Standard Test Method for
Traction Characteristics of the Athletic Shoe–Sports Surface Interface[1]

1. Scope

1.1 This test method covers specifications for the performance of sports shoe-surface traction measuring devices, but does not require a specific device or mechanism to be used. Figs. 1 and 2 show schematic diagrams of generic apparatus.

1.2 This test method is appropriate for measuring the effects of athletic shoe outsole design and materials on traction at the shoe-surface interface.

1.3 This test method is appropriate for measuring the effects of sport surface design and materials on traction at the shoe-surface interface.

1.4 This test method specifies test procedures that are appropriate for both field and laboratory testing.

1.5 Traction characteristics measured by this test method encompass friction forces developed between shoe outsoles and playing surfaces.

1.6 Traction characteristics measured by this test method encompass traction achieved by penetration of cleats or studs into playing surfaces.

1.7 This test method specifies test procedures for the measurement of traction during linear translational motion and rotational motion, but not simultaneous combinations of linear and translational motion.

1.8 The loads and load rates specified in this test method are specific to sports activities. The test method is not intended for measurement of slip resistance or traction of pedestrian footwear.

1.9 Test results obtained by this method shall be qualified by the characteristics of the specimen.

1.9.1 Comparative tests of surfaces shall be qualified by the characteristics of the shoes used to test the surfaces, including the cushioning, outsole material, and sole design.

1.9.2 Comparative tests of shoes shall be qualified by the pertinent characteristics of the surfaces on which shoes are tested, including the surface type, material, condition, and temperature.

1.10 This test method does not establish performance or safety criteria. The level of traction required between a sport shoe and surface varies with the level of performance and from individual to individual. The extent to which particular levels of traction contribute to individual athletic performance and risk of injury is not known.

1.11 The values stated in SI units are to be regarded as the standard.

1.12 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *SAE Standard:*
SAE J211 Recommended Practice for Instrumentation for Impact Tests[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *footform*—a rigid form approximating the shape of a foot or shoe last to which the shoe under test may be tightly fitted and through which the loads required by this test method may be transmitted.

3.1.2 *traction*—resistance to relative motion between a shoe outsole and a sports surface that does not necessarily obey classical laws of friction.
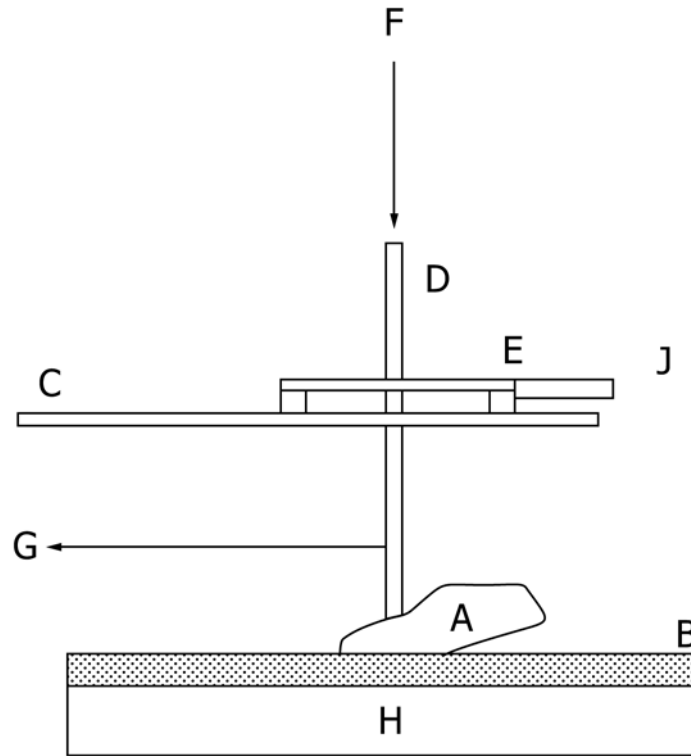
3.1.2.1 *dynamic traction*—traction measured during relative sliding motion between the shoe and the surface.

3.1.2.2 *linear traction*—traction related to rectilinear motion parallel to the surface.

A. Shoe under test, mounted on a footform.
B. Surface under test.
C. Guide rails with linear bearings or other means of maintaining rectilinear motion.
D, E. Vertical shaft and bearing mounted carriage or other means of maintaining motion parallel to the plane of the shoe-surface interface.
F. Weights, actuator or other means of applying a downward vertical force.
G. Actuator or other means of applying a horizontal force.
H. Force plate or other means of measuring vertical and horizontal forces.
J. Velocity transducer.

FIG. 1 Schematic Diagram of a Generic Device for Measuring Linear Traction

3.1.2.3 *rotational traction*—traction related to rotational motion about an axis normal to the surface.

3.1.2.4 *static traction*—traction measured at the start of relative sliding motion between the shoe and the surface.

3.1.3 *traction ratio*—ratio of the traction force or torque and the normal force acting at the shoe-surface interface.

3.1.3.1 *dymamic traction ratio* (T_k, R_k)—linear or rotational traction ratio measured during constant velocity relative motion between the shoes and the surface.

3.1.3.2 *linear traction ratio (T)*—ratio of the force resisting relative rectilinear motion of the shoe parallel to the surface and the normal force at the shoe-surface interface.

3.1.3.3 *rotational traction ratio (R)*—ratio of the torque resisting relative rotational motion about an axis normal to the surface and the normal force acting at the shoe-surface interface.

3.1.3.4 *static traction ratio* (T_s, R_s)—linear or rotational traction ratio measured at the start of relative sliding motion between the shoe and the surface.

4. Summary of Test Method

4.1 A test shoe outsole or specimen is tested for traction characteristics on the type of playing surface for which the shoe is intended.

4.2 A shoe containing the outsole to be tested is pulled over a foot form, creating a tight fit capable of properly transmitting forces through the shoe material to the outsole-playing surface interface. Alternatively, an outsole material specimen can be fastened to a mounting plate and tested in the same manner as an outsole on an intact shoe.

4.3 The shoe on the footform is loaded against the test surface under a normal load specific to the sport category for which the shoe is intended. These normal loads, depending upon the sport, will typically be higher than an athlete's body weight. Normal loads, and the shoe axes along which traction needs are greatest, have been determined by research. Some of the loading conditions that have relevance for traction testing of outsoles designed for particular sports are itemized by sport category in Table 1. Tests should be conducted at these normal loads or at a normal load of 1000 ± 75 N unless otherwise specified. The normal loads can be applied by means of weights or hydraulic cylinders, springs in compression or other appropriate means and transmitted through a shaft to which the footform is securely attached.

4.4 The normal load is distributed entirely beneath the distal half or the forefoot region of the outsole unless otherwise specified. The proximal half or the rearfoot should not contact the playing surface except as noted in Table 1. Alternatively, if deemed appropriate for the sports movement for which the
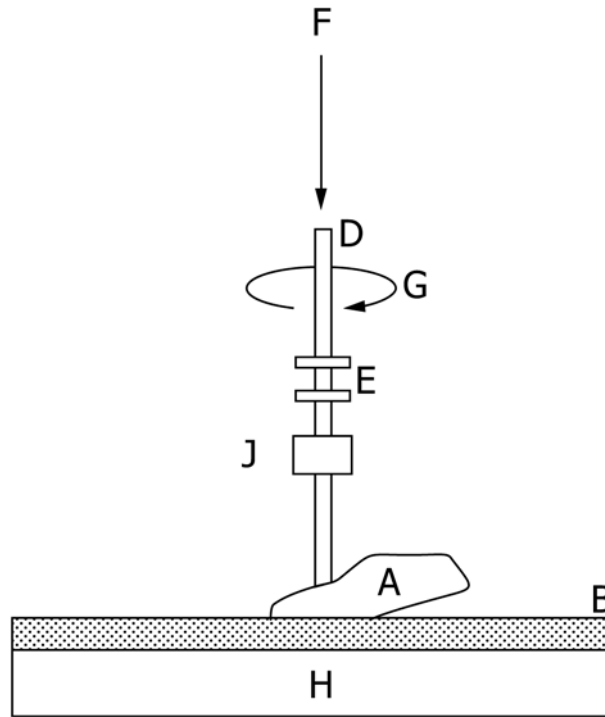
A. Shoe under test, mounted on a footform.
B. Surface under test.
D, E. Vertical shaft and bearings or other means of constraining rotation about the vertical axis parallel to the plane of the shoe-surface interface.
F. Weights, actuator or other means of applying a downward vertical force.
G. Actuator or other means of applying a torque.
H. Force plate or other means of measuring vertical force and torque about the vertical axis.
J. Angular velocity transducer.

FIG. 2 Schematic Diagram of a Generic Device for Measuring Rotational Traction

TABLE 1 Distribution of Normal Loads and Application of Pulling Forces

Sport	Movement	Normal Load (N)	Load Distribution	Direction of Motion
Running[A]	Push-off	800	Forefoot	Distal-proximal
Sprinting	Push-off	1500	Forefoot	Distal-proximal
Tennis, basketball,[B] soccer,[C] football	Cutting	2200	Forefoot	Medial-lateral
	Stopping	3000	Forefoot	Proximal-distal
	Shuffling[D]	1300	Forefoot	Medial-lateral
	Starting	1500	Forefoot	Distal-proximal
Football	Pushing	900	Forefoot	Distal-proximal
Aerobic dance		500	Forefoot	Medial-lateral
Golf	Downswing	600	Lateral outsole	Medial-lateral

[A] Valiant, G. A., "Friction–Slipping–Traction," *Sportverletzung Sportschaden*, 7, 1993, pp. 171-178.
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[C] Valiant, G. A., "Ground Reaction Forces Developed on Artificial Turf," *Science and Football*, T. Reilly, A. Lees, and W. J. Murphy, Eds., E. & F.N. Spon, London, 1988, pp. 406-415.
[D] McClay, I. S., Robinson, J. R., et al., "A Profile of Ground Reaction Forces in Professional Basketball," *Journal of Applied Biomechanics*, 10(3), 1994, pp. 222-236.

shoe outsole design is intended, normal loads are distributed uniformly beneath the proximal half or the rearfoot portion of the outsole. If the shoe construction typically includes a midsole that provides cushioning, an appropriate midsole should be included in the test shoe. If the test involves a specimen of outsole material fastened to a mounting plate, an equivalent midsole material of appropriate thickness is to be included between the mounting plate and the outsole material.

Note 1—The cushioning material helps to distribute normal loads more uniformly between the outsole and the playing surface. The cushion does not reproduce the distribution of loads transmitted through the shoe bottom to the outsole by the loaded human foot, but does increase test repeatability.

4.5 For linear traction measurements, a linear actuator is used to overcome the static traction and produce relative rectilinear motion of the shoe and surface, parallel to the shoe outsole-playing surface interface. The actuator may be pneumatically, hydraulically, or electrically driven. The distance of relative sliding motion between the shoe and the surface shall be a minimum of 20 cm, unless the interacting surfaces deform or fail at a smaller distance.

4.6 Sliding velocity shall be recorded and reported. The recommended minimum sliding velocity is 0.3 m s^{-1}.

Note 2—Under some conditions, for example, cleated shoes on artificial turf, spiked shoes on running tracks, it may not be possible to generate sliding at the recommended velocity. Under these circumstances, the force and velocity developed should be recorded and dynamic traction coefficients should not be reported.

4.7 For rotational traction measurements, the loaded shoe outsole is rotated about the vertical shaft transmitting the normal loads. The rotary motion may be applied manually, or by means of a rotary actuator. The minimum rotation applied

shall be 90° unless the interacting surfaces deform or fail at a lesser rotation. The minimum rate of rotation shall be 45°/s. Angular velocity shall be recorded and reported.

4.8 For linear traction tests, the measured variables are normal forces, horizontal or traction forces, and sliding velocity. For rotational traction tests, measured variables are normal forces, the moment (torque) resisting rotation about a vertical axis, and angular velocity during rotation. Traction ratios are calculated from these measurements.

4.9 All variables are recorded as functions of time, from before the application of horizontal or rotational motion until after the cessation of motion.

5. Significance and Use

5.1 This test method will be used by athletic footwear manufacturers to characterize the traction of the athletic shoe-sports surface interface, and as a tool for development of athletic shoe outsoles.

5.2 This test method will be used by researchers to determine the effect of sport surface conditions (for example, moisture, grass species, turf density, soil texture, soil composition, and so forth) on traction characteristics of the athletic shoe-sports surface interface.

5.3 This test method will be used by sports surface manufacturers to characterize the traction of the athletic shoe-sports surface interface, and as a tool for development of sports surfaces.

5.4 Careful adherence to the requirements and recommendations of this test method will provide results that compare with results from different laboratory sources.

5.5 The method will be used to research relationships between traction at athletic shoe-sports surface interfaces and athletic performance or injury. This research may lead to recommendations for appropriate levels of traction.

6. Apparatus

6.1 A footform.

6.2 A means of securely mounting surface samples to be tested and of controlling or constraining relative motion between the footform-mounted shoe and the surface.

6.3 A means of applying a minimum normal load of 1000 N through the footform is required. The normal load should be adjustable within ±75 N. Typical means of load application include weights, hydraulic cylinders, and compressed air cylinders.

6.4 A means of producing relative sliding motion between the shoe and the surface. Typical methods of applying horizontal motion include linear actuators, hydraulic cylinders, compressed air cylinders, and variable speed motors. It is recommended that the velocity of the actuator be controllable. Since traction ratios at the shoe-surface interface may exceed 1.0, the motion generating device must be capable of applying horizontal forces that are even higher than the applied normal forces.

Note 3—Under some circumstances (for example, tests with portable equipment used in the field) it may be necessary to produce relative sliding

motion manually (for example, by means of manually drawn cables). Manual induction of motion is not recommended because it may be more variable than controlled mechanical actuators.

6.5 Guides, or a means of maintaining rectilinear motion parallel to the shoe-playing surface interface, such as low friction bearings, are required.

6.6 A means of maintaining the outsole or sample perpendicular to the playing surface during rotation (for example, low friction rotary bearings) is required for measurement of rotational traction ratios.

6.7 Transducers, signal conditioners and other instrumentation are required to measure normal force, horizontal force, torque, velocity, and angular velocity. The performance of the measurement systems shall, as a minimum, conform to the requirements of a CFC Class 100 Data Channel, as defined by SAE J211. Anti-aliasing filters shall be used to filter data channels at a -3dB cutoff frequency of 250 ± 20 Hz before they are digitized.

Note 4—For laboratory-based measurements, an appropriate means of measuring forces and torques is a multi-axis force plate to which the surface being tested is securely attached (Figs. 1 and 2).

6.8 The apparatus should have the capability of differentiating static traction forces from dynamic traction forces. Typically, the velocity or angular velocity measuring transducer will be used for this purpose.

6.9 The data acquisition system should sample and store force, torque, velocity, and angular velocity signals at a minimum sampling rate of 500 samples/s.

6.10 The complete apparatus used to make the traction measurements shall be anchored or have a large enough inertia to prevent it from being moved by the application of linear or rotary motion to the shoe-surface system under test.

7. Procedure

7.1 Select a sample of the playing surface appropriate for the outsole to be tested and prepare it in accordance with the required conditions of the traction test.

7.2 If the test is conducted in the field, locate the traction testing device on an area of the playing surface that has the required conditions.

7.3 Adjust the normal force to a magnitude appropriate to the sport for which the outsole is intended. The normal force shall be either the appropriate value selected from Table 1 (±75 N) or 1000 ± 75 N.

7.4 Clean all debris and foreign material, mould release compounds, and so forth from the shoe outsole, unless the test method is being used to determine the effects of a specific contaminant on traction.

7.5 Attach a shoe with the outsole to be tested or a test sample to the device component that transmits the high normal force. Orient the outsole along a desired axis of translation (see Table 1).

7.6 Lower the sample onto the playing surface.

7.7 For measurements of linear traction, immediately induce a horizontal motion to the outsole, parallel to the playing

surface in the desired direction of translation. For measurements of rotational traction, immediately induce an angular motion about a vertical axis passing through the forefoot region of the footform. The applied torque or force used to induce motion shall be high enough to initiate and maintain motion of the outsole relative to the surface at the required velocity or angular velocity.

7.8 During the horizontal or rotational motion, continuously measure and record the normal force, horizontal force, or torque and velocity or angular velocity at a sample rate no less than 500 samples/s.

7.9 Repeat the test five times, cleaning the playing surface and outsole between trials as necessary. If the test procedure alters the playing surface, conduct each trial on a new, unaltered section of the playing surface.

8. Calculation

8.1 To remove unwanted signal noise, appropriate filtering may be applied to the sampled force, moment, and velocity signals. The definition of the CFC data channel specification required by section 6.7 implies that, as a minimum, a 4-pole Butterworth Filter with a -3dB cutoff of frequency of 107.2 Hz shall be used.

8.2 For each data sample of each individual trial, divide the resultant horizontal force or torque by the normal force to calculate the traction ratio, T. Example data and calculated values of T for a linear traction trial and shown in Fig. 3.

8.3 For each individual trial:

8.3.1 Identify a period of time during outsole motion for which normal force and sliding velocity are approximately constant (refer to Appendix X2).

8.3.2 Calculate the average normal force, average horizontal force, and average translational or rotational velocity for individual trial data during the delineated time period.

8.3.3 Determine the minimum and maximum values of T and average T during the delineated time period.

8.3.4 In a rotational traction measurement, determine the peak magnitude of torque resisting rotation about the vertical axis.

8.4 For each sample:

8.4.1 Calculate the average of the five determinations of average normal force, average translational or rotational velocity, average R, and peak magnitude of torque resisting rotation.

8.4.2 Determine the largest and smallest values among the five determinations of minimum and maximum R.

9. Expression of Results

9.1 Record normal load history as a function of time, velocity (translational or rotational) history as a function of time, orientation of the outsole relative to direction of friction force, outsole compound, outsole pattern, surface type, surface condition, and area of outsole loaded. For most tests outsole area associated with male shoe sizes is sufficient.

9.2 Express T_s or T_k, static or dynamic ratios of horizontal friction force divided by normal loading force, within a range defined by minimum measured T to maximum measured T with a precision of 0.01.

9.3 Alternatively, T_s or T_k may be expressed as a mean 0.01.

9.4 Express peak magnitude of moment about the vertical axis resisting rotation as a mean with a precision of 1 Nm.

9.5 Alternatively, peak magnitude of moment resisting rotation may be expressed within a range defined with a precision of 1 Nm.

10. Report

10.1 Report the following information:

10.1.1 Report date and test date.

10.1.2 Name of laboratory, company, or individual issuing the report.

10.1.3 In the case of a field test, the location of the test site.

10.1.4 Description of the playing surface type, material, condition, ambient temperature, and any other conditions that would influence the test results.

10.1.5 Complete description of the shoe outsole or outsole specimen including material, manufacturer, and condition.

10.1.6 Average normal load and average horizontal force.

10.1.7 Average translational or rotational velocity.

10.1.8 Range of T or R, or both, defined by the smallest minimum and largest maximum from all five trials, or peak moment resisting rotation about a vertical axis, averaged across five trials.

10.1.9 Mean, median, and standard deviation of T or R, or both, for the five trials. Mean, median, and standard deviation of the peak moment resisting rotation of the five trials.

11. Precision and Bias

11.1 The precision and bias of this test method has not been formally determined. Based on published data and a preliminary interlaboratory study conducted during the development of this standard, the 95 % repeatability and reproducibility for measurements of linear traction ratio are estimated to be ±0.05 and ±0.10, respectively. The reproducibility of the test method is significantly affected by variability among samples of the same shoe model and surface type. Wear on the shoe and surface, including wear on test samples caused by the act of testing them, changes their traction characteristics. Variability is also significantly influenced by the nature of the shoe-surface system under test. Greater variability can be expected for tests of friable surfaces (for example, cleated outsoles on natural turf), while more unitary systems (for example, basketball shoes on hardwood floors) can be expected to produce more repeatable results.

12. Keywords

12.1 athletic shoe; friction; sports surface; traction
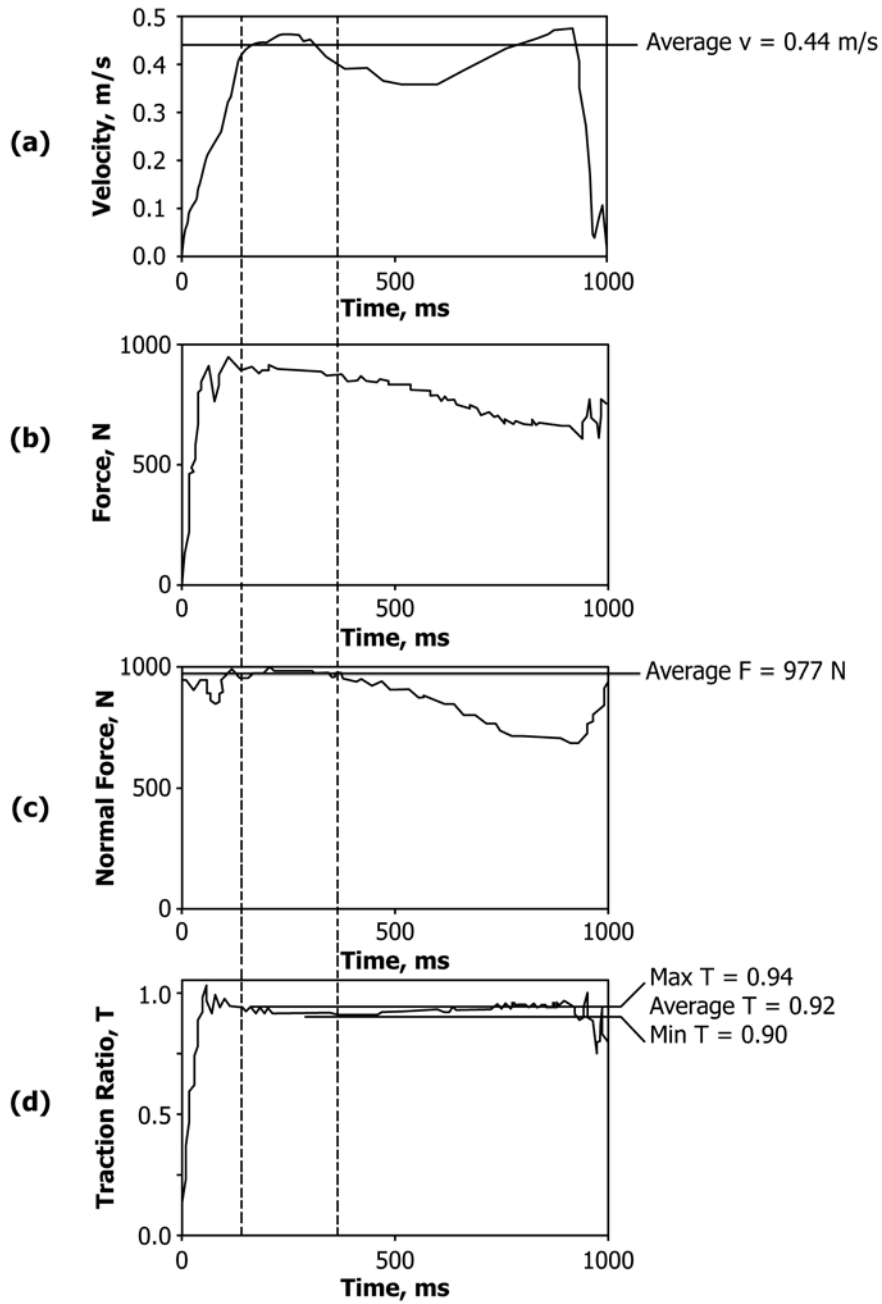
(a) Velocity–time curve
(b) Horizontal force–time curve
(c) Normal force–time curve
(d) Traction Ratio, *T*

NOTE 1—Dotted lines indicate region of approximately constant velocity for which average, maximum and minimum values of *T* are calculated.
FIG. 3 Example Data from a Linear Traction Measurement Trial

APPENDIXES

(Nonmandatory Information)

X1. RATIONALE

X1.1 The traction characteristics of athletic shoe-sports surface interfaces do not obey the classical laws of Coulomb friction (**1,2**).[3] It is generally the case that the shoe-surface interface is neither smooth nor planar and that the forces resisting relative motion between them include not only friction, but also other forces due to mechanical interaction and interpenetration of the shoe outsole and the surface. Also, the materials used to manufacture shoe outsoles and surfaces are non-linearly elastic and non-rigid, violating the assumptions of classical friction.

X1.2 In contrast to classical theory, in which coefficients of friction between two surfaces are independent of normal force, sliding velocity, and contact area, traction between the shoe and the surface is not constant and may vary non-linearly with normal force, sliding velocity and contact area. Unlike classical friction coefficients, dynamic traction ratios frequently exceed 1.0. The moments opposing frictional resistance to rotation can range from 20 to 60 Nm, increasing in an approximately linear

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[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

manner with increasing normal force.

X1.3 The non-linearity of shoe-surface traction requires that measurements be made at loads and loading rates in the range that can be expected *in vivo*. Tests conducted at normal loads exceeding athlete body weights and for dynamic friction measures at realistic sliding velocities (**3,4**) are acceptable while those conducted at low normal loads (**5,6**) are less appropriate. Test methods that rely on the assumptions of Coulomb friction are not appropriate for measuring traction at the athletic shoe-sport surface interface. Since many athletic activities are played on surfaces that can deform and move, such as natural turf and running trails, test methods should account for movement of soil or turf during testing and the subsequent effects on the measurement of traction characteristics. A test method should also provide a procedure for evaluating traction in field conditions, including cleated footwear applications, and also in realistic laboratory conditions.

X1.4 This test method attempts to address these issues by describing a means of measuring traction at appropriate loads and loading rates that does not rely on classical laws of friction.

X2. RELEVANCE

X2.1 *Enhancement of Performance*:

X2.1.1 The traction between a sport shoe and a playing surface is an important determinant of human athletic performance. High traction characteristics of athletic shoe outsoles enhance athletes' abilities to run fast, make quick starts and stops, and make rapid changes in running direction. For example, Krahenbuhl (**7**) reported that athletes wearing cleated shoes could not run through an agility course as fast on natural turf as on an artificial turf surface. He assumed that the artificial turf provided a greater gripping effect between shoe outsole and turf. Morehouse and Morrison also measured faster performance times on artificial compared to natural turf for football players completing an agility run, a 10-yard sprint, a 40-yard sprint, and a blocking drill (**8**). The implications are that the greater traction provided by artificial turf surfaces results in performance enhancement. Similarly, increased outsole traction would have equivalent performance enhancement benefits.

X2.1.2 Many athletic movements result in the development of high horizontal forces between the shoe and the playing surface. During the first few accelerating foot steps out of starting blocks, 100 m sprinters are developing backward directed horizontal force components exceeding 120 % of their body weight. Penetration of spikes into the track surface contributes to the high traction forces that prevent slip during this critical phase of the race.

X2.1.3 Within the final 60 to 80 ms of a rapid downswing of a golf club, the laterally directed shear forces developed by the target or front foot approach 40 % body weight when the vertical force under the front foot is about 150 % body weight (**9**). While sufficient outsole traction opposing forces of these magnitudes is not too difficult to achieve under dry conditions, the damp turf conditions commonly played on generally require cleats or other traction elements to ensure that slip, which would dramatically affect the shot, not occur.

X2.2 *Prevention of Injury*:

X2.2.1 In some sporting contexts, low traction is desirable. Excessively high coefficients of friction of tennis surfaces may be related to increased injury (**10**). High coefficients of friction may increase the "braking forces" during stops and sudden changes of direction. More rapid deceleration of the body results in higher joint loads and soft tissue stresses, potentially contributing to an increased incidence of overuse injuries. In tennis on clay courts, sliding on the surface is an important and a natural mechanism for reducing load on the body. In these cases it may be determined that the shoe and surface should combine to allow slip when horizontal forces exceed a certain level.

X2.2.2 With respect to excessive traction, however, excessive frictional resistance to rotation has received the greatest attention. Foot fixation, or the inability of the foot to rotate

freely against the surface, has been implicated in the etiology of knee injuries. Increased resistance to rotation of certain cleated outsoles used on shoes designed for American football has been associated with an increase in the number and severity of knee injuries (11,12).

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