, 1682, and 1833 N at the same vertical loads (Table 1). A significant difference in the amount of force required to produce movement at the shoe-surface interface was found between the Reebok Pit Bull and the Viscious shoes [F(1, 192) = 24.848, p=.000], in favor of the Pit Bull shoe (Figure 4). A significant difference in force was also found with an increase in vertical load [F(2, 192) = 44.833, p=.000] (see Appendix, Table 15). The significant differences in force were found between 890 and 1112.5 N, 890 and 1335 N, and also 1112.5 and 1335 N vertical loads. The interaction between shoe and vertical load was not

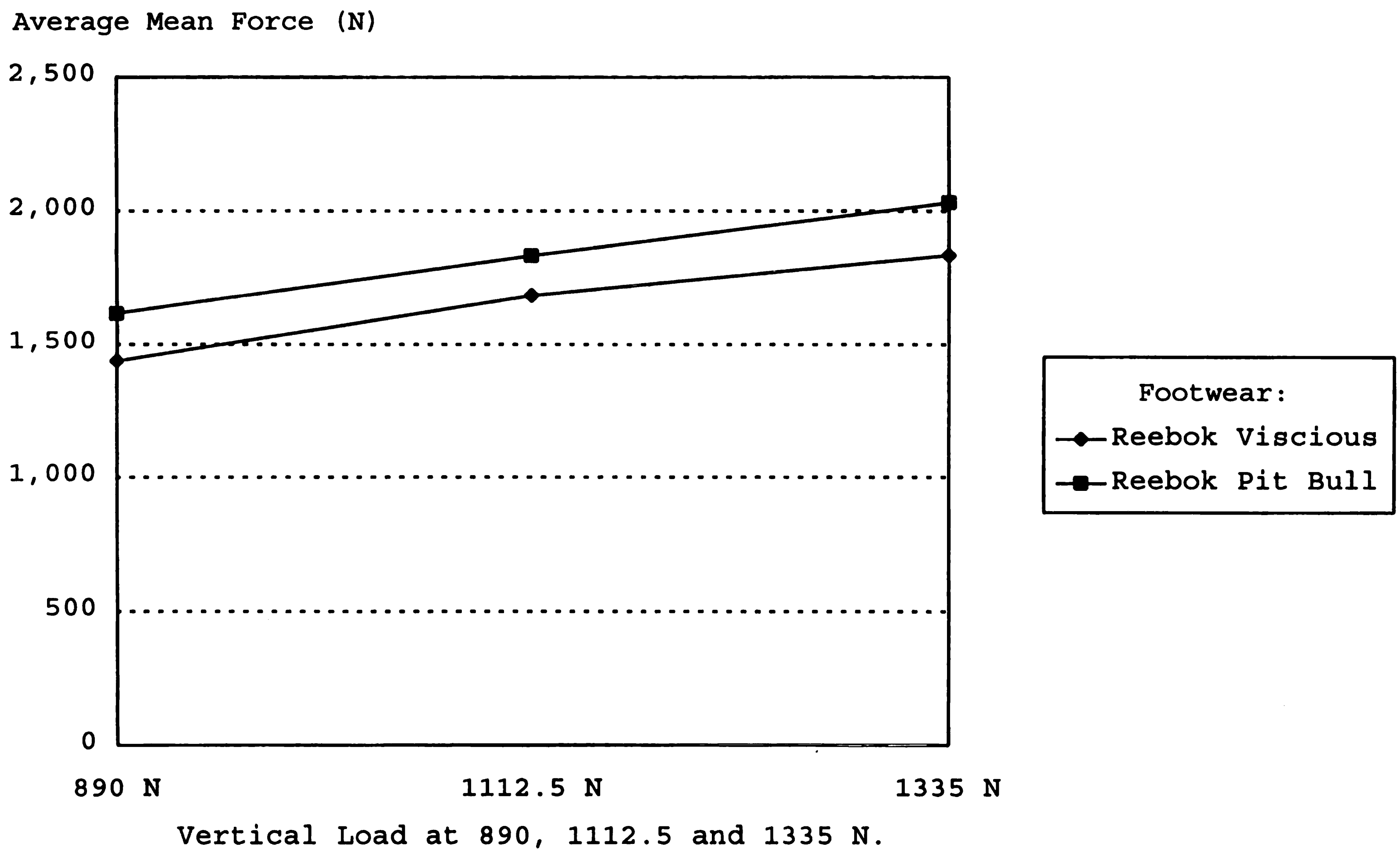

Figure 4. Traction properties of the Reebok Pit Bull and Viscious shoes on dry natural grass at vertical loads of 890, 1112.5, and 1335 N.

significant. The hypothesis for Experiment 2 was supported.

In Experiment 3 friction differences in shoe-surface interface were compared between dry AstroTurf using the Reebok Dry Rat shoe and dry natural grass using the Reebok Viscious shoe at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N). It was hypothesized that more force would be required to produce movement at the shoe-surface interface on dry AstroTurf using the Dry Rat shoe at the selected weights than on dry natural grass using the Viscious shoe at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N). The average mean forces produced on AstroTurf using the Dry Rat were 1609, 1754, and 1932 N at the 3 vertical loads while the average mean forces of the natural grass using the Viscious shoe were 1438, 1682, and 1833 N, respectively (Table 1). The differences in the forces required to produce movement on AstroTurf and natural grass were significant [$F(1, 192) = 12.261$, $p=.001$], in favor of the AstroTurf surface using the Dry Rat shoe (Figure 5). A significant difference in force was also found with an increase in vertical load [$F(2, 192) = 40.986$, $p=.000$] (see Appendix, Table 16). The significant differences in force were found between 890 and 1112.5 N, 890 and 1335 N, and 1112.5 and 1335 N. There were no significant interaction effects for shoe and vertical load. The hypothesis for Experiment 3 was supported.

Experiment 4 compared friction differences between dry AstroTurf, using the Reebok Wet Rat shoe at vertical loads of

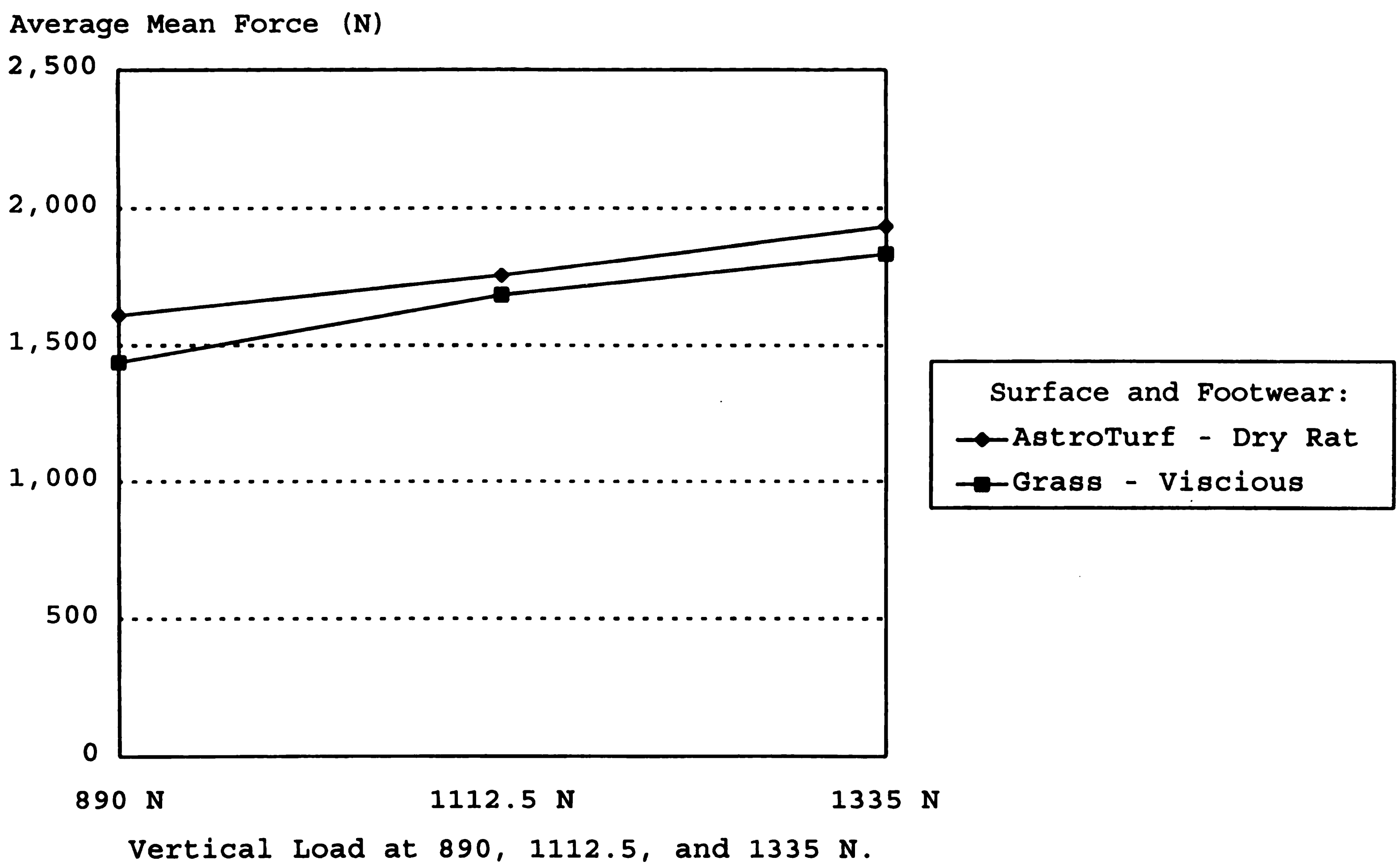

Figure 5. Friction differences between dry AstroTurf, using the Reebok Dry Rat shoe, and natural grass, using the Reebok Viscious shoe, at vertical loads of 890, 1112.5, and 1335 N.

200, 250, and 300 pounds (890, 1112.5, 1335 N), and dry natural grass, using the Pit Bull at the same vertical loads. It was hypothesized that more force would be required to produce movement at the shoe-surface interface on the AstroTurf using the Wet Rat shoe at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N) than on dry natural grass using the Pit Bull at the same vertical loads. The average mean forces required to produce movement at the shoe-surface interface on AstroTurf using the Wet Rat were 1738, 1914, and 2156 N while the average mean forces for natural grass using the Pit Bull were 1616, 1831, and 2032 N at the 3 vertical loads (Table 1). The differences in forces required to produce movement on AstroTurf and natural grass were significantly different [$F(1, 192) = 12.825$, $p=.000$], in favor of the AstroTurf surface using the Wet Rat shoe (Figure 6). A significant difference in force with an increase in vertical load was also found [$F(2, 192) = 62.295$, $p=.000$] (see Appendix, Table 17). The significant differences in force were found between 890 and 1112.5 N, 890 and 1335 N, and also 1112.5 and 1335 N vertical loads. There were no significant interaction effects for shoe and vertical load. The hypothesis for Experiment 4 was supported.

Experiment 5 tested the Reebok Dry Rat shoe on dry AstroTurf at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N). It was hypothesized that force required to produce movement at the shoe-surface interface increases linearly as vertical load increases. It was found that a

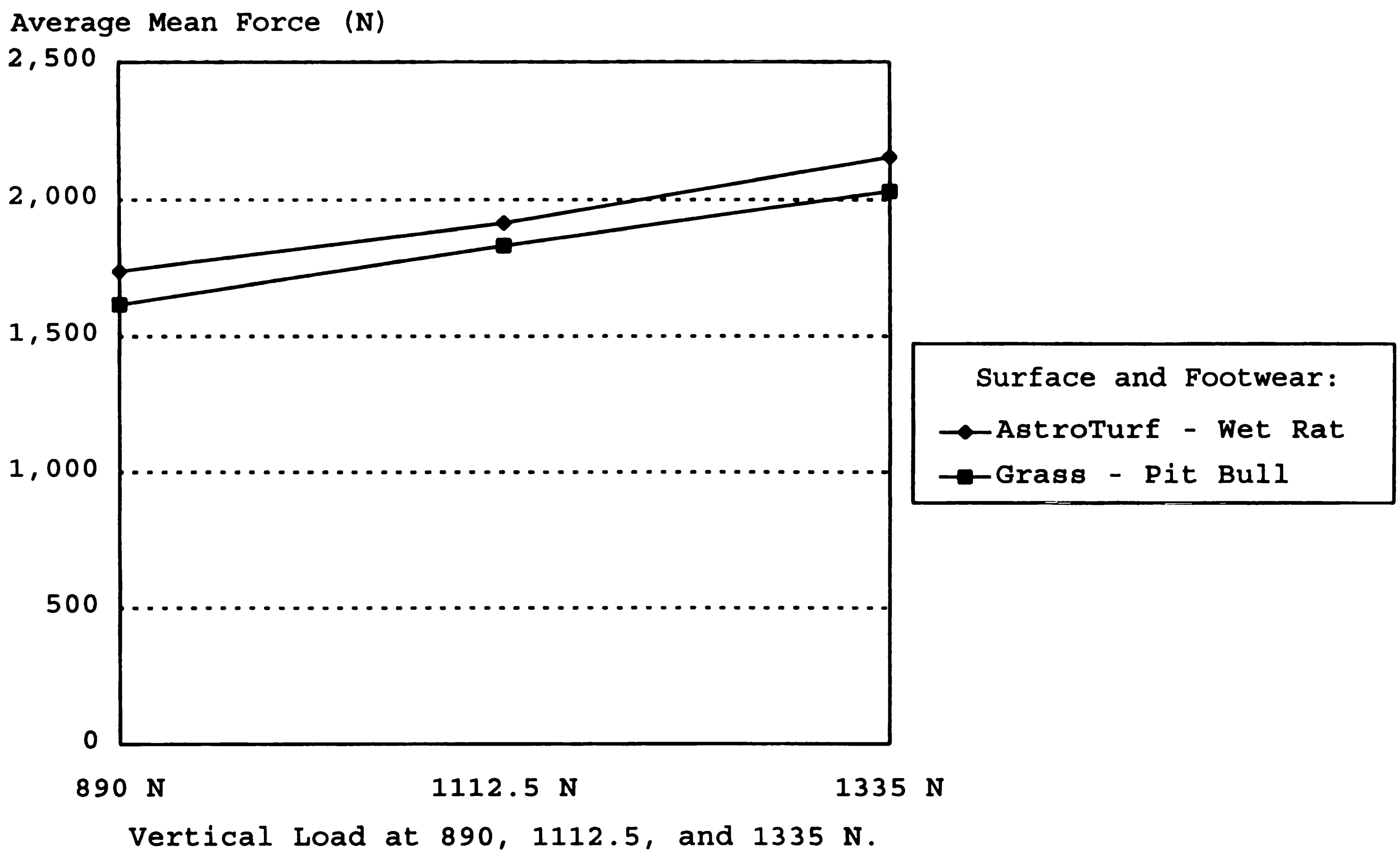

Figure 6. Friction differences between dry AstroTurf, using the Reebok Wet Rat shoe, and natural grass, using the Reebok Pit Bull shoe, at vertical loads of 890, 1112.5, and 1335 N.

linear relationship existed between force and vertical load using the Reebok Dry Rat shoe [F(2, 96) = 52.138, p=.000], (Figure 3 and Table 18 in the Appendix). Significant differences in force were found to occur between the 890 and 1112.5 N vertical loads, 890 and 1335 N vertical loads, and also the 1112.5 and 1335 N vertical loads (Figure 7). Results from the linear regression statistical testing showed that the amount of force produced was highly dependent on the amount of vertical load placed on the shoe where R = .3587 (see Appendix, Table 19).

Experiment 6 tested the Reebok Wet Rat shoe on dry AstroTurf at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N). It was hypothesized that force increases linearly as vertical load increases. Results show that a linear relationship between the force required to produce movement at the shoe-surface interface and vertical load existed using the Reebok Wet Rat shoe [F(2, 96) = 69.602, p=.000], (Figure 3 and Table 20 in the Appendix). Results also show that force is dependent on the amount of vertical load placed on the shoe where R = .4267 (see Appendix, Table 21). Significant differences in force were found to occur between the 890 and 1112.5 N vertical loads, the 890 and 1335 N vertical loads, and also the 1112.5 and 1335 N vertical loads (Figure 8).

Experiment 7 tested the Reebok Viscious shoe on dry natural grass at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N). It was hypothesized that force

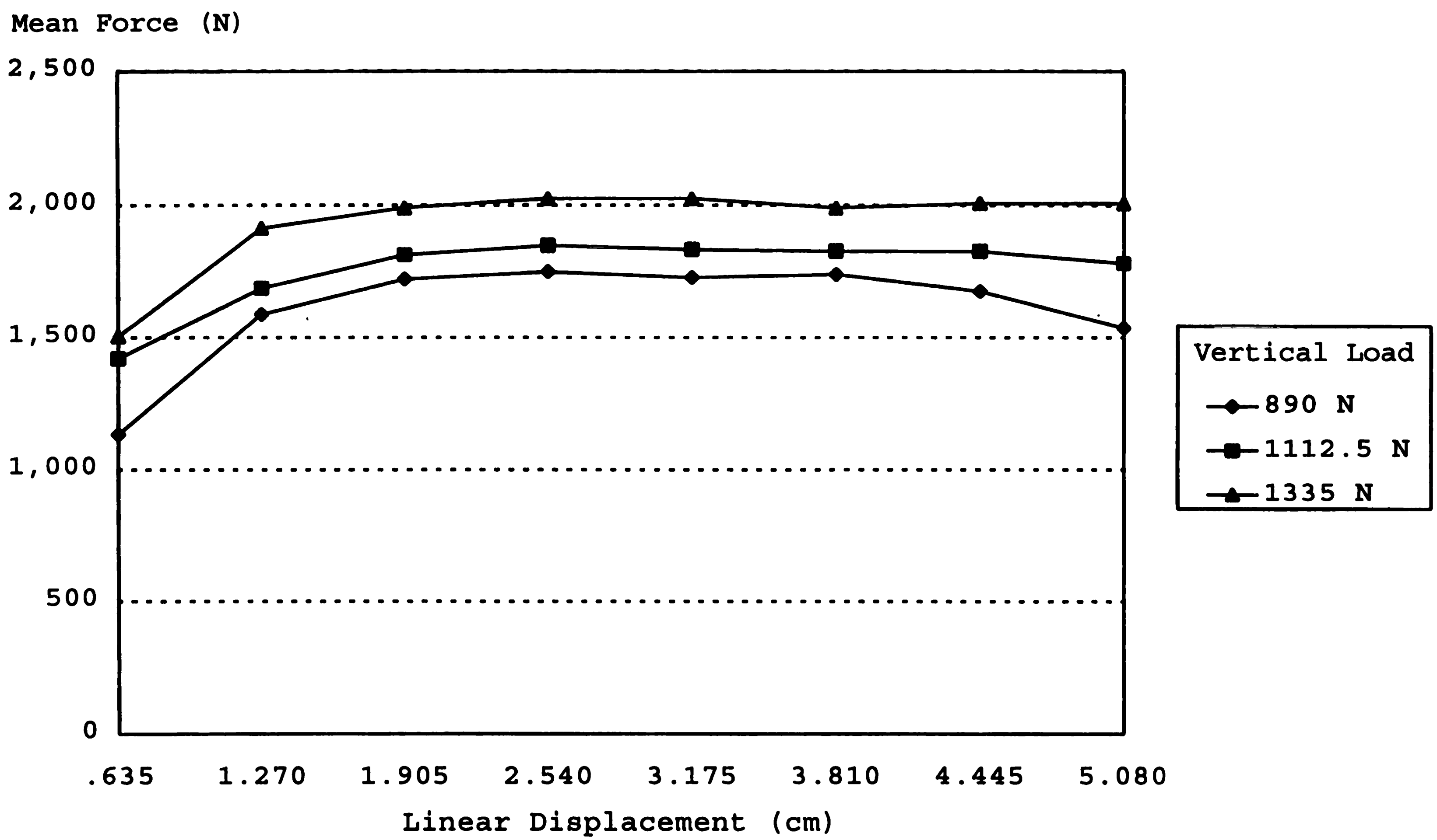

Figure 7. Friction values of dry AstroTurf using the Reebok Dry Rat at 890, 1112.5, and 1335 N.

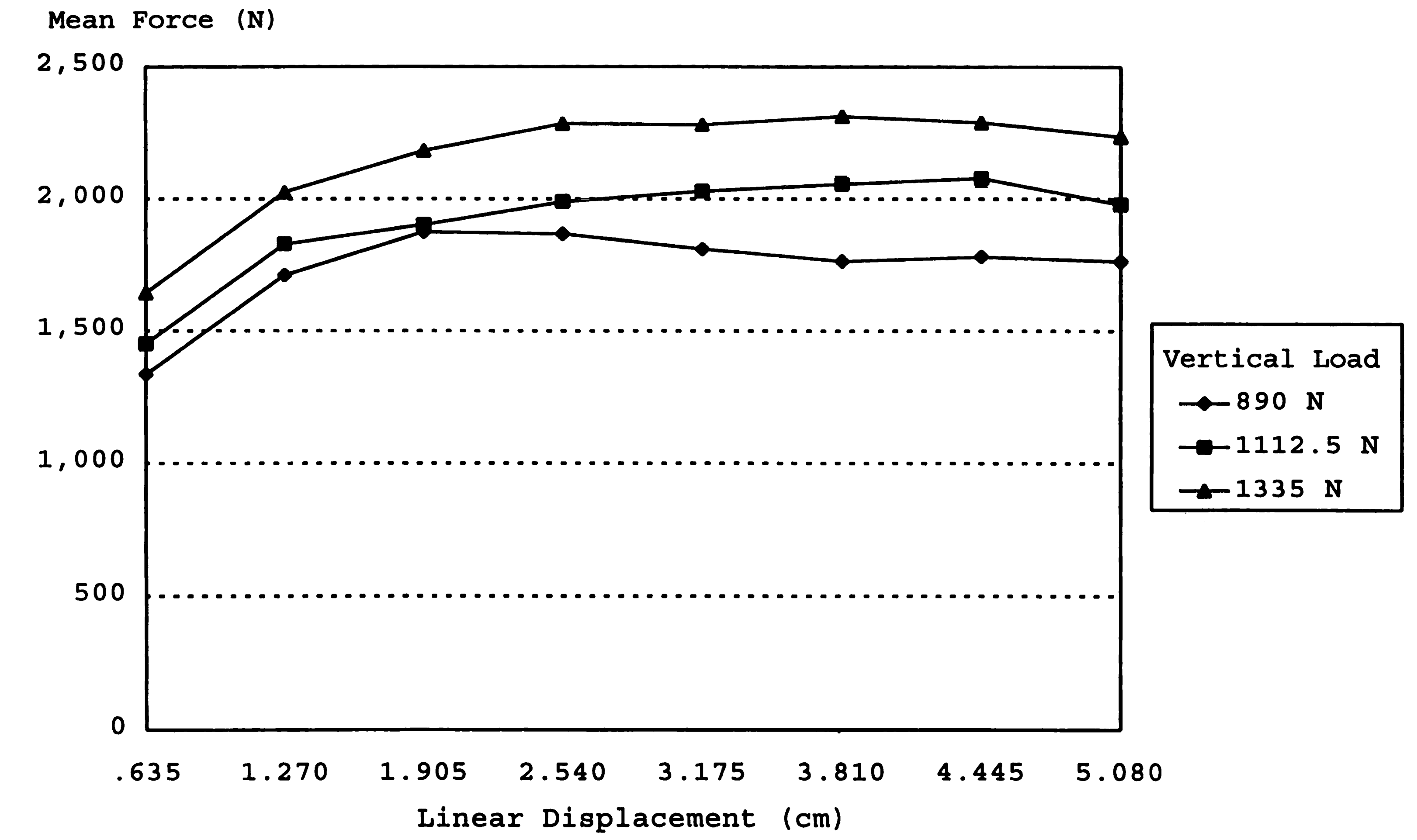

Figure 8. Friction values of dry AstroTurf using the Reebok Wet Rat at 890, 1112.5, and 1335 N.

increases linearly as vertical load increases. Results show that a linear relationship between force and vertical load exists when using the Reebok Viscious shoe [$F(2, 96) = 36.253$, $p=.000$], (Figure 4 and Table 22 in the Appendix). The amount of force produced was found to be dependent on the amount of vertical load placed on the shoe where R = .2790 (see Appendix, Table 23). Significant differences in force were only found to occur between 890 and 1112.5 N vertical loads and the 890 and 1335 N vertical loads (Figure 9).

Experiment 8 tested the Reebok Pit Bull shoe on dry natural grass at vertical loads of 200, 250, and 300 pounds (890, 1112.5, and 1335 N). It was hypothesized that force increases linearly as vertical load increases. A linear relationship between force and vertical load was found for the Reebok Pit Bull shoe [$F(2, 96) = 56.312$, $p=.000$], (Figure 4 and Table 24 in the Appendix). It was also found that force is dependent on the amount of vertical load placed on the shoe where R = .3771 (see Appendix, Table 25). Significant differences in force were found to occur between the 890 and 1112.5 N vertical loads, the 890 and 1335 N loads, and 1112.5 and 1335 N (Figure 10).

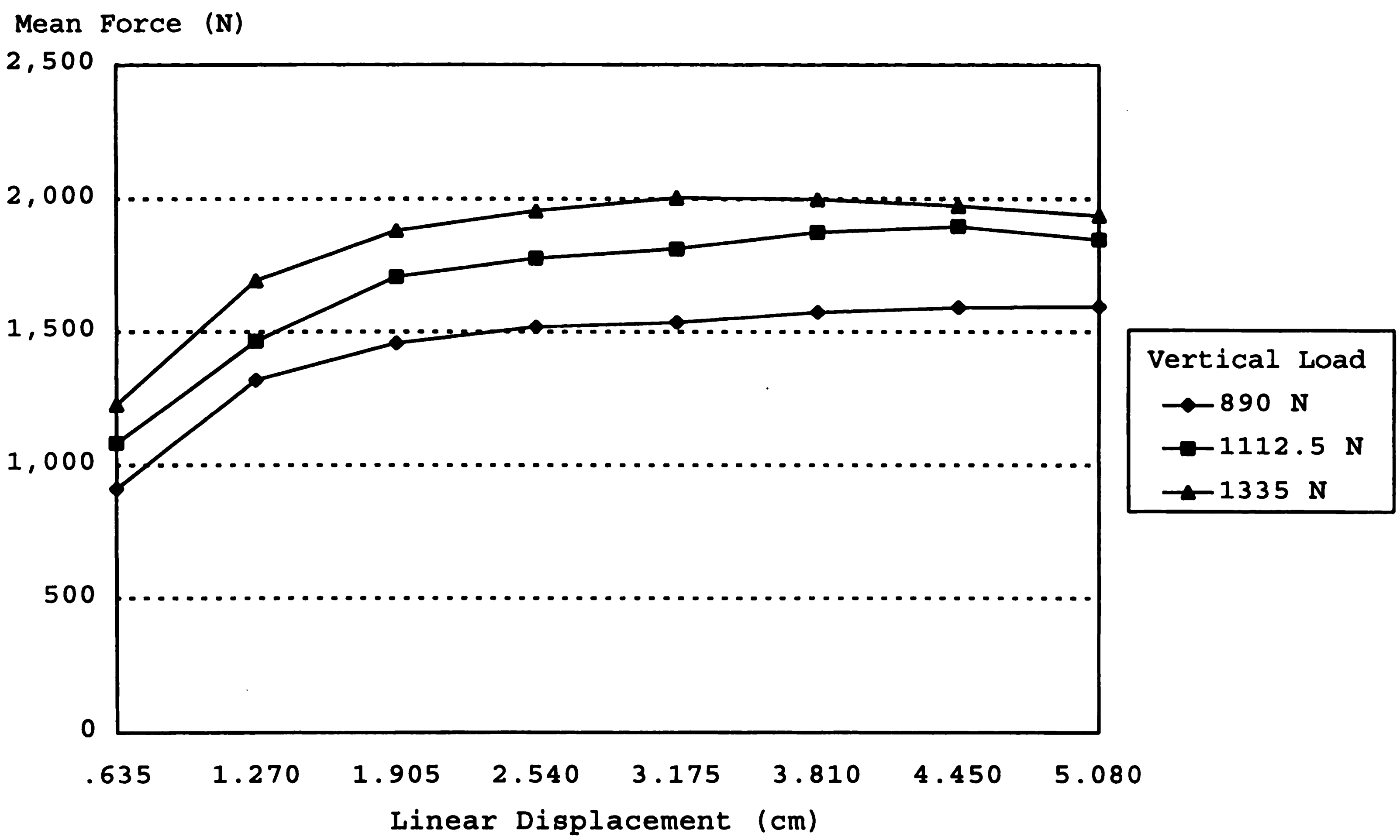

Figure 9. Friction values of dry natural grass using the Reebok Viscious at 890, 1112.5, and 1335 N.

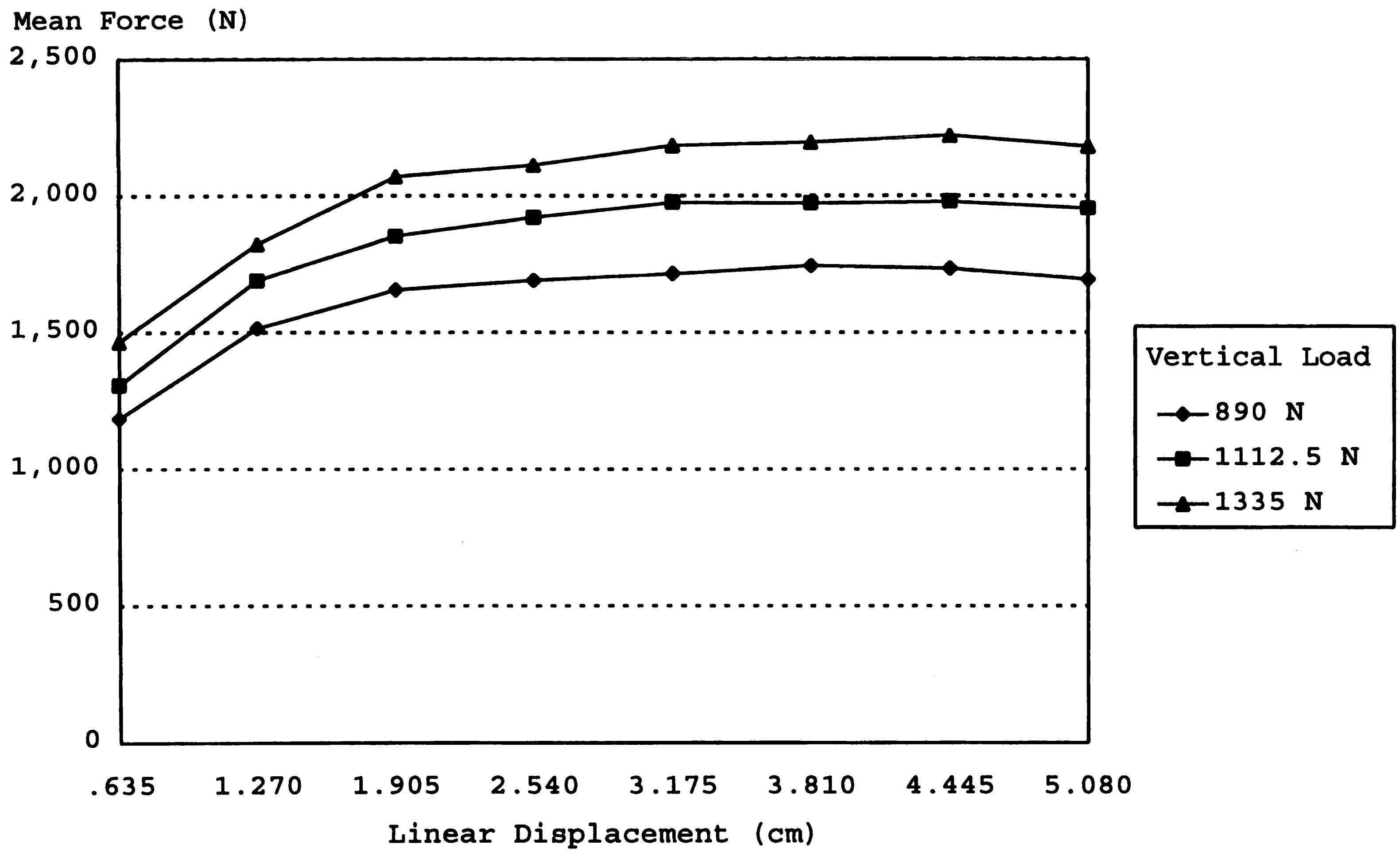

Figure 10. Friction values of dry natural grass using the Reebok Pit Bull at 890, 1112.5, and 1335 N.

CHAPTER 5: DISCUSSION

The results of this study indicate that various shoe styles, when tested at different vertical loads, can have effects on the amount of force required to produce movement at the shoe-surface interface. When testing the natural grass surface, the Reebok Pit Bull multicleated shoe required more force for movement to occur than the Reebok Viscious conventional style shoe. The increase in force can be attributed to the higher number of cleats that the multicleated Pit Bull shoe possesses. The higher number of cleats can provide better traction on the surface, thus producing more friction. This finding does not agree with Torg et al. (1971) and Bonstingl et al. (1975). Torg and his associates (1971) believed that the fewer the number of cleats a shoe has, the smaller the surface area that is transmitted through each cleat. Thus, the smaller surface area of the cleats produces a greater pressure on the surface. Torg et al. (1971) and Bonstingl et al. (1975) found that more torque was required to rotate a conventional seven-studded shoe on natural grass, while the current study found that more force was required to move the multicleated shoe.

When testing footwear on the AstroTurf surface, it was found that the Reebok Wet Rat shoe required more force for movement to occur than the Reebok Dry Rat. It was also found that the Wet Rat shoe, when tested on AstroTurf, required more force for movement to occur than any other shoe-surface combination tested. The higher number and longer cleat length of the Wet Rat shoe may provide greater traction contributing to the increased friction force produced. The non-cleated sole of the Dry Rat may not grip the surface as well as the Wet Rat, thus the Dry Rat does not require as great a friction force for movement to occur. This agrees with the finding of Andreasson et al. (1986). Andreasson and his colleagues found that a non-cleated shoe requires less torque for movement to occur on artificial surfaces than a cleated shoe. Another finding of Andreasson et al. (1986) was that the coefficient of friction is highly dependent on the vertical load placed on the shoe. This is consistent with the findings of the current study in which force was found to be highly dependent on the amount of vertical load. In Experiment 5, vertical load accounted for 35.87 percent of the force required to produce movement. In Experiment 6, vertical load accounted for 42.67 percent of the force required to produce movement while only 27.9 percent of the force required to produce movement in Experiment 7 was explained by vertical load. Finally, 37.7 percent of the force required to produce movement at the shoe-surface interface in Experiment 8 was explained by vertical load. In the current study, it was also found that a linear relationship existed between the amount of friction force required to produce movement and the vertical load. The linear relationship between force and vertical load was also found by Bowers and Martin (1975); Torg et al. (1974); Andreasson et al. (1986); and Culpepper et al. (1983). An increase in friction force with an increase in vertical load was also found by Bonstingl et al. (1975), although no linear relationship between force and vertical load was found.

As discussed previously, there are many different ways an athlete can become injured while performing. The mechanism that is of primary concern in the current study is foot-fixation. In 1974, Torg et al. developed a friction release coefficient (r) for shoe-surface combinations. The release coefficient is derived from dividing the force produced by the amount of vertical load placed on the shoe. Using the release coefficient (r), Torg et al. (1974) assigned relative safety characterizations and established a risk criterion for each shoe-surface combination. Any shoe-surface combination with a release coefficient ranging from .49 to .55 was characterized as not safe and may put an athlete at risk of more injuries. Release coefficients ranging form .40 to .49 were characterized as probably not safe. Release coefficients from .31 to .40 were probably safer than the shoe-surface combinations with a higher release coefficient. According to Torg et al., the safest shoe-surface combination had release coefficients of less than .30. Torg et al. (1974) calculated the rotational force that was produced at the shoe-surface interface while the current study measured linear force. Because the data in the current study was measured in Newtons

(N) and the data in Torg et al. was measured in ft/lbs., an accurate comparison to the risk criterion scale could not be made.

Results from Stanitski, McMaster, & Ferguson (1974), (cited in Bell, Baker, & Canaway, 1985) showed that the friction coefficients of AstroTurf, using a rubber-studded cleat shoe, ranged from 1.16 to 1.34. Bowers & Martin (1975) tested cleat-surface friction on new and old AstroTurf. A plate consisting of 3 cleats was pulled across the surface with vertical loads ranging form 2 to 14 pounds. Friction coefficients ranged from 0.93 to 1.95 on new, dry AstroTurf and 1.22 to 1.63 on old, dry AstroTurf. When converting the data of the current study from N to pounds, the coefficients of friction for dry AstroTurf using the Dry Rat shoe ranged from 1.45 to 1.80. In addition, the coefficients of friction for dry AstroTurf using the Wet Rat shoe ranged from 1.61 to 1.72. The friction coefficients from the current study are higher than those of Stanitski et al. (cited in Bell et al., 1985) and Bowers and Martin (1975). The higher friction coefficients of the current study may be due to a difference in the style of shoe sole that was used, and also to the amount of vertical load that was placed on the shoe. Bowers & Martin tested only 3 cleats that were placed on a circular plate while the current study tested a shoe sole placed in the toe-stance position. In addition, the amount of vertical load used by Bowers & Martin was considerably less than the vertical load used in the current study.

Friction coefficients for natural grass, using a rubber-soled training shoe, were also determined by Stanitski and his associates (cited in Bell et al., 1985). The coefficients of friction ranged from .92 to 1.23 on an unspecified natural grass surface. The friction coefficients from the current study for natural grass, using the Pit Bull shoe, ranged from 1.52 to 1.81. In addition, the coefficients of friction for natural grass, using the Viscious shoe, ranged from 1.37 to 1.61. The type of shoe used for testing, the species of natural grass, and the amount of vertical load placed on the shoe were not specified in the literature. The differences in the coefficients of friction, between the two studies, may be explained by these variables.

The shoes used for testing in the current study have different sole styles that give them different amounts of traction on the surface. Some of the shoe sole styles have been developed specifically to provide better traction on the surface. The Reebok Pit Bull shoe sole design has 15 hard rubber, triangular-shaped studs along the outer edge of the bottom of the shoe. The center of the sole consists of 9 pyramid-shaped rubber cleats. This particular sole design was developed to provide better traction than the Reebok Viscious, which consists of 7 cone-shaped plastic cleats. The better traction design of the Pit Bull has the potential to produce more foot-fix on the surface than the Viscious. The more foot-fix that occurs on the surface, the higher the risk of a traction related injury. Thus, the 7 studded Viscious shoe would be a safer shoe to use on dry natural grass than the multicleated Pit Bull.

The shoe sole design also differs between the Wet Rat and Dry Rat artificial turf shoes. The Wet Rat consists of several short rubber cleats that can grip the surface better than the flat-soled Dry Rat shoe. The risk of a foot-fix injury is higher on dry AstroTurf when wearing the Wet Rat shoe due to the better traction of the sole design. Thus, the flat-soled Dry Rat shoe would be safer that the multicleated Wet Rat shoe on dry AstroTurf.

CHAPTER SIX: SUMMARY AND CONCLUSIONS

Summary

There are many ways an athlete can become injured while participating in sports. The type of injury that is of primary concern for the current study is the injury that is caused from improper traction between the shoe and the playing surface. In some instances, injury may result from too much traction in which the shoe does not break loose from the surface when a shear force is applied. In other instances, injury may result from not enough traction in which slipping occurs between the shoe and the surface. These injuries, due to improper traction, are dependent on many variables. Surface hardness, surface temperature, relative wetness of the playing surface, shoe style, and the amount of vertical load (normal force) applied are variables that effect traction and friction on the playing surface.

The purpose of this study was to examine the shoe-surface interface for artificial and natural surfaces under a variety of conditions, and to measure the effects these variables have on the coefficient of friction. The data were collected using the PENNFOOT friction and traction testing apparatus developed by Pennsylvania State University.

The PENNFOOT uses a system of hydraulic pumps to pull a weighted foot across the surface being tested. The PENNFOOT friction testing apparatus was used in eight experiments testing the effects that varying vertical loads and different footwear styles have on the friction properties of AstroTurf and natural grass. Measurements were taken, on AstroTurf and natural grass, using four styles of Reebok football shoes at vertical loads of 200, 250, and 300 pounds. It was hypothesized that more friction would be produced on the AstroTurf surface, using the artificial turf footwear, than on the natural grass surface, using the natural grass footwear. It was also hypothesized that the Reebok Wet Rat shoe would provide greater traction than the Reebok Dry Rat shoe on the AstroTurf surface. In addition, it was believed that the Reebok Pit Bull shoe would provide greater traction than the Reebok Viscious on natural grass. Finally, it was hypothesized that the amount of force produced is highly dependent on the amount of vertical load placed on the shoe, and that a linear relationship exists between force and vertical load. The findings of the current study are as follows:

1. The Reebok Wet Rat shoe provided greater traction on dry AstroTurf than the Reebok Dry Rat shoe when tested at vertical loads of 890, 1112.5, and 1335 N.

2. The Reebok Pit Bull shoe provided greater traction on dry natural grass than the Reebok Viscious shoe at the 3 vertical loads.

3. More friction was produced on AstroTurf, using the

artificial turf footwear, than on natural grass, using the natural grass footwear.

4. The amount of linear force produced was highly dependent on the vertical load.

5. A linear relationship existed between the force required to produce movement and the amount of vertical load applied.

Conclusions

In conclusion, the results of this study indicate that various shoe styles, when tested at different vertical loads, can have effects on the amount of force required to produce movement at the shoe-surface interface. It can also be concluded that various shoe-surface combinations can produce different amounts force that may predispose an athlete to injury. With the collected information, coaches, athletes, and athletic trainers may select safe shoe styles for specific playing surfaces and field conditions. The information from this study can also be used to aid in the awareness of potentially hazardous conditions that may place athletes at risk of injury.

In order to increase the knowledge of the shoe-surface interface, more research needs to be conducted on the friction and traction properties of playing surfaces. It is important that future research studies measure friction and traction with an apparatus that simulates real conditions. For instance, an apparatus that can simulate correct human biomechanical movement is necessary to obtain data that is as close to real life situations as possible. In addition, more styles of footwear should be tested on both artificial and natural surfaces in order to find more information about the friction of these two surfaces. Data collected using a variety of footwear styles and surface conditions may have an influence on future results.

APPENDIX

Table 6
Friction Values of Dry AstroTurf Using the Reebok Dry Rat at 1112.5 N.

Shoe Displacement at each .635 cm	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	1397.00	1424.94	1466.85	1397.00	1421.00	33.01
1.27	1676.40	1704.34	1690.37	1676.40	1686.50	13.37
1.905	1816.10	1802.13	1816.10	1816.10	1812.50	6.99
2.54	1885.95	1816.10	1858.01	1830.07	1847.25	30.98
3.175	1885.95	1816.10	1816.10	1816.10	1833.25	34.93
3.18	1885.95	1802.13	1816.10	1802.13	1826.25	40.13
4.445	1955.80	1802.13	1802.13	1746.25	1826.25	90.08
5.08	1816.10	1746.25	1816.10	1746.25	1781.00	40.33
			Average Mean Force (N):		1754.25	143.93

Table 3
Friction Values of Dry AstroTurf Using the Reebok Wet Rat at 1112.5 N.

Shoe Displacement at each .635 cm	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	1397.00	1536.70	1480.82	1397.00	1452.50	68.44
1.27	1858.01	1816.10	1830.07	1816.10	1830.00	19.76
1.905	1816.10	1955.80	1955.80	1885.95	1902.00	66.88
2.54	1899.92	2025.65	2095.50	1941.83	1990.00	87.24
3.175	1969.77	2039.62	2095.50	2025.65	2030.00	51.64
3.81	1955.80	2081.53	2095.50	2095.50	2056.50	67.84
4.445	2025.65	2095.50	2095.50	2095.50	2077.50	34.92
5.08	1955.80	2053.59	1955.80	1955.80	1979.50	48.89
			Average Mean Force (N):		1914.75	203.75

Table 4
Friction Values of Dry AstroTurf Using the Reebok Wet Rat at 1335 N.

Shoe Displacement at each .635 cm	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	1816.10	1466.85	1606.55	1690.37	1644.50	146.68
1.27	2025.65	1955.80	2025.65	2095.50	2025.00	57.03
1.905	2235.20	2095.50	2165.35	2235.20	2182.00	66.88
2.54	2305.05	2249.17	2235.20	2346.96	2283.75	51.64
3.175	2305.05	2305.05	2277.11	2235.20	2280.00	33.01
3.81	2332.99	2305.05	2305.05	2305.05	2311.75	36.03
4.445	2235.20	2346.96	2235.20	2235.20	2287.75	55.88
5.08	2235.20	2235.20	2235.20	2235.20	2235.00	0.00
				Average Mean Force (N):	2156.28	226.47

Table 5
Friction Values of Dry AstroTurf Using the Reebok Dry Rat at 890 N.

Shoe Displacement at each .635 cm	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
.635	1117.60	1047.75	1117.60	1257.30	1134.50	87.89
1.27	1536.70	1536.70	1606.55	1676.40	1588.00	66.88
1.905	1746.25	1718.31	1746.25	1676.40	1721.50	33.01
2.54	1816.10	1690.37	1746.25	1746.25	1749.50	51.49
3.175	1746.25	1746.25	1676.40	1746.25	1728.50	34.93
3.81	1788.16	1676.40	1816.10	1676.40	1739.00	73.48
4.445	1676.40	1676.40	1676.40	1676.40	1676.00	0.00
5.08	1536.70	1536.70	1536.70	1536.70	1536.00	0.00
			Average Mean Force (N):		1609.12	206.67

Table 8
Friction Values of Dry Natural Grass Using the Reebok Viscious at 890 N.

Shoe Displacement at each .635 cm	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	977.90	977.90	852.17	838.30	911.00	76.80
1.27	1327.15	1327.15	1257.30	1369.06	1320.00	46.33
1.905	1438.91	1397.00	1466.85	1536.70	1459.00	58.72
2.54	1466.85	1466.85	1536.70	1606.55	1518.00	66.88
3.175	1466.85	1522.73	1550.67	1606.55	1536.00	40.33
3.81	1522.73	1550.67	1606.55	1620.52	1574.00	46.16
4.445	1536.70	1564.64	1606.55	1662.43	1592.00	54.70
5.08	1564.64	1606.55	1606.55	1606.55	1595.00	20.96
				Average Mean Force (N):	1438.12	231.44

Table 9
Friction Values of Dry Natural Grass Using the Reebok Viscious at 1112.5 N.

Shoe Displacement at each .635 N	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	1257.30	838.20	1117.60	1117.60	1082.25	175.78
1.27	1606.55	1117.60	1536.70	1606.55	1466.25	235.15
1.905	1802.13	1536.70	1676.40	1816.10	1707.50	130.24
2.54	1844.04	1676.40	1746.25	1844.04	1777.50	81.76
3.175	1816.10	1732.28	1816.10	1885.95	1812.25	62.86
3.81	1955.80	1802.13	1858.01	1885.95	1875.00	63.89
4.445	2011.68	1802.13	1885.95	1885.95	1895.75	86.40
5.08	2011.68	1676.40	1885.95	1816.10	1847.00	139.87
			Average Mean Force (N):		1682.93	278.55

Table 10
Friction Values of Dry Natural Grass Using the Reebok Viscious at 1335 N.

Shoe Displacement at each .635 cm	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	1257.30	1145.54	1257.30	1257.30	1229.00	55.88
1.27	1746.25	1676.40	1606.55	1746.25	1693.50	66.88
1.905	1955.80	1746.25	1871.98	1955.80	1881.75	99.03
2.54	2039.62	1746.25	1955.80	2081.53	1955.25	149.16
3.175	2095.50	1816.10	2011.68	2095.50	2004.25	131.79
3.81	2123.44	1816.10	2025.65	2025.65	1997.25	129.55
4.445	2095.50	1816.10	2025.65	1955.80	1972.75	119.29
5.08	2025.65	1816.10	1955.80	1955.80	1937.75	87.89
			Average Mean Force (N):		1833.94	264.14

Table 11
Friction Values of Dry Natural Grass Using the Reebok Pit Bull at 890 N.

Shoe Displacement at each .635 cm	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	1117.60	1257.30	1187.45	1187.45	1187.00	57.03
1.27	1466.35	1536.70	1536.70	1522.73	1515.00	33.50
1.905	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
3.175	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
4.445	1746.25	1676.40	1760.22	1746.25	1732.00	37.83
5.08	1676.40	1676.40	1676.40	1746.25	1693.00	34.93
			Average Mean Force (N):		1616.00	187.50

Table 12
Friction Values of Dry Natural Grass Using the Reebok Pit Bull at 1112.5 N.

Shoe Displacement at each .635 N	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	1397.00	1257.30	1327.15	1257.30	1309.50	66.88
1.27	1746.25	1676.40	1662.43	1676.40	1690.00	37.83
1.905	1885.95	1816.10	1816.10	1885.95	1850.50	40.33
2.54	1941.83	1844.04	1955.80	1941.83	1920.25	51.64
3.175	1997.71	1955.80	1955.80	1997.71	1976.00	24.19
3.81	1983.74	1941.83	1969.77	1997.71	1972.50	23.86
4.445	2025.65	1955.80	1983.74	1955.80	1979.50	33.01
5.08	1955.80	1955.80	1955.80	1955.80	1955.00	0.00
			Average Mean Force (N):		1831.65	232.58

Table 13
Friction Values of Dry Natural Grass Using the Reebok Pit Bull at 1335 N.

Shoe Displacement at each .635 cm	Trial 1 Force (N)	Trial 2 Force (N)	Trial 3 Force (N)	Trial 4 Force (N)	Mean Force in (N)	SD
0.635	1536.70	1397.00	1397.00	1536.70	1466.50	80.65
1.27	1855.95	1816.10	1746.25	1871.98	1822.00	56.04
1.905	2095.50	2095.50	2011.68	2081.53	2070.50	40.12
2.54	2165.35	2025.65	2095.50	2165.35	2112.50	66.88
3.175	2235.20	2165.35	2109.47	2235.20	2186.00	60.89
3.81	2235.20	2165.35	2137.41	2249.17	2196.50	53.95
4.445	2249.17	2193.29	2165.35	2277.11	2221.00	51.01
5.08	2165.35	2165.35	2165.35	2235.20	2182.50	34.92
			Average Mean Force (N):		2032.18	262.13

Table 14
A 2x3 Analysis of Variance for Experiment 1: Force, Shoe, and Weight (Vertical Load)

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	5770435	3	1923478.406	53.706	.00
Shoe	1388220	1	1388220.188	38.761	.000
Weight	4382215	2	2191107.516	61.178	.00
2-way Interactions	67879	2	33939.391	.948	.390
Shoe Weight	67879	2	33939.391	.948	.390
Explained	5838314	5	1167662.800	32.603	.00
Residual	6661610	186	35815.107		
Total	12499924	191	65444.627		

Table 15
A 2x3 Analysis of Variance for Experiment 2: Force, Shoe, and Weight (Vertical Load)

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	6769836	3	2256612.087	38.171	.00
Shoe	1468950	1	1468950.188	24.848	.000
Weight	5300886	2	2650443.036	44.833	.00
2-way Interaction	19829	2	9914.734	.168	.846
Shoe Weight	19829	2	9914.734	.168	.846
Explained	6789666	5	1357933.146	22.970	.00
Residual	10996044	186	59118.516		
Total	17785710	191	93118.899		

Table 16
A 2x3 Analysis of Variance for Experiment 3: Force, Shoe, and Weight (Vertical Load)

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	4769041	3	1589680.172	31.411	.00
Shoe	620506	1	620506.380	12.261	.001
Weight	4148534	2	2074267.068	40.986	.00
2-way Interactions	84481	2	42240.318	.835	.436
Shoe Weight	84481	2	42240.318	.835	.436
Explained	4853521	5	970704.230	19.180	.00
Residual	9413397	186	50609.663		
Total	14266918	191	74695.908		

Table 17
A 2x3 Analysis of Variance for Experiment 4: Force, Shoe, and Weight (Vertical Load)

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	6090745	3	2030248.234	45.805	.00
Shoe	568437	1	568436.505	12.825	.000
Weight	5522308	2	2761154.099	62.295	.00
2-way Interactions	15486	2	7743.193	.175	.840
Shoe Weight	15486	2	7743.193	.175	.840
Explained	6106231	5	1221246.218	27.553	.00
Residual	8244256	186	44323.959		
Total	14350487	191	75133.442		

Table 18
One Way Analysis of Variance for Force by Weight: Experiment 5

Source	DF	Sum of Squares	Mean Squares	F Ratio	F Prob
Between Groups	2	1682385.250	841192.6250	26.1625	.0000
Linear Term	1	1676377.563	1676377.563	52.1381	.0000
Deviation from Linear	1	6007.6875	6007.6875	.1868	.6666
Within Groups	93	2990196.375	32152.6492		
Total	95	4672581.625			

Table 19
Multiple Regression for Force and Weight: Experiment 5

Analysis of Variance	DF	Sum of Squares	Mean Square	F	Signif F
Regression	1	1676377.56250	1676377.56250	52.59304	.0000
Residual	94	2996204.06250	31874.51130		

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
Weight	161.843750	22.316793	.598973	7.252	.0000
(Constant)	1441.750000	48.209782		29.906	.0000

Multiple R	.59897
R Square	.35877
Adjusted R Square	.35195
Standard Error	178.53434

Table 20
One Way Analysis of Variance for Force by Weight: Experiment 6

Source	DF	Sum of Squares	Mean Squares	F Ratio	F Prob
Between Groups	2	2767708.563	1383854.281	35.0542	.0000
Linear Term	1	2747720.641	2747720.641	69.6021	.0000
Deviation from Linear	1	19987.9219	19987.9219	.5063	.4785
Within Groups	93	3671413.438	39477.5638		
Total	95	6439122.000			

Table 21
Multiple Regression for Force and Weight: Experiment 6

Analysis of Variance	DF	Sum of Squares	Mean Square	F	Signif F
Regression	1	2747720.64062	2747720.64062	69.96956	.0000
Residual	94	3691401.35938	39270.22723		

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
Weight	207.203125	24.770896	.653240	8.365	.0000
(Constant)	1521.093750	53.511252		28.426	.0000

Multiple R	.65324
R Square	.42672
Adjusted R Square	.42062
Standard Error	198.16717

Table 22
One Way Analysis of Variance for Force by Weight: Experiment 7

Source	DF	Sum of Squares	Mean Squares	F Ratio	F Prob
Between Groups	2	2550629.521	1275314.760	18.4650	.0000
Linear Term	1	2503910.641	2503910.641	36.2535	.0000
Deviation from Linear	1	46718.8802	46718.8802	.6764	.4129
Within Groups	93	6423200.969	69066.6771		
Total	95	8973830.490			

Table 23
Multiple Regression for Force and Weight: Experiment 7

Analysis of Variance	DF	Sum of Squares	Mean Square	F	Signif F
Regression	1	2503910.64063	2503910.64063	36.37875	.0000
Residual	94	6469919.84896	68828.93456		

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
Weight	197.796875	32.794086	.528227	6.031	.0000
(Constant)	1256.145833	70.843323		17.731	.0000

Multiple R	.52823
R Square	.27902
Adjusted R Square	.27135
Standard Error	262.35269

Table 24
One Way Analysis of Variance for Force by Weight: Experiment 8

Source	DF	Sum of Squares	Mean Squares	F Ratio	F Prob
Between Groups	2	2770086.021	1385043.010	28.1683	.0000
Linear Term	1	2768896.000	2768896.000	56.3123	.0000
Deviation from Linear	1	1190.0208	1190.0208	.0242	.8767
Within Groups	93	4572842.969	49170.3545		
Total	95	7342928.990			

Table 25
Multiple Regression for Force and Weight: Experiment 8

Analysis of Variance	DF	Sum of Squares	Mean Square	F	Signif F
Regression	1	2768896.00000	2768896.00000	56.90301	.0000
Residual	94	4574032.98958	48659.92542		

Variables in the Equation

Variable	B	SE B	Beta	T	Sig T
Weight	208.000000	27.573744	.614071	7.543	.0000
(Constant)	1410.677083	59.566094		23.683	.0000

Multiple R	.61407
R Square	.37708
Adjusted R Square	.37046
Standard Error	220.58995

Table 26
Surface Temperature and Surface Hardness Values for Experiments 1-8.

Experiment	Surface	Surface Temperature	Surface Hardness
Experiment 1	AstroTurf	57.7	63
Experiment 2	Natural Grass	54.2	44
Experiment 3	AstroTurf	58.3	60
	and		
	Natural Grass	53.0	46
Experiment 4	AstroTurf	58.2	56
	and		
	Natural Grass	55.5	43
Experiment 5	AstroTurf	57.7	64
Experiment 6	AstroTurf	57.9	62
Experiment 7	Natural Grass	53.0	46
Experiment 8	Natural Grass	55.5	43

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