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Development and assessment of a device and method for studying the mechanical interactions between shoes and playing surfaces in situ at loads and rates generated by elite athletes

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Abstract
The literature is lacking the description of a device and method for simulating and measuring shoe–turf interactions at loads and rates generated in situ by elite athletes during performance. A transportable device was built to quantify these interactions through three tests that reflect generic classes of tasks: 1) translation test; 2) rotation test; and 3) translation/drop test. All the three tests were performed using the cleated portion of a molded American football shoe on two types of natural grass surfaces. To assess repeatability of tests, we performed multiple trials of each test under the same testing conditions. To assess sensitivity of the device, the type of playing surface, temperature, and moisture level were varied. The variation among the results of repeated trials of a given set of testing conditions was less than that between the results of a given test under differing testing conditions, so the device and method were deemed to have acceptable levels of repeatability and sensitivity in the set of conditions considered.

Keywords: Foot, ankle, force measurement, footwear, injury

Introduction
One of the primary concerns in the function of sporting shoes is the interaction between a player's foot, the shoe, and the playing surface. For example, a player’s grip with the surface dictates how fast he/she can accelerate, stop, and change direction. This same interaction may also be a factor in the risk of injury to the lower extremities. Among lower extremity injuries in American football and soccer, 21–61% are ‘non-contact’ type injuries—juries that do not result from direct loading of the affected limb by another player or object (Bradley et al., 2002; Woods et al., 2003; Agel et al., 2005; Ramirez et al., 2006; McHugh et al., 2007). It has been postulated that these types of injuries may be caused by foot ‘entrapment’, which can cause injurious stresses within the lower extremities.
Particular attention has been paid to the role of pivoting (rotational) foot entrapment in anterior cruciate ligament (ACL) injury (Torg et al., 1974; Lambson et al., 1996), although entrapment during other loading motions such as lateral movement causing inversion of the ankle (Bloemers & Bakker, 2006) may also be detrimental. Yet understanding of the interaction between the shoe and various types of playing surfaces under realistic conditions remains largely incomplete.

A common method for examining the interaction between shoes and playing surfaces involves mechanical testing. Torg et al. (1974) performed one of the first of these studies, which analyzed resistance to rotational motion from different combinations of cleated shoes and playing surfaces. Subsequent studies have investigated shoe–surface interactions through additional rotation-type testing (Bonstingl et al., 1975; Andreasson et al., 1986; Heidt et al., 1996; Torg et al., 1996; Dura et al., 1999; Livesay et al., 2006; Villwock et al., 2009), and through drag-type testing, where a shoe is pulled in a linear manner across a playing surface (Bowers & Martin, 1975; Heidt et al., 1996). These previous studies contributed to the development of standards for the testing of shoe–surface interactions, although the standards are specific to conditions of rotational and drag-type movement (American Society for Testing and Materials [ASTM], 1990; Federation Internationale de Football Association [FIFA], 2008).

Previous studies of shoe–surface interaction were limited in a few key areas. First, the vertical forces investigated were too low to represent the forces generated by elite athletes in performance situations (e.g. collegiate or professional American football players) (Cavanagh & Lafortune, 1980; Reilly et al., 1987; McClay et al., 1994; Hunter et al., 2005; Kaila, 2007; Stafilidis & Arampatzis, 2007). Second, previous studies did not control, or considered only limited, loading rates (Torg et al., 1974, 1996; Baker, 1990; Lambson et al., 1996), which is particularly important for natural turfs that contain water and hence flow-related, rate-dependent mechanical characteristics. Third, researchers performed previous studies in laboratory settings with isolated test samples of playing surfaces (Torg et al., 1974, 1996; Bonstingl et al., 1975; Bowers & Martin, 1975; Andreasson et al., 1986; Heidt et al., 1996; Lambson et al., 1996). Results of such tests can be affected by the boundary conditions imposed on the test samples (Naunheim et al., 2004). In addition, the properties of playing surfaces can be affected by weather conditions (such as temperature) (Torg et al., 1996; Naunheim et al., 2004), moisture content (Orchard et al., 2001; Orchard & Powell, 2003; Naunheim et al., 2004), and maintenance practices. Thus, it is important to study shoe–surface interactions on a playing surface installed in the environment of its actual and intended use. Fourth, all of the previous studies used one (or both) of two specific types of testing—either a planted foot rotating on the surface or a planted foot dragging across the surface. Neither testing method represents a maneuver commonly associated with both performance and injury—landing on one foot either following a running jump or during a running cut. Such maneuvers involve velocity components of the foot in both the horizontal and vertical directions. Finally, interpretation of previous findings is limited by the historical use of a ‘traction coefficient’. This traction coefficient is a ratio of either the horizontal force or torque on the shoe and the vertical ground reaction force, and its use presents two significant limitations. First, the traction coefficient does not reflect any information about the magnitude of the loading. Second, the use of a single coefficient implies a friction-like linear relationship between the numerator and the denominator. A shoe interacting with a playing surface under realistic loads does not exhibit such a linear relationship (Van Gheluwe et al., 1983; Fendley, 1995).

The goal of this study was to develop a repeatable and sensitive device and method to test the forces generated by shoe–surface interactions of elite athletes under realistic
performance conditions, and to assess the device and method descriptively with the cleated portion of a shoe mounted on a rigid foot form interacting with two natural grass playing surfaces.

**Methods**

The design specifications for the test device (termed as BioCore Elite Athlete Shoe–Surface Tester, or BEAST; Figure 1) were as follows:

- Must be able to perform three types of tests: pre-loaded translation, pre-loaded rotation, and combined translation/drop;
- Must be able to generate vertical forces up to three times the body weight of a 95 kg elite athlete (nom. 2.8 kN) under all testing conditions;
- Must be portable and thus be able to test playing surfaces as installed *in situ*;
- Must perform all tests at dynamic loading rates; and
- Must measure all components of force and motion of the foot form with acceptable levels of repeatability.

The BEAST consists of a foot form connected to a shaft that can move horizontally and vertically along an inner support frame. For the experiments reported here, the foot form was rigid and only the cleated portion (bottom) of the shoe was tested (although other foot forms could be used if an intact shoe is to be tested). The inner support frame can move vertically on a heavy outer frame (shown schematically in Figure 2). The various degrees of freedom (DOF) of the shaft (rotation, vertical, and horizontal motion) and of the inner support frame (vertical motion) can be constrained or freed to perform each of the three tests. In all cases, motion of the foot form is powered by a high-speed pneumatic actuator connected to the

Figure 1. Photograph of the BEAST test device configured for a translation test. In this image the foot form is located at the lower end of the shaft on the far left.
shaft by a steel cable. Wheels attached to the outer frame can be lowered to lift the BEAST device for transport, and raised to allow the device to rest on the playing surface for testing. The functions of the device are explained below in the context of each of the three tests.

**Pre-loaded translation test**

This test was designed to displace the foot form horizontally across the playing surface while under vertical load. To perform the pre-loaded translation test, the horizontal DOF

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Figure 2. Schematic depictions of the BEAST test device configured for the three tests: (a) translation, (b) rotation, and (c) translation/drop.
of the shaft is unconstrained, while the rotational DOF is constrained. The vertical DOF of the shaft relative to the inner support frame is constrained by a roller attached to the shaft, which rides in a horizontal rail system attached to the inner frame. The vertical DOF of the inner frame relative to the outer frame is freed so that the entire weight of the inner frame, shaft, etc. is supported by the cleated foot form resting on the surface. The desired vertical force is achieved by attaching weights to the top of the inner frame. The cleats are pulled across the surface by venting compressed gas into the pneumatic actuator through a high-speed solenoid valve. The device inputs are the vertical pre-load and the firing pressure, and the outputs are the motions and loads on the foot form. In conducting the translation test, the vertical pre-load force on the foot form was 2.8 kN, as measured by the load cell shown in Figures 2 and 3c, and the maximum pulling force (which could be adjusted based on the pressure introduced in the actuator) was set to be the highest that the device could produce safely (approximately 4.2 kN, based on the specifications of the pneumatic system).

**Pre-loaded rotation test**

This test was designed to rotate the foot form on the playing surface while under vertical load. To perform the pre-loaded rotation test, the horizontal DOF of the shaft is locked and the rotational DOF of the shaft is unconstrained. The vertical DOF of the shaft relative to the inner frame is constrained, the vertical DOF of the inner frame relative to the outer frame is freed such that the entire weight is supported by the foot form, and the desired vertical force is generated by applying weights to the inner frame. The loading cable is wound around a pulley fixed to the shaft. When the pneumatic cylinder is fired the shaft and foot form rotate. The device inputs are the vertical pre-load and the firing pressure, and the outputs are the motions and loads on the foot form. In conducting the rotation test, the vertical pre-load force on the foot form was 2.8 kN, and the pulling force of the actuator was adjusted to produce a peak torque on the foot form (approximately 190 Nm) just above the threshold needed for the cleats to tear natural grass when subjected to this vertical force (approximately 150 Nm torque, based on initial trials with this device).

![Figure 3. (a) Photographs of the forefoot of the molded cleat, and (b) of the molded cleat mounted to the foot form.](image-url)
Combined translation/drop test

This test was designed to launch the foot form into the playing surface with both vertical and horizontal components of velocity. To accomplish the combined translation/drop test, the inner support frame is raised and locked in place such that the foot form is off of the playing surface by a controlled height at its initial position. The rotational DOF of the shaft is locked, the horizontal DOF of the shaft is freed, and the stoppers are removed so that the shaft roller can fall off the rails during the test. The shaft is initially placed at the end of the machine (furthest from the actuator), supported above the playing surface by the inner rail. Then the pneumatic actuator is fired, pulling the shaft along the inner rail (with the foot form still above the playing surface). When the shaft arrives at the end of the inner rail, the shaft roller falls off of the rail allowing the shaft to fall vertically until the cleats impact the surface. The lengths of the rail and the loading cable are designed such that the loading cable goes slack when the shaft falls off of the rail allowing the foot form to continue in a state of free-flight until it impacts the playing surface. Thus, at the point of playing surface impact, the foot form has programmable velocity components in both the horizontal and vertical directions, and the foot form motion is arrested only by the interaction of the cleats with the surface. The device inputs are the mass, the drop height, and the firing pressure (which dictates the horizontal speed) and the outputs are the foot form motion and the loads on the foot form after the point of surface contact. In conducting the combined translation/drop test, a mass of 42 kg, a horizontal speed of 1.5 m/s, and a drop height of 67 mm were used. These values were selected to generate a vertical ground reaction force peaking at approximately 3 kN with a duration of 100 ms when tested on natural grass.

Cleated foot form

In previous studies, there was a variation in the manner in which cleats of a shoe were attached to test machines. Many studies have used whole shoes, attached to the test machines by fitting them around an artificial foot (Torg et al., 1974, 1996; Bonstingl et al., 1975; Van Gheluwe et al., 1983; Andreasson et al., 1986; Heidt et al., 1996; Grund et al., 2007; Villwock et al., 2009). Such a method can be affected, however, by the fit of the shoe on the artificial foot and the deformation in the shoe upper and sole. For example, Villwock et al. (2009) used whole shoes in rotation tests and found that deformation in the shoe upper caused the soles to rotate under the artificial foot, thereby confounding the test results. To isolate the interaction of cleat patterns with the playing surface, other researchers chose to rigidly attach shoe bottoms directly to the test machine (Livesay et al., 2006). The BEAST device described in this study can accommodate either method.

One characteristic cleat pattern was studied in the tests discussed herein. Shoe bottoms were taken from size 12 shoes (right foot) designed for professional American football players. The cleat pattern was regarded as an ‘all purpose’ pattern, intended for use on either natural grass or artificial infill turf (Figure 3a). The pattern consists of eight round molded cleats around the periphery of the forefoot (11 mm diameter at base, 8 mm at tip, and 13 mm length), with four smaller, shorter triangular cleats located interiorly (7 mm length), two small cleats on the anterior edge of the periphery (8 mm length), and 15 very small plastic cleats positioned laterally, medially, and down the mid-line (2 mm length).

To simulate a player pushing, pivoting, or landing with a raised hindfoot (ASTM, 1990; Queen et al., 2008), only the forefoot sections of the cleat patterns were used. First, the forefoot portion of the shoe bottom was cut off of new shoes. Automobile body filler was then applied to the upper surface of the samples to create a rigid, reinforced, flat surface that could
be bolted to the flat plate foot form of the test device (Figure 3b). In the translation test, the cleated portion of the shoe was oriented such that the cleats dragged in a posterior direction across the surface, simulating a player pushing on the surface to move forward. In the combined translation/drop test, the cleats were rotated at an angle of 90° such that the horizontal velocity vector was orthogonal to the long-axis of the shoe, simulating the leading foot of a player to move laterally across the surface (e.g. during a cut or landing from a laterally-moving jump).

**Instrumentation**

The forces and torques generated by the interaction of the cleated foot form and the playing surface were measured by a strain-gage load cell (Model 1914, R.A. Denton, Rochester Hills, MI, USA) mounted between the foot form and the shaft of the machine (Figures 2 and 3b). This load cell is capable of measuring the forces and torques generated in each of the three principle directions, but only the vertical force, horizontal force (in the direction of motion), and torque about the vertical axis (in the rotation test) are reported here. A linear displacement transducer (TLM Series, Novotechnik, Southborough, MA, USA) measured the horizontal motion of the foot form relative to the playing surface, a string potentiometer (161 Series, Firstmark Controls, Creedmoor, NC, USA) measured the vertical motion (in the combined translation/drop test), and a rotary potentiometer (Model SP22GS, ETI Systems, Carlsbad, CA, USA) measured the rotation of the foot form. All signals were recorded at a rate of 10 kHz with a Compact DAQ data acquisition system (National Instruments, Austin, TX, USA). All signals were filtered according to the Society of Automotive Engineers (SAE) Recommended Practice for Instrumentation for Impact Tests (SAE, 1995).

**Testing surfaces and conditions**

Two different natural grass playing surfaces, separated by approximately 1,100 km, were used as the testing surfaces in this study. First (S1) was an outdoor field of new (i.e. less than 1-year-old) Kentucky Bluegrass. Second (S2) was an outdoor field of 13-year-old Bermuda grass. Professional, full-time maintenance staffs maintain both the fields that are used as practice fields by professional American football teams. The test device and mechanical and data acquisition equipment were transported to each of these sites. The number of repeated trials performed in any set of test conditions was ad hoc based on availability.

The first series of experiments involved repeated trials of all three tests (translation, rotation, and translation/drop) on S1 in late August 2009 on a warm, sunny day between 11:36 am and 5:44 pm (ambient temperature 29.8 ± 6.7°C, ground temperature 23.8 ± 0.8°C, ambient humidity 36.4 ± 10.8%). A second series of repeated trials of the three tests took place on S2 in late September 2009 on a warm, sunny day between 10:39 am and 3:27 pm (ambient temperature 25.2 ± 3.1°C, ground temperature 20.5 ± 2.8°C, ambient humidity 37.3 ± 7.2%). A third series of repeated trials of the three tests occurred on S1 in early February 2010 on a cold, sunny day (ambient temperature 5.3 ± 1.9°C, ground temperature 3.2 ± 1.1°C, ambient humidity 34.3 ± 2.9%). Finally, additional tests were performed on S1 in May 2010 on a warm, sunny day (ambient temperature 22.8 ± 3.0°C, ground temperature 22.0 ± 2.2°C, ambient humidity 59.2 ± 9.3%). Specifically, the combined translation/drop test was performed with the playing surface in an as-found (i.e. dry) condition and a saturated (i.e. wet) condition, which was attained by soaking the portion of the playing surface with a hose until saturation. The cleat samples
were inspected in between the tests for damage, although no significant damage was observed. After each test, the device was lifted and moved approximately 0.7 m to a new spot on the field for the repeated trial. Care was taken to avoid testing on seams or painted areas of the playing surfaces.

Analysis and interpretation of findings

Repeatability and sensitivity were assessed by comparing the range of outcome values (force, etc.) measured in repeated trials at any set of conditions against those measured in a different set of conditions. Repeatability and sensitivity were deemed acceptable if the range in any condition was small compared to the differences among sets of conditions.

Results

The test matrix is shown in Table I. Twenty-three tests were performed in total, including repeated trials of all three tests on both surfaces, repeated trials of the three tests on S1 while cold, and singular trials of the translation and combined translation/drop tests on S1 while wet.

The device performed all three tests with acceptable levels of repeatability in trials of a given set of testing conditions, as illustrated in Figure 4. In addition, the device and method were sensitive to testing conditions, including the type of natural grass playing surface (Figure 4), temperature (Figure 5), and moisture level (Figure 6). The range of results of repeated trials of a given set of testing conditions was less than those of a given test under

<table>
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<th>Test identifier</th>
<th>Surface</th>
<th>Test type</th>
<th>Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>S1</td>
<td>Translation/drop</td>
<td>1</td>
</tr>
<tr>
<td>44</td>
<td>S1</td>
<td>Translation/drop</td>
<td>2</td>
</tr>
<tr>
<td>45</td>
<td>S1</td>
<td>Translation</td>
<td>1</td>
</tr>
<tr>
<td>46</td>
<td>S1</td>
<td>Translation</td>
<td>2</td>
</tr>
<tr>
<td>51</td>
<td>S1</td>
<td>Rotation</td>
<td>1</td>
</tr>
<tr>
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<td>S1</td>
<td>Rotation</td>
<td>2</td>
</tr>
<tr>
<td>53</td>
<td>S1</td>
<td>Translation/drop</td>
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</tr>
<tr>
<td>84</td>
<td>S2</td>
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<tr>
<td>85</td>
<td>S2</td>
<td>Translation/drop</td>
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</tr>
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</tr>
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<td>Rotation</td>
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<tr>
<td>126</td>
<td>S1 (cold)</td>
<td>Translation/drop</td>
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<tr>
<td>127</td>
<td>S1 (cold)</td>
<td>Translation/drop</td>
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<td>239</td>
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<td>S1 (wet)</td>
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<td>247</td>
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<td>Translation/drop</td>
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</tr>
<tr>
<td>248</td>
<td>S1 (wet)</td>
<td>Translation/drop</td>
<td>1</td>
</tr>
</tbody>
</table>

*Test identifier is the test number which is iterated sequentially after every test performed with the BEAST device, so this is an indicator of the overall order of testing across the various conditions.
differing testing conditions (Figure 7). This finding indicates that the device and the method were repeatable and sensitive to the conditions considered.

**Sensitivity to type of natural grass playing surface**

Test results varied on S1 versus S2, but not to the same degree as the differences in test results when adjusting temperature or moisture. In the translation test, S1 allowed the foot...
form to displace more rapidly over the range of motion than S2 (134–138 ms vs. 148–154 ms), and resulted in horizontal force opposing the motion that was both lower in peak (2.9–3.0 kN vs. 3.1–3.2 kN) and of a shorter duration (Figure 4a). The rotation test indicated a similar mechanical difference between surfaces, with S1 allowing the foot form to rotate more quickly over its range of angular motion (96–97 ms vs. 107–116 ms) and generating an axial torque lower in peak magnitude (131–135 Nm vs. 152–158 Nm) and of a shorter duration (Figure 4b). In the combined translation/drop test, S1 generated greater
peak force in both the horizontal (2.4–2.6 kN vs. 2.2–2.4 kN) and vertical (4.2–4.3 kN vs. 3.3–3.4 kN) directions.

Sensitivity to temperature

Test results on S1 differed dramatically with adjustments to temperature. In the translation test, the cold surface (relative to the baseline) substantially increased the time required for the foot form to displace over its range of motion (134–138 ms baseline vs. 195–200 ms cold) and generated a horizontal force that was much greater in magnitude (2.9–3.0 kN baseline vs. 3.4–3.5 kN cold) and of a longer duration. The rotation test exhibited a similar difference between the cold and baseline surfaces (Figures 5b and 7b). The most striking consequence of the temperature change was the substantial increase in vertical force measured in the combined translation/drop test (4.2–4.3 kN baseline vs. 7.0–7.6 kN cold). The peak horizontal force was also greater with the cold surface (2.4–2.6 kN in baseline vs. 2.6–2.7 kN cold).

Sensitivity to moisture

The translation test also showed a pronounced effect of saturating S1, with the wet surface preventing the foot form from reaching its full range of motion until over 700 ms after test initiation (Figure 6a). This restricted motion was the result of a horizontal force that was
both greater in magnitude (3.9 kN wet vs. 3.6 kN dry) and of longer duration. The combined translation/drop test did not indicate any difference between the wet and dry surfaces (Figure 6b).

Figure 7. Summary of repeatability and sensitivity for selected mechanical characteristics of the shoe–surface interaction. Length of the bars is the range of responses measured in that test condition. (a) Translation, (b) Rotation, (c) Drop.
Discussion and implications

Overall performance

Overall, the BEAST performed as intended. The device executed the three tests specified (translation, rotation, and combined translation/drop), produced the desired vertical pre-loads (three times the body weight of a 95 kg elite athlete), measured all components of force and motion of the foot form, and performed the tests dynamically (with speeds up to 2.4 m/s and 2,400 rotational degrees/s). The device was portable and used to test natural grass playing surfaces installed at two different sites. Since the vertical separation between bars in Figure 7 is generally much larger than the length of the bars, we conclude that the device is sensitive and repeatable (i.e. it discriminates among conditions). The device produced repeatable test results when moved to a different (undisturbed) location of the natural grass playing surface during trials. The device also demonstrated sensitivity to the type of natural grass playing surface, temperature, and moisture level. Further, although not a primary goal of this study, this test device proved to be compatible with the ASTM F2333-04 ‘[s]tandard test method for traction characteristics of the athletic shoe-sports surface interface’.

Shoe–surface interaction (mechanism of description and release)

In previous studies, the interaction between the cleated portion of shoes and playing surfaces has been described using a single ratio of vertical force to horizontal force (or torque), commonly termed as the ‘traction coefficient’. This traction coefficient derives from the friction coefficient used in studying the forces generated when two relatively flat surfaces slide across each other, and implies that the horizontal force (or torque) needed to cause relative motion (breakaway) is linearly related to the applied vertical force.

The interaction of the cleated foot form and a deformable, grass-like surface is not governed, however, by the conventional linear concept of friction (Fendley, 1995; Van Gheluwe et al., 1983). The complexity of the interaction is highlighted by the fact that the

![Figure 8. Ratio of horizontal to vertical force over time for the translation test and the combined translation/drop test on S1 and S2, illustrating the limitations of a ‘traction coefficient’ for describing shoe–surface interactions.](image-url)
combined translation/drop test exhibited different mechanisms of interaction than either of the tests that started with the foot form and surface in contact. The translation test described herein may represent the case closest to that of classic friction, but the highly transient horizontal force measured in these translation tests (see, e.g. Figure 4a) illustrates the lack of a constant, or even linear, relationship between the horizontal and vertical force. Instead, as illustrated by the translation and rotation tests, the cleats dug into the small area of grass in which they were engaged. Instead of sliding across the surface, the foot form tore the patch of grass below the cleats away from the surrounding grass—reducing the resisting force and allowing the foot form to move over its entire range of motion.

Because the mechanism of breakaway was the grass tearing away, there is likely an upper limit to the horizontal force that can be generated during the shoe–surface interaction that is dependent solely on the strength of the surrounding grass. By definition, this represents a nonlinear relationship between the applied vertical force and the resulting breakaway force (or torque), which cannot be described by a single traction coefficient. This is illustrated in Figure 8 that plots the ratio of horizontal to vertical force as a function of time in the combined translation/drop test on S1 and S2. The first important aspect of this ratio is that it is highly transient, ranging nonlinearly and non-monotonically from zero to approximately 2.5. Furthermore, the characteristics of this ratio are more strongly dependent on the test condition (translation vs. drop) than on the surface being characterized. This has important consequences in the interpretation of a particular shoe–surface interaction. In cases illustrated in Figure 8, the ratio based on the translation tests may be interpreted to mean that surface S2 has less ‘traction’ (see Test 90 compared to Test 45) than surface S1, despite the fact that S2 required a longer time for the foot form to move through its range of motion and maintained a greater horizontal force for a longer duration than S1.

Reporting data in terms of normalized breakaway forces (whether in the form of traction coefficients or otherwise) masks the underlying mechanics of the interaction. It is more appropriate to report the individual components of the force vector as a function of time and to compare shoe–surface combinations based on breakaway forces at specified vertical force levels. Both the vertical forces and the breakaway forces (or torques) are unique pieces of information needed to understand testing conditions and compare results. This reporting practice also removes the implicit assumption of linearity inherent to the comparison of results by normalized data, and facilitates both the comparison of the observed breakaway forces with published values on the performance requirements for various tasks and the injury tolerance of the lower extremity (Funk et al., 2002).

Future work

The study reported here is insufficient to assess injury risk or quantitative performance metrics for the shoe–surface interactions studied. Future research should assess different shoe–surface interactions within the context of performance and injury risk, such that footwear recommendations for specific classes or conditions of playing surfaces can be made. Further study is also needed to fully investigate shoe–surface interactions under various conditions that can occur during play. Furthermore, by showing that the mechanics in translation and drop conditions are substantially different, this study highlights the fact that observations made with a single applied vertical force should not be extrapolated to predict the mechanics that occur under other levels of vertical force. Further study should be conducted on the breakaway forces under the range of vertical forces expected to occur during play. The device developed here provides a means to do so. Finally, it is important to realize the limited scope of the tests reported here. This study is limited by its use of only the
forefoot portion of the cleated shoe bottom, removed from the shoe structure, and mounted to a rigid foot form. This study neglected the complexity of the entire shoe on a deformable foot to isolate the particular research questions of interest. Thus, some aspects of the mechanics of the entire shoe mounted on a deformable foot have not been studied here.

Conclusions

A portable device and method were developed to test shoe–surface interaction under the loads and rates generated by elite athletes during collegiate or professional-level performance situations. Tests were performed with one cleat pattern on two different types of natural grass playing surfaces. Temperature and moisture content were varied for one of the surfaces. Repeatability was assessed and found through multiple trials of a test on different sections of the same playing surface, and sensitivity was assessed and found by comparing test results across testing conditions. The device provides a means to test different cleat and playing surface combinations under various conditions. In addition, the device allows for the measurement of the vector components of all loads acting on the foot during shoe–surface interaction, and of the kinematics that result from those loads, which are required for a comprehensive understanding of the mechanical interactions that dictate performance and injury risk.

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References


