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RESEARCH

Comparison of Rotational Traction of Athletic Footwear on Varying Playing Surfaces Using Different Normal Loads

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Abstract

As an athlete accelerates, stops, and changes direction, numerous forces are transmitted to the lower extremities. The interaction between an athlete's shoe and the playing surface has been indicated as a factor in lower extremity injury risk. In particular, high rotational forces may result in increased injuries to the lower extremities. Rotational traction forces produced by eight different cleated shoes on Kentucky bluegrass (*Poa pratensis* L.), AstroTurf GameDay Grass 3D, FieldTurf Revolution, and Sportexe Omnigrass 51 under three normal loads (vertical forces) of 787, 1054, and 1321 N were measured using Pennfoot, a portable traction testing device. Of the treatments in this study, shoe type influenced rotational traction most, with differences among shoes being nearly four times as large as those among playing surfaces. Traction was either the same or within several Nm on each surface tested. Traction on the three synthetic turf surfaces ranged from 49.3 to 53.1 Nm and the traction level of Kentucky bluegrass was 52.3 Nm. Traction levels among shoes ranged from 43.8 to 58.6 Nm. The results of this study indicate that footwear selection has a larger effect on rotational traction, and potentially injury risk, than the playing surfaces evaluated in this study.

Traction Testing on Natural and Synthetic Turf

The interaction between an athlete's shoe and the playing surface likely influences lower extremity injury risk. Specifically, injuries to lower extremities may result from an athlete's foot becoming "entrapped" in the playing surface during pivoting movements (Lambson et al, 1996; Orchard et al., 2001; Torg et al., 1974).

Researchers have attempted to quantify lower extremity injury risk by measuring the rotational traction forces that occur between shoes and playing surfaces (Andreasson et al., 1986; Bonstingl et al, 1975; Heidt et al., 1996; Livesay et al., 2006; McNitt et al., 2004a; Torg et al., 1996; Villwock et al., 2009a, 2009b). Rotational traction is the traction related to rotational motion about an axis normal to the surface (American Society for Testing and Materials, 2009). In the following studies,

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rotational traction was measured mechanically using testing apparatus designed to mimic human movement. Bonstingl et al. (1975) used a testing apparatus consisting of a foot and leg assembly equipped with a lever arm. When the lever arm was impacted by a weighted pendulum, a rotational force was created about the leg assembly's vertical axis. Testing was conducted using normal loads (vertical forces) of 756 and 890 N. Instead of inducing rotation of a foot on a fixed surface, Andreasson et al. (1986) tested rotational traction by keeping the shoe in a fixed position and rotating a sample playing surface. Traction forces were measured using a normal force of 241 N. Similarly, Heidt et al. (1996) measured traction by rotating a sample surface in relation to a shoe in a fixed position using a 111 N normal load. Torg et al. (1996) used a torque wrench to apply rotational force to a prosthetic leg-foot assembly using a normal load of 445 N. McNitt et al. (2004a) measured traction using Pennfoot (McNitt et al., 1997), a portable device consisting of a framed steel leg-foot assembly which measures traction via hydraulic-induced movement of a foot placed on a test in a forefoot stance with a forefoot normal load distribution of 1054 N. This device conforms to the American Society for Testing and Materials (ASTM) standard test method for rotational traction measurement (American Society for Testing and Materials, 2009) with the exception of the degrees of rotation, which was 45 degrees using Pennfoot. The ASTM standard states testing should be performed using 90 degrees of rotation unless the surface deforms or fails at a lesser rotation (American Society for Testing and Materials, 2009). In this case, a minimum of 45 degrees of rotation is specified. Villwock et al. (2009a, 2009b) also used a device consisting of a leg-foot assembly. Traction was measured by rotating a shoe 90 degrees with the entire sole of the shoe in contact with the ground under a normal load of 1000 N. This device conforms to the ASTM testing standard with the exceptions of normal load distribution and foot stance. Villwock et al. (2009a, 2009b) tested traction with the normal load distributed near the rear portion of the foot as opposed to the forefoot as outlined in the ASTM method. Additionally, the ASTM method states that the rearfoot should not be in contact with the playing surface during traction testing unless deemed appropriate for the sports movement for which the shoe is intended, i.e., golf shoe.

Rotational traction data collected using mechanical devices allows for comparisons among shoe and playing surfaces; however, 'safe' and 'unsafe' traction standards have not been established, as these types of data have not been directly correlated with injury risk. Hirsh and Lewis (1965), using the lower extremities of cadavers, suggested that the maximum torque that a human ankle can support is approximately 75 Nm under a normal load of 1000 N. Although research has yet to establish 'safe' threshold levels, it is generally accepted that a lower level of rotational traction is desired over a higher level from a lower extremity injury risk standpoint (Lambson et al., 1996). However, if traction is too low, playability may be reduced as athletes may be prone to slipping, thus increasing the potential for other types of injuries such as ankle sprains and muscle injuries (Ekstrand and Nigg, 1989; Kirk et al., 2007)

Many studies have focused on comparing the traction characteristics of varying playing surfaces. However, studies that include multiple shoes often report larger differences among shoes than among surfaces (Bonstingl et al., 1975; Heidt et al., 1996; Villwock et al., 2009b). Therefore, it may be possible for an athlete to decrease injury risk through shoe selection (Smeets et al., 2012).

The purpose of this study was to evaluate rotational traction of various cleated athletic shoes on three synthetic turf systems and Kentucky bluegrass under various normal loads.

Shoe Types

The following seven shoe models produced by Nike, Inc. (Beaverton, OR) and one shoe produced by Adidas Group (Herzogenaurach, Germany) were evaluated: (i) Nike Zoom Vapor Carbon Fly TD (hybrid 12-stud peripheral cleat style; Fig. 1), (ii) Nike Air Zoom Blade Pro TD (12-stud peripheral cleat style; Fig. 2), (iii) Nike Air Zoom Apocalypse IV (nine-stud peripheral cleat style; Fig. 3), (iv) Nike Air Zoom Blade D (seven-stud screw-in cleat style; Fig. 4), (v) Nike Vapor Jet TD (edge

Figure 1. Nike Zoom Vapor Carbon Fly TD, a hybrid 12-stud peripheral cleat style.

Figure 2. Nike Air Zoom Blade Pro TD, a 12-stud peripheral cleat style.

Figure 3. Nike Air Zoom Apocalypse IV, a nine-stud peripheral cleat style.

Figure 4. Nike Air Zoom Blade D, a seven-stud screw-in cleat style.

Figure 5. Nike Vapor Jet TD, an edge cleat style.

Figure 6. Nike Air Destroyer 5/8, a nub cleat style.

Figure 7. Nike Air Zoom Turf, a nub cleat style.

Figure 8. Adidas Scorch Thrill FieldTurf, a hybrid cleat style.

cleat style; Fig. 5), (vi) Nike Air Destroyer 5/8 (nub cleat style; Fig. 6), (vii) Nike Air Zoom Turf (nub cleat style; Fig. 7), (viii) Adidas Scorch Thrill FieldTurf (hybrid cleat style; Fig. 8). These shoes represent a cross-section of shoe types available to consumers.

Playing Surfaces

Four playing surfaces were evaluated in this study: (i) AstroTurf GameDay Grass 3D (General Sports Venue/ AstroTurf, Rochester, MI) consisting of monofilament polyethylene fibers with a 9.5-mm (3/8-in) gauge combined with a nylon rootzone containing ambient styrene-butadiene rubber (SBR) infill installed five years before testing by AstroTurf installers (Fig. 9), (ii) FieldTurf Revolution (FieldTurf Tarkett, Montreal, Quebec, Canada) consisting of monofilament polyethylene fibers with a 19.0-mm (3/4-in) gauge containing an approximate 50/50 combination of layered silica sand and cryogenically processed SBR with a top layer of cryogenic SBR installed six months before testing by FieldTurf installers (Fig. 10), (iii) Sportexe Omnigrass 51 (Shaw Sports Turf, Calhoun, GA) consisting of parallel slit film polyethylene fibers with a 9.5-mm (3/8-in) gauge containing ambient SBR installed nine years before testing by Sportexe

Figure 9. AstroTurf Gameday Grass 3D (monofilament polyethylene fibers, 9.5-mm [3/8-in] gauge combined with a nylon rootzone containing styrene-butadiene rubber [SBR]).

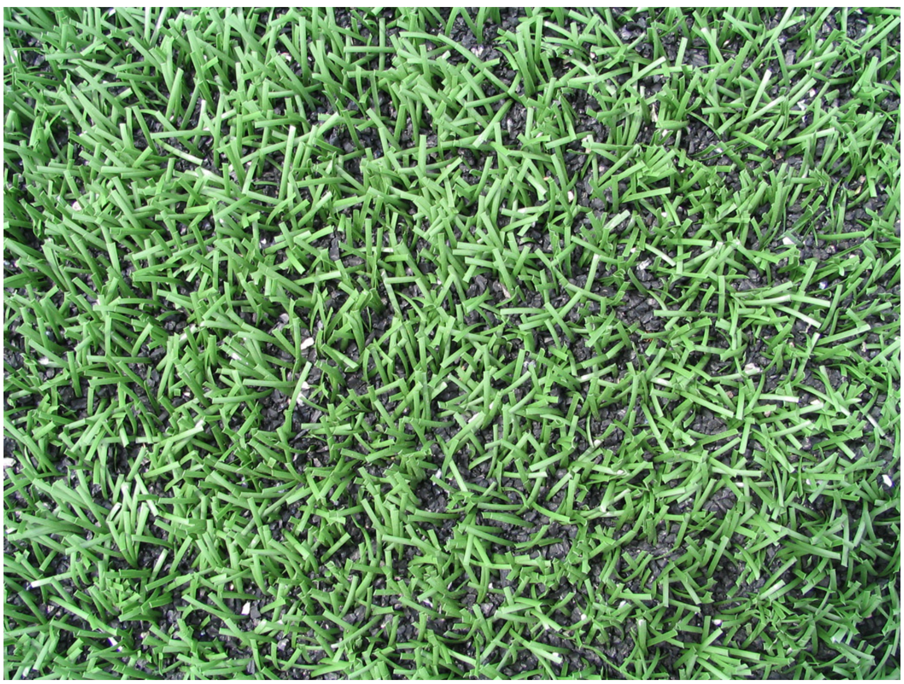

Figure 10. FieldTurf Revolution (monofilament polyethylene fibers, 19.0-mm [3/4-in] gauge containing an approximate 50/50 combination of layered silica sand and cryogenically processed styrene-butadiene rubber [SBR] with a top layer of cryogenic SBR).

installers (Fig. 11), and (iv) Kentucky bluegrass (40% 'P105', 30% 'Award', 30% 'Midnight') sod installed three years before testing containing a thatch layer of 12.8 mm maintained at a mowing height of 3.8 cm (Fig. 12). The sod was harvested from a sandy soil (92.4% sand, 4.5% silt, 2.8% clay) and installed on a custom engineered sand-based rootzone (94.2% sand, 3.0% silt, 2.8% clay). The plot area was fertilized with approximately 170 kg N/ha annually. Irrigation was applied to prevent drought stress. Testing was conducted in July on plots with 100% turfgrass coverage. The volumetric water content of the rootzone was 19.2% at the time of testing as measured by a Theta Probe (Type ML2x, Delta-T Devices, Cambridge, England). There was no surface moisture present on any playing surfaces during testing.

Figure 11. Sportexe Omnigrass 51 (parallel slit film polyethylene fibers, 9.5-mm [3/8-in] gauge containing ambient styrene-butadiene rubber [SBR]).

Figure 12. Kentucky bluegrass (40% 'P105', 30% 'Award', 30% 'Midnight').

Normal Loads

Three normal loads were used to test each shoe–surface combination: 787, 1054, and 1321 N. The 1054 N normal load complies with the ASTM traction testing requirements (American Society for Testing and Materials, 2009). These normal loads represent athletes with weights of 177, 237, and 297 lbs.

Traction Testing and Data Analysis

The Pennfoot traction tester (McNitt et al., 1997) was used to measure rotational traction (Fig. 13). Pennfoot consists of a frame which supports a steel leg with a cast aluminum foot pinned to the lower end. The simulated foot can be fitted with commercially-available athletic footwear. All traction measurements were taken with the forefoot in contact with the surface and the heel of the

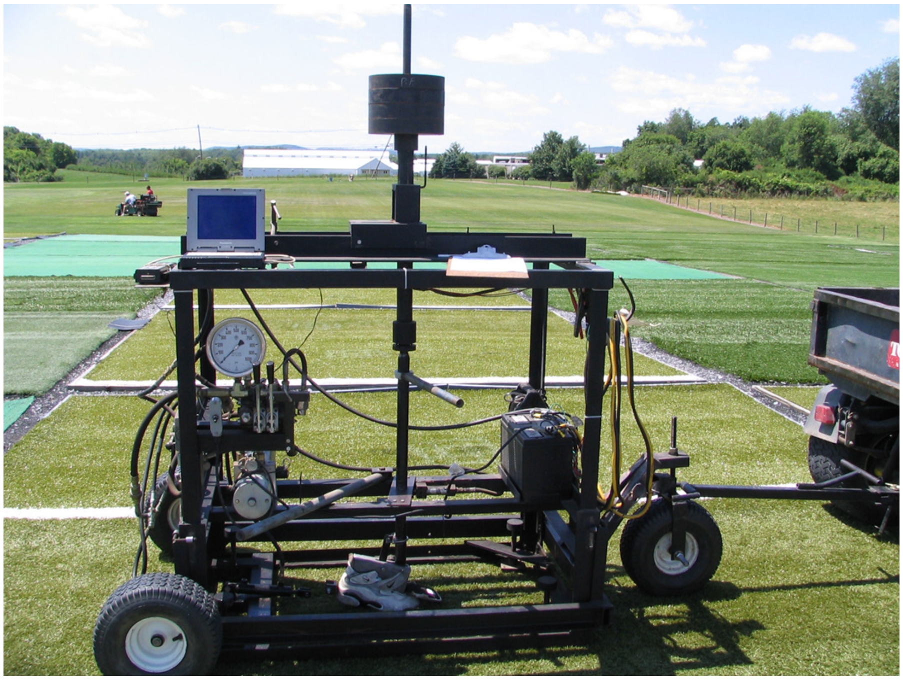

Figure 13. Pennfoot traction testing device.

foot raised off the ground. For each measurement, the shoe was rotated 45 degrees. Pennfoot was repositioned on the playing surface between trials.

The study included three replications for each playing surface–shoe–normal load combination resulting in a total $n = 288$. Rotational traction measurements were quantified as the peak force during rotation through 45 degrees. The experimental design was a $3 \times 4 \times 8$ factorial arrangement. The peak rotational values from each trial were analyzed using a three-factor analysis of variance (ANOVA) with the main effects of playing surface ($n = 4$), shoe ($n = 8$), and normal load ($n = 3$) using Minitab Statistical Software (Minitab, 2013). Tukey's post hoc tests were performed when main effects and interactions were significant at the 0.05 level.

Table 1. Shoe type, playing surface, and normal load main effects and interactions for rotational traction.

Source of variation	Degrees of freedom	Rotational traction (Pr > F)
Shoe	7	***
Playing surface	3	***
Normal load	2	***
Shoe × playing surface	21	***
Shoe × normal load	14	***
Playing surface × normal load	6	NS[†]
Shoe × playing surface × normal load	42	NS
Error	192	
Total	287	

*** $p < 0.001$.

[†]NS = not significant.

Effects of Shoe Type, Playing Surface, and Normal Load

Shoe type, playing surface, and normal load each affected rotational traction (Table 1). Additionally, the shoe by playing surface interaction was significant and the shoe by normal load interaction was significant.

Shoe by Playing Surface Interaction

The shoe by playing surface interaction was significant and shows that several shoes produced the same level of traction regardless of the playing surface while the traction level of other shoes was affected by playing surface type (Table 2). For example, the Nike Air Zoom Blade D, Adidas Scorch Thrill FieldTurf, Nike Zoom Vapor Carbon Fly TD, and Nike Air Zoom Blade Pro TD produced the same level of traction on all tested playing surfaces. Surface type influenced the traction level of several shoes such as the Nike Air Zoom Apocalypse IV, which produced lower traction on Kentucky bluegrass compared to Sportexe Omnigrass 51 and FieldTurf Revolution. Rotational traction levels for the shoe by playing surface combination ranged from 37.9 to 62.7 Nm.

Shoe by Normal Load Interaction

The interaction between shoe and normal load indicates that the influence on rotational traction due to normal load differed among shoes (Table 3). For example, the Nike Air Zoom Apocalypse IV and Nike Air Destroyer 5/8 produced the same level of traction regardless of normal load. Conversely, the Nike Zoom Vapor Carbon Fly TD produced traction levels of 57.6, 51.3, and 43.7 Nm under normal loads of 1321, 1054, and 787 N, respectively. Additionally, the Nike Air Zoom Apocalypse IV produced higher traction at the lowest normal load (787

Table 2. Rotational traction values (Nm) for the shoe type by playing surface interaction.

Shoe type	Playing surface	Rotational traction (Nm)
Nike Air Zoom Apocalypse IV	FieldTurf Revolution	62.7 A[†]
Nike Air Zoom Blade D	Sportexe Omnigrass 51	60.1 AB
Nike Air Zoom Apocalypse IV	Sportexe Omnigrass 51	59.8 ABC
Nike Air Zoom Apocalypse IV	AstroTurf GameDay Grass 3D	58.9 ABCD
Nike Air Zoom Blade D	Kentucky Bluegrass	58.7 ABCD
Nike Air Zoom Blade D	AstroTurf GameDay Grass 3D	56.8 ABCDE
Nike Air Destroyer 5/8	FieldTurf Revolution	56.0 BCDE
Adidas Scorch Thrill FieldTurf	Sportexe Omnigrass 51	55.3 BCDEF
Nike Air Zoom Blade D	FieldTurf Revolution	54.8 BCDEFG
Nike Air Destroyer 5/8	Sportexe Omnigrass 51	53.7 CDEFGH
Adidas Scorch Thrill FieldTurf	FieldTurf Revolution	53.5 DEFGH
Nike Vapor Jet TD	FieldTurf Revolution	53.4 DEFGH
Nike Air Zoom Apocalypse IV	Kentucky Bluegrass	53.1 DEFGHI
Nike Air Destroyer 5/8	Kentucky Bluegrass	52.7 DEFGHI
Adidas Scorch Thrill FieldTurf	Kentucky Bluegrass	52.4 EFGHIJ
Nike Zoom Vapor Carbon Fly TD	FieldTurf Revolution	52.2 EFGHIJK
Nike Vapor Jet TD	Kentucky Bluegrass	52.1 EFGHIJK
Nike Zoom Vapor Carbon Fly TD	AstroTurf GameDay Grass 3D	51.3 EFGHIJKL
Nike Zoom Vapor Carbon Fly TD	Kentucky Bluegrass	51.1 EFGHIJKL
Adidas Scorch Thrill FieldTurf	AstroTurf GameDay Grass 3D	50.6 EFGHIJKL
Nike Vapor Jet TD	Sportexe Omnigrass 51	49.7 FGHIJKLM
Nike Air Zoom Blade Pro TD	Kentucky Bluegrass	49.1 FGHIJKLM
Nike Air Zoom Turf	Kentucky Bluegrass	49.0 GHIJKLM
Nike Zoom Vapor Carbon Fly TD	Sportexe Omnigrass 51	48.9 GHIJKLM
Nike Air Destroyer 5/8	AstroTurf GameDay Grass 3D	48.2 HIJKLMN
Nike Air Zoom Blade Pro TD	AstroTurf GameDay Grass 3D	46.9 IJKLMN
Nike Air Zoom Blade Pro TD	FieldTurf Revolution	46.4 JKLMN
Nike Air Zoom Turf	FieldTurf Revolution	46.0 KLMN
Nike Air Zoom Blade Pro TD	Sportexe Omnigrass 51	45.7 LMN
Nike Vapor Jet TD	AstroTurf GameDay Grass 3D	43.7 MNO
Nike Air Zoom Turf	Sportexe Omnigrass 51	42.3 NO
Nike Air Zoom Turf	AstroTurf GameDay Grass 3D	37.9 O
HSD[‡]		6.3

[†]Means followed by the same letter are not statistically different from one another at $p < 0.05$ according to Tukey's post hoc tests.

[‡] Tukey's Honestly Significant Difference.

N) than five shoes at 1054 N and two shoes at 1321 N. The difference between the shoe by normal load combination that produced the highest traction (1321 N, Nike Air Zoom Blade D) and the combination that produced the lowest (787 N, Nike Air Zoom Turf) was 22.4 Nm.

Shoes

Differences in rotational traction among shoes were larger than the differences among any other variable evaluated (15.0 Nm) (Table 4).

Playing Surface

When comparing playing surfaces, FieldTurf Revolution and Sportexe Omnigrass 51 produced the same level of traction as Kentucky bluegrass (Table 5). The rotational traction level on AstroTurf GameDay Grass 3D was slightly less than the other three surfaces; however, the differences were small (range of 3.8 Nm) and likely of little practical significance.

Normal Load

As expected, traction differences due to normal loads show that the highest normal load produced the highest traction and the lowest normal load resulted in the lowest traction values (Table 6).

Discussion of the Results

Under the conditions of this study, shoe type had a much greater effect on rotational traction compared to the playing surfaces and normal loads evaluated. The range of traction values due to shoes was nearly four times as large as the range measured across playing surface types. Other researchers have also reported larger differences among shoes than among commonly used playing surfaces

Table 3. Rotational traction values (Nm) for the shoe type by normal load interaction.

Shoe type	Normal load	Rotational traction (Nm)
Nike Air Zoom Blade D	1321	62.0 A†
Nike Air Zoom Apocalypse IV	1321	60.0 AB
Nike Air Zoom Apocalypse IV	1054	58.5 ABC
Adidas Scorch Thrill FieldTurf	1321	57.7 ABCD
Nike Zoom Vapor Carbon Fly TD	1321	57.6 ABCD
Nike Air Zoom Blade D	1054	57.4 ABCD
Nike Air Zoom Apocalypse IV	787	57.3 ABCD
Nike Vapor Jet TD	1321	55.2 BCDE
Nike Air Destroyer 5/8	1321	54.5 CDEF
Adidas Scorch Thrill FieldTurf	1054	53.8 CDEF
Nike Air Zoom Blade D	787	53.4 CDEF
Nike Air Destroyer 5/8	787	53.2 DEF
Nike Zoom Vapor Carbon Fly TD	1054	51.3 EFG
Nike Air Zoom Blade Pro TD	1321	51.0 EFG
Nike Vapor Jet TD	1054	50.4 EFG
Nike Air Destroyer 5/8	1054	50.3 EFG
Nike Air Zoom Turf	1321	49.3 FG
Nike Air Zoom Blade Pro TD	1054	47.6 GH
Adidas Scorch Thrill FieldTurf	787	47.3 GH
Nike Vapor Jet TD	787	43.7 HI
Nike Zoom Vapor Carbon Fly TD	787	43.7 HI
Nike Air Zoom Turf	1054	43.2 HI
Nike Air Zoom Blade Pro TD	787	42.4 HI
Nike Air Zoom Turf	787	38.8 I
HSD‡		5.2

† Means followed by the same letter are not statistically different from one another at $p < 0.05$ according to Tukey's post hoc tests.

‡ Tukey's Honestly Significant Difference.

(Bonstingl et al., 1975; Heidt et al., 1996; Sorochan, 2013; Villwock et al., 2009b). While shoe type was shown to have a large influence on traction in the current study, the shoe by playing surface interaction and the shoe by normal load interaction each further illustrate the effect of shoe type.

Regarding the influence of the playing surface on traction, it is difficult to draw conclusions without also considering shoe type. For example, the highest traction level was observed on all four surfaces in the study depending on the shoe (Nike Air Zoom Apocalypse IV or Nike Air Zoom Blade D). Overall, within shoe types, differences among playing surfaces were generally small or nonexistent.

The influence of shoe type is evident when comparing the range in traction values for the shoes at each normal load. Under the conditions of this study, an athlete weighing 787 N (177 lbs), 1054 N (237 lbs), and 1321 N (297 lbs) would experience a range in rotational traction of 19.2, 15.2, and 12.7 Nm, respectively, depending on shoe selection. These data show a wider range of traction among shoes for lower normal loads compared to higher normal loads. Since traction varies depending on shoe type, it is advisable that athletes make informed decisions on shoe selection regardless of their size. Based on the results of this study, the importance of shoe selection for lighter weight athletes may be even greater than for heavier athletes.

Table 4. Rotational traction values for shoe type.

Shoe type	Rotational traction (Nm)
Nike Air Zoom Apocalypse IV	58.6 A†
Nike Air Zoom Blade D	57.6 A
Adidas Scorch Thrill FieldTurf	52.9 B
Nike Air Destroyer 5/8	52.7 B
Nike Zoom Vapor Carbon Fly TD	50.9 BC
Nike Vapor Jet TD	49.7 C
Nike Air Zoom Blade Pro TD	47.0 D
Nike Air Zoom Turf	43.8 E
HSD‡	2.5

† Means followed by the same letter are not statistically different from one another at $p < 0.05$ according to Tukey's post hoc tests.

‡ Tukey's Honestly Significant Difference.

Table 5. Rotational traction values for each playing surface.

Playing surface	Rotational traction (Nm)
FieldTurf Revolution	53.1 A†
Kentucky Bluegrass	52.3 A
Sportexe Omnigrass 51	51.9 A
AstroTurf GameDay Grass 3D	49.3 B
HSD‡	1.5

† Means followed by the same letter are not statistically different from one another at $p < 0.05$ according to Tukey's post hoc tests.

‡ Tukey's Honestly Significant Difference.

Table 6. Rotational traction values for each normal load.

Normal load	Rotational traction (Nm)
1321 N	55.9 A†
1054 N	51.6 B
787 N	47.5 C
HSD‡	1.2

† Means followed by the same letter are not statistically different from one another at $p < 0.05$ according to Tukey's post hoc tests.

‡ Tukey's Honestly Significant Difference.

Although research data illustrates the importance of shoe selection on injury risk, athletes may put an emphasis on factors other than safety when selecting a shoe. For example, a 2006 National Football League Players Association (NFLPA) survey revealed that 39% of players base shoe selection on comfort, 22% on weight of the shoe, 21% on appearance, and 18% on safety rating (NFL Players Association, 2008). This survey demonstrates the importance of athletic trainers, parents, and coaches in selecting appropriate footwear for athletes to reduce injury risk as athletes may value other factors above safety.

In this study, rotational traction values on synthetic turf surfaces were either the same or only several Nm lower than values measured on natural turf (Kentucky bluegrass) (Table 5). Villwock et al. (2009a) reported larger differences between synthetic and natural turf than those observed in this study. One reason for this difference may be the manner in which traction was tested. Villwock et al. (2009a, 2009b) measured traction by rotating each shoe 90 degrees with the entire sole of the shoe in contact with the surface and the normal load located near the rear of the foot. In the current study, traction was measured by rotating the shoe in a forefoot stance with the load on the forefoot as suggested by ASTM for most sports (American Society for Testing and Materials, 2009).

An attempt to repeat the current study using methods similar to Villwock (2009a, 2009b), including rotating the shoe 90 degrees in a full foot stance, resulted in severe shoe buckling and twisting, thus creating a scenario that is unlikely to occur as an athlete interacts with the surface.

Although ASTM provides a standardized method to measure traction, much debate remains among researchers on how to best simulate athlete movement and the associated traction forces an athlete experiences during play (Kent et al., 2012).

In addition to varying traction measurement techniques, synthetic and natural turf traction differences between the current study and the study conducted by Villwock et al. (2009a) illustrate the inherent difficulties of comparing synthetic to natural turf. The characteristics of natural turf vary from field to field and are constantly changing. For example, mowing height, turf species, soil type, soil moisture, and level of rooting have been reported to significantly influence traction (McNitt 1994; McNitt et al., 2004b; Rogers et al., 1988). Air temperature has also been shown to influence traction (Torg et al., 1996). The amount of wear and subsequent loss of turf cover affects traction to a large degree (Roche et al., 2008) and traction has been shown to vary significantly across the same field (Kirby and Spells, 2006). The characteristics of synthetic turf change over time and within a playing surface as well (Wannop et al., 2012), further increasing the difficulty of comparing synthetic and natural turf characteristics. These factors were not a focus of the current study and it is important to note that the traction levels of the shoes tested would likely be influenced by environmental and physiological factors and may differ over time. The amount of turfgrass coverage on athletic fields varies throughout the year and also likely has a large effect on traction.

Mechanical studies provide valuable information for comparing playing surface and shoe combinations. However, because traction data acquired from mechanical devices have not been directly correlated to injury risk, and because variations exist among traction testing devices and surface conditions at the time of testing, caution should be used when making conclusions about the relative safety of varying surfaces, especially when these differences are small.

In summary, shoe type largely influenced rotational traction among both normal loads and playing surfaces. The differences in rotational traction among shoes in this study were nearly four times larger than differences measured among playing surfaces. These data suggest that shoe selection has a greater influence on rotational traction, and potentially lower extremity injury risk, than the surfaces evaluated in this study.

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