SHOE-SURFACE TRACTION OF CONVENTIONAL AND IN-FILLED SYNTHETIC TURF FOOTBALL SURFACES

Martyn Shorten[1], Bret Hudson[1, 2] and Jennifer Himmelsbach[1]
[1]BioMechanica LLC, Portland, Oregon, USA.
[2]University of California, Davis, California, USA

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INTRODUCTION

The traction between a sports shoe and an athletic surface is important for both the performance and the safety of the athlete. While traction is frequently necessary for athletic performance, excessive traction increases the risk of 'foot fixation', an etiological factor in some types of injury.

The goal of this study was to determine how well natural turf, conventional synthetic turf and in-filled synthetic turf surfaces, in combination with different shoes, meet the traction needs of high school football players. This report compares *in-vivo* traction requirements with the results of *in-vitro* measurements of shoe-surface traction and resistance to rotation.

Traction and Friction

Both "friction" and "traction" describe the dissipative force that resists relative motion between two surfaces in sliding contact. The classical Amontons-Coulomb laws of friction (Amontons, 1699; Coulomb, 1781) offer a paradigm in which the resistance to relative motion is determined by the coefficient of friction, μ. Modern adaptations of the classical friction paradigm distinguish between "static" friction, the resistance at the instant of impending motion and "dynamic" friction, the resistance during relative sliding motion at constant velocity. In the traditional paradigm, coefficients of friction are material-dependant constants that are independent of time, velocity and contact pressure and the coefficient of static friction, μ_s, is always greater than the dynamic coefficient, μ_k.

As Marpett (2002) eloquently argues, Coulomb's "Laws" are not fundamental physical laws but rather "abstractions"

that have been widely taught and adopted. The Amontons-Coulomb friction paradigm adequately describes the time-averaged behaviour of some simple interactions between uniform, rigid surfaces. However, classical friction does not adequately describe the complex interactions between compliant, resilient, non-uniform surfaces such as those found in typical shoe-surface contact problems. Empirically, the resistance to sliding motion between shoe sole materials and real surfaces varies with contact area, pressure, sliding velocity and normal load (James, 1980; Van Gheluwe *et al*, 1983; Valiant, 1987, 1990).

We use the term "traction" to distinguish friction-like shoe-surface interactions to which the classical laws of friction do not apply. The traction coefficient τ, describes the ratio of traction force and normal force, just as μ describes the ratio of friction force and normal force. In the case of a cleated shoe interacting with a turf surface, for example, the observed traction effect is dominated by normal, rather than tangential contacts between shoe cleats and surface materials rather than by classical friction forces. Unlike μ, τ is not a simple material constant and is free to vary with time, normal load and pressure, contact area and sliding velocity.

One consequence of using a "traction" rather than a "friction" paradigm is that it is desirable to measure shoe-surface traction properties should be measured normal loads and velocities of similar magnitude to those observed in vivo.

Traction and Athletic Performance

During athletic activity, movements like running, quick stops and starts, rapid changes of direction, etc., result in the development of high horizontal forces between the shoe and the playing surface. During cutting and shuffling movements for example, the magnitude of sideways forces may reach or exceed the athlete's bodyweight (McClay *et al*, 1994). In order to prevent slipping, a high traction coefficient between the shoe and the surface is required.

Some aspects of performance can be directly related to the available traction. For example, the traction between the shoe and the field determines the extent to which a football player can "lean" into the surface or make cutting movements without slipping (Page, 1978). Figure 1 shows an athlete applying an instantaneous resultant force F at an angle θ from the vertical. F is opposed by the normal reaction force, N and the reaction to the traction force T. Neglecting acceleration and resolving vertically and horizontally gives

$$\tan \theta = T / N \qquad (1)$$

If T_m, is the traction force when θ has the maximum value, θ_m that is achievable without slipping, then

$$T_m = \tau_s F_N \qquad (2)$$

Normal Reaction Force (N)

Traction Force (T)

θ

Applied Force (F)
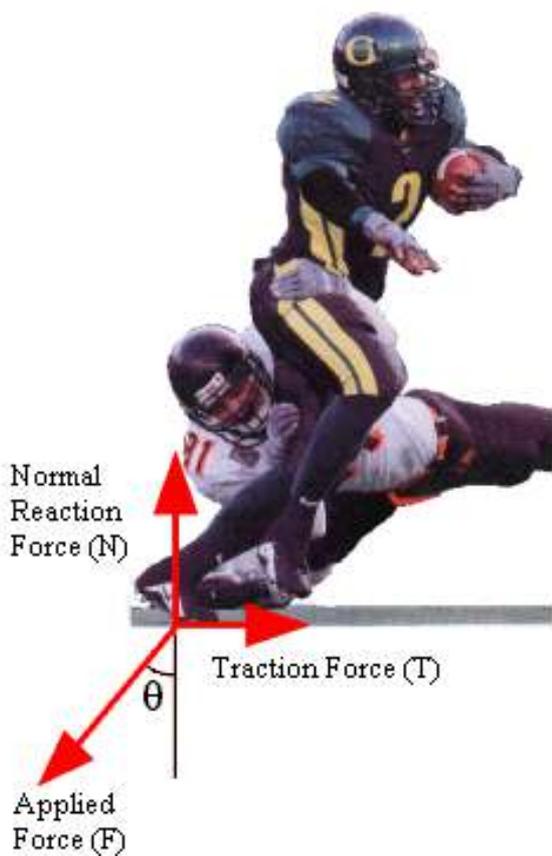
where τ_s is the traction coefficient. Combining (1) and (2):

$$\tan \theta_m = \tau_s \qquad (3)$$

Equation 3 implies that θ_m is directly related to the available traction between the foot and the surface. Since the angle at which the athlete can apply force without slipping determines how effectively he can change direction or push against another player, traction is a fundamental determinant of performance in these kinds of activities.

Performance differences among turf systems have not been widely studied. However, it has been shown that athletes wearing cleated shoes can run faster on synthetic turf than on natural turf (Krahenbuhl, 1975). At least of the portion of the difference may be attributable to the greater traction available on synthetic turf.

Traction, Synthetic Turf and Injury

With the introduction of first generation synthetic turf athletic fields, athletes found that cleated shoes design for on natural turf fields did not provide enough slip resistance on synthetic turf. The resulting slips and falls lead to only minor injuries, but also started a trend towards the use of shoes with more and longer cleats

Although these new outsole designs solved the slip problem, they increased the risk of the "foot fixation", which occurs when excessive resistance to rotation or "rotational traction" prevents the shoe from moving freely during twists, pivots and cuts. Foot fixation leads to the development of high forces in the knee during rotational movements and is believed to be a factor in the aetiology of knee injury.

The perception that foot fixation increased injury rates lead to a burst of research activity comparing the traction properties of natural and synthetic turf surfaces in combination with different shoe designs. The consensus of published studies is that traction forces and resistance to rotation are greater on synthetic turf than on natural turf. For example, a comparison of the force required to initiate movement on natural and synthetic turf using four different shoes found that the force was greater on synthetic turf (Stanitski et al, 1974). A similar study of 11 shoes on three types of synthetic turf and natural turf found that both flat soled and cleated shoes had generally higher resistance to rotation on synthetic turf (Bonstingl et al, 1975). Heidt *et al* (1996), in a study of 15 shoes on wet and dry, synthetic and natural turf surfaces, reported that both turf shoes and traditional screw-in cleated shoes required significantly greater torque to rotate on synthetic turf than on natural turf. The authors considered the rotational traction coefficients ("release coefficients") they measured on dry synthetic turf to be unsafe under all the conditions they tested. In a similar study of release coefficients (Henschen *et al*, 1989) shoes with molded and multi-studded soles were rated as "unsafe" or "probably unsafe" when used on synthetic turf.

Many studies have postulated a link between higher resistance to rotation and injury rates, some showing that injury rates are 30 to 50% higher on synthetic turf (Cameron &, 1973; Henschen *et al*, 1989; Skovron *et al*, 1990; Powell & Shootman, 1992; Zemper, 1989; Torg *et al*, 1974). Other studies did not find significant differences in injury rates (e.g. Clarke & Miller, 1977; Culpepper & Morrison, 1987) .

One concern with many of these studies is that only surface effects were considered while it is the combination of both the shoe and the surface that is implicated in traction related injuries. For example, Torg *et al* (!974) found that high school football players wearing shoes with shorter cleats had a lower injury rate than those using longer cleats, a difference attributable to differences in the shoes' rotational traction. More recently, Lambson *et al* (1999) studied the relationship between the rotational resistance of shoes and the incidence of anterior cruciate ligament tears among 3119 high school football players. Shoes with peripheral cleats were associated with a significantly higher injury rate, compared with other shoe types.

A second concern is that most of the published studies of performance and injury on synthetic turf relate to first generation designs consisting of a woven or knitted carpet of short, densely-packed fibers, sometimes with a foam pad underlayment (e.g. Astroturf®, Polygrass®). In recent years, "in-filled" surfaces with long, grass-like fibers and a top dressing of sand and / or rubber granules (e.g. Fieldturf®, AstroPlay®) have replaced first generation systems as the synthetic surface of choice in new football field installations. While the structure of in-filled surfaces suggests the possibility of very different shoe-surface interaction, their traction characteristics have not been previously reported.

Traction Requirements of Football Players

It is desirable for the traction between a shoe and a playing surface to lie in an optimum range that provides adequate slip resistance for dynamic movements without producing excessive resistance to rotation.

Foot fixation has been empirically linked with knee injuries and there is no evidence to suggest that resistance to rotation is a factor in athletic performance. Consequently, it is reasonable to suppose that the resistance to rotation (rotational traction) between the shoe and the surface should be as low as possible providing adequate slip resistance is maintained.

Slip resistance requirements can be determined by measuring the ratio of horizontal and vertical components of the ground reaction force during movements performed under non-slip conditions. A minimum translational traction coefficient in excess of 0.3 is required to prevent slip during normal pedestrian walking (e.g. Chaffin *et al*, 1992). Slip resistance standards for pedestrian surfaces typically specify a minimum of 0.5 (e.g. ANSI A1264.2) Higher minimum values are required to perform athletic activities, but these requirements rarely exceed traction coefficient values of 1.0. Valiant (1990), for example, found that stopping on Astroturf in indoor soccer shoes requires a minimum traction coefficient of 0.8 and sideward direction changes require a minimum value of 0.6.

Most studies of friction requirements document the minimum or average friction requirement for to complete a given movement. However, the average traction requirement of a number of subjects does not adequately specify the traction that should be made available by a particular shoe-surface combination. If the available traction of a surface is equal to the average traction requirement for a given

movement, 50% of subjects will experience a slip when executing that movement on that surface.

PURPOSE

Previous research offers strong evidence that excessive resistance to rotation at the shoe-surface interface increases the risk of foot fixation and hence of lower extremity injuries. There is also evidence that this mechanism contributes to a higher rate of injury among football players playing on first generation synthetic turf surfaces.

Two questions emerge, however. Firstly, relatively little is known about the interaction among different shoe and surface types. Secondly, the traction properties and foot fixation risk of in-filled surfaces remain unknown, even though surfaces of this type account for the majority of current football field installations.

Consequently, the purpose of the study was to compare the traction properties of natural turf, conventional synthetic turf and in-filled synthetic turf with the measured traction requirements of football players. A further goal was the development of guidelines for selecting footwear for a particular surface that would provide adequate traction while minimizing resistance to rotation

MEASUREMENT OF TRACTION REQUIREMENTS

The traction required to perform cutting maneuvers was determined by analysis of the surface normal and surface tangential ground reaction forces produced during cutting movements.

Methods

Ten High School football players performed five trials of maximum effort changes of direction at angles of 45º, 90º and 180º . The active changes of direction were performed with the foot of the supporting leg in contact with an AMTI force plate mounted in a laboratory surface (Figure 2). To ensure non-slip conditions, both the force plate and the surface were covered with a rubber surfacing material and subjects wore athletic shoes with flat rubber soles. Ground reaction forces were sampled at a rate of 500 samples per second and filtered at a cutoff frequency of 50 Hz with a fourth order, zero-lag Butterworth digital filter. For each trial, the instantaneous traction requirement was calculated as the ratio of the normal reaction force component to the magnitude of the horizontal reaction force vector.

Figure 2 : High Speed Video Frame showing superimposed ground reaction force vector during a cutting trial

Results

Across subjects, the peak traction coefficient during cutting movements averaged 0.74 ± 0.20 sd with a $\pm 95^{th}$ percentile range of 0.41 to 1.07. If intra-subject variability in the ground reaction forces is taken into account, the 95th percentile of friction requirements has somewhat greater range, peaking at 1.19, 1.23.and 1.25 for 45˚ , 90˚ and 180˚ degree cuts respectively (Figure 3). During 180 cuts some subjects made two contacts with the ground rather than one. Since this behaviour leads to erroneously high variability measurements in ensemble averages, standard deviations have been omitted from Figure 3 in the region where loss of contact with the ground occurred.
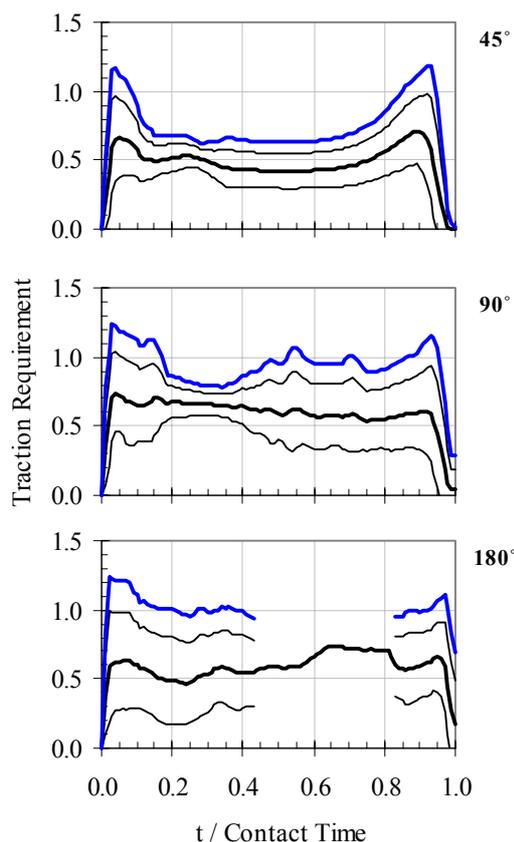

Figure 3: Ensemble mean (—) $\pm$ sd (–) and 95th percentile (—) of traction requirements during 45˚ , 90˚ and 180˚ cuts. (n = 5 trials x 5 subjects)

## MEASUREMENT OF AVAILABLE TRACTION AND RESISTANCE TO ROTATION

The traction made available and the resistance to rotation produced by different combinations of shoes and surfaces were determined by mechanical testing.

Samples

Measurements were made on each combination of six shoes and four dry surfaces. The shoes represented the variety of outsole designs used by football players, ranging from a basketball shoe to an aggressively cleated "turf" shoe (Figure 4). The surfaces were a conventional synthetic turf (Astroturf, [AT]), two in-filled synthetic systems (AstroPlay [AP] and Fieldturf [FT]) and a natural turf [NT] test site. The synthetic surfaces are described in Table 1.

Table 1: Synthetic Surface Characteristics

Condition	AT	AP	FT
Product Name	AstroTurf	AstroPlay	Fieldturf
Underlayment	10 mm foam	-	-
Grass-Fibres	10 mm	50 mm	50 mm
Infill depth	-	40 mm	40 mm
Infill material	-	Rubber granules	Rubber granules and sand particles

A **B** **C**

D **E** **F**
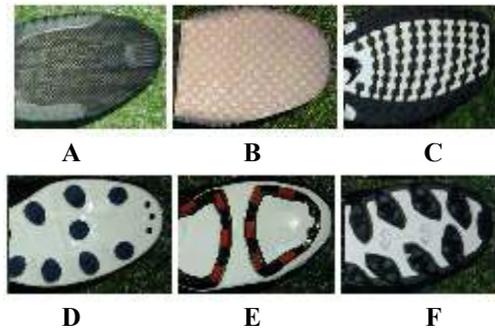
Figure 4: Shoe Outsole Conditions

Methods

The traction and resistance to rotation produced by each combination of the six shoes and four dry surfaces were measured using an Exeter Research traction device (Exeter Research Inc., Exeter, NH). During translational tests, a vertical load of 529 N was applied and a pulling force generated with a variable speed electric motor, resulting in a typical peak velocity of 0.3 m s^{-1}. The translational traction coefficient (T_T) was determined from the average ratio of horizontal and vertical force components during the initial period of shoe motion, averaged over five trials. During resistance to rotation tests, a vertical load of 529 N was applied the shoe and the shoe was rotated on the surface manually, using an instrumented torque wrench, at a typical angular velocity if 3 s^{-1}. Resistance to rotation was characterized by the and the peak value of the moment resisting rotation (T_R), recorded during each trial and averaged over five trials.

Shoe-surface combinations were characterized by the average value of the traction coefficient during linear sliding motion (T_T) and the peak value of the moment resisting rotation (T_R), each averaged over five trials.

Results

Across all shoe-surface combinations, T_T ranged from 0.54 - 1.45 and T_R from 11.5 - 64.3. Two-way analysis of variance found significant surface, shoe and interaction effects ($p<0.01$) on both T_T and T_R. In *post-hoc* analysis, T_T was significantly lower and T_R significantly higher on AT than on FT and NT ($p<0.05$). There was no statistically significant in average T_R scores recorded on in-filled surfaces (AP, FT) and NT.

Among shoe conditions, the uncleated basketball shoe (A) produced the lowest average peak moment resisting rotation (19 N m) and the lowest average traction coefficient (0.82). The "aggressively" cleated turf shoe (F) and the rubber

multi-studded turf shoe (C) produced the highest average traction coefficients, 1.15 and 1.23 respectively and shoe F the highest moment (45 N m). These extremes aside, strong and statistically significant interactions between shoe and surface conditions were observed for both T_T and T_R ($p<<0.01$). In part due to these interactions, the mean values by shoe, averaged across surfaces were generally similar. Statistically, only the shoes with the highest traction coefficients (E & F) differed significantly from the shoe with the lowest traction coefficient (A).
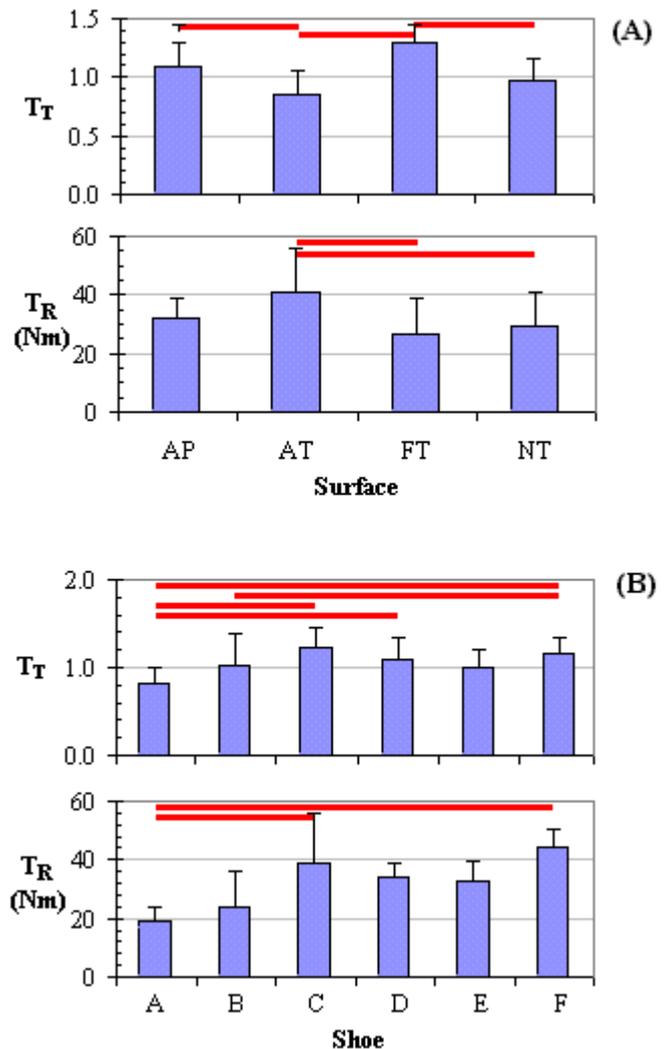
Figure 5: Translational Traction Coefficients (T_T) and Resistance to Rotation (T_R) by (A) shoe and (B) surface condition. Mean $\pm$ sd, n=2- trials per shoe, 30 trials per surface. Red bars indicate statistically significant differences ($p<0.05$).

DISCUSSION

Ultimately the choice of an appropriate shoe for use on a given surface requires a judgment regarding what level of risk (either of slip or of foot fixation) is acceptable. Slip and foot fixation are both stochastic phenomena and many factors contribute to the probability that either will occur; including shoe and surface properties, athlete dynamics and the unknowns introduced by competitive contact sports. In addition to their dependence on contact geometry and dynamics, traction coefficients on turf surfaces vary with temperature (Torg et al, 1996), with the presence of moisture and contaminants, and as the surface ages (Bowers & Martin, 1975). A laboratory study like that described here controls rather than explores many of these factors.

Consequently, only the relative traction performance of different shoe-surface combinations may be compared, without reference to absolute risk.

The observed significant interaction of shoe and surface effects highlights the qualitatively different ways in which shoes and surfaces affect T_T and T_R. Among shoes, average T_R and T_T were positively correlated (r = 0.85), i.e. as slip resistance increased, resistance to rotation also increased. Among the four surfaces tested, surfaces, average T_R and T_T were negatively correlated (r = -0.81), i.e. greater traction was associated with lower resistance to rotation (Figure 6). The latter effect is reflective of qualitative differences among the surfaces tested in this study and should not be extrapolated across turf surfaces as a whole.

The interaction suggests that appropriate shoe selection for a given surface is an important element in risk reduction. Each of the six shoe types demonstrated adequate slip resistance on dry, in-filled surfaces so an athlete's shoe selection could be based on minimizing resistance to rotation (for example by selecting a shoe with fewer, shorter cleats.). Aggressively cleated shoes (C, F) cannot be recommended because of their high resistance to rotation On the AT surface, available traction was lower, on average, and the resistance to rotation higher. The recommendation of an appropriate shoe for AT surfaces is consequently more difficult.
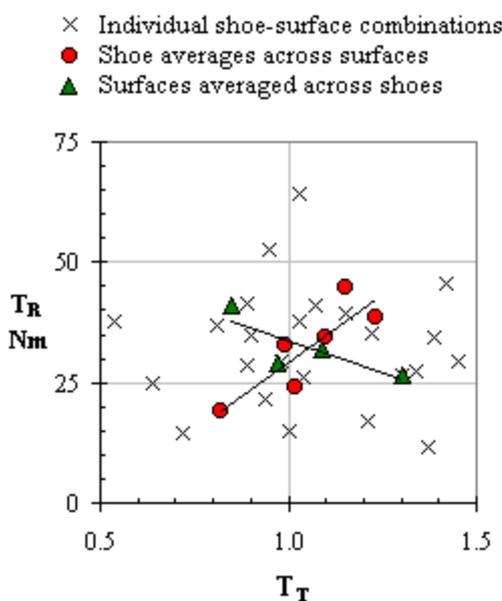

Figure 6: Interaction of Translational Traction (T_T) and Resistance to Rotation (T_R)

The finding that AT has less traction and greater resistance to rotation than NT is consistent with previous research and the subjective reports of coaches and athletes. However, surfaces with granular in-fills appear to function differently; showing significantly higher translational traction, and lower resistance to rotation, similar to that of natural turf. In contrast to NT and AT, the average traction made available by in-filled surfaces (AP and FT) exceeded the 95th percentile requirements of football players in this study, reducing the probability of slipping during aggressive changes of direction.

The higher resistance to rotation of AT has been linked with non-contact and ACL injuries among football players. Since in-filled surfaces have more natural turf-like properties in this regard, epidemiological studies linking synthetic turf to higher injury rates may not apply to them. Whether the different traction properties result in different injury patterns remains for new epidemiological studies to determine.

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