

While good grip is an advantage for everyday walking, it is essential for most sporting activities. SATRA slip specialist Mike Wilson looks at the elements that must be considered to provide sufficient shoe-ground interaction to meet the most demanding performance expectations in sports footwear.

# Slip and grip

**T**he biomechanics of shoe-ground interaction is fundamental to player performance and risk of injury in virtually all indoor and outdoor sports. From badminton and tennis to athletics and football of all codes, players make high demands on their footwear in order to perform to their maximum ability and to do so with minimum risk of injury.

There are three main parameters in the shoe-ground interaction equation: traction, impact forces and stability. Both the shoe and the playing surface perform a critical role with respect to all three.

Traction is the grip between footwear outsole and ground without which we could not walk, run or turn at all.

Impact forces occur whenever the foot strikes the ground and sends jarring shock waves upwards through the footwear midsole and into the leg and torso.

Stability is how well the foot and ankle—and to a lesser degree the knee—withstands the traction and impact forces without twisting or buckling.

## Traction

Traction is a doubled-edged sword in that it can both enhance athletic performance and also contribute to sports injuries. The various terms commonly used when talking about traction and slip resistance may mean slightly different things to different people. The English Concise Oxford Dictionary, for instance, defines the term traction as “the act of drawing or pulling a thing over a surface” or “the grip of a tyre on a road or a wheel on a rail”. Grip is defined as “to take a firm hold, especially by friction”, while friction is “the

action of one object rubbing against another” or “the resistance one object encounters moving over another”.

So there is an overall sense that traction refers to the driving mechanism that produces motion, while friction opposes or resists that motion. In order to obtain traction (forward propulsion) we need to push backwards against the ground, and to grip the ground we need friction otherwise we slip. In a more technical sense, however, and as used in this article, the terms traction and friction describe two different mechanisms by which two objects are able to move over one another, either to produce motion or to resist it.

## Friction

Friction in dry conditions is primarily concerned with the adhesion forces that occur between two relatively smooth objects or materials that tend to make them stick together. Adhesion forces occur when there is a sliding movement or rolling action and when there is no movement. In wet or lubricated conditions the microscopic surface roughness of the materials also plays a part in breaking through the lubricant film such that intimate contact is made between the two materials.

Friction is measured in terms of a coefficient of friction (CoF) where the CoF is the ratio of the horizontal frictional force resisting motion (H) to the applied vertical contact force (V), thus  $\text{CoF} = H/V$ . There are two CoFs:

**Static** – the limiting resistance to sliding just before motion occurs.

**Dynamic** – the resistance to motion during sliding at constant velocity.



The classical laws of friction stated by Amontons and Coulomb describe both CoFs as being physical constants, the values of which are dependent only on the material types in contact and are independent of contact time, pressure (contact area) and velocity. For example, if the applied vertical force is doubled, the horizontal frictional force must also double so that the CoF (H/V) remains constant.

These laws, however, have been proved over time to be an over simplification of the frictional interaction between many types of materials. In particular, when dealing with rubber and polymeric materials such as those used in shoe soles and many man-made sports playing surfaces which are relatively soft, compliant and resilient, the measured CoF clearly varies with vertical load, contact area, pressure and velocity.

### Interaction

Traction goes much further than friction and includes the grip that can be achieved through physical interlock between one irregular surface

and another irregular surface or with a compliant surface. Cleated or studded soles which penetrate into natural turf or interlock with the structure of artificial grass pitches or rough off road surfaces, will achieve high levels of traction where friction itself may be minimal. Metal spiked crampons for mountaineering on snow and ice are perhaps the ultimate example.

As with friction, the level of traction achieved also depends on vertical load, contact area and pressure, as these variables will determine the depth of penetration of cleats into the compliant surface. Traction, however will also depend on cleat design and how much resistance to shearing or ploughing through the playing surface in a horizontal direction the cleat offers. The strength and integrity of the playing surface itself will of course also play a big part. Fine dry sand will, for example, offer little opportunity for traction while running spikes can bite securely into synthetic running tracks such as those made with rubber crumb embedded in polymeric binders.

Traction, like friction, is also measured in terms of the H/V ratio but, strictly speaking, should now be referred to as the coefficient of traction. However, in practice there are many situations where elements of both friction and traction occur, so the term CoF is normally used to cover all situations.

### Slip resistance

This is the term used to describe the maximum available friction and/or traction under given surface conditions before slippage occurs and the player loses grip and balance. When the ratio of forces (H/V) applied by the

player through their footwear to the ground exceeds the available shoe-ground CoF then the footwear will slide.

The level of slip resistance provided by the shoe-ground combination can then be seen as the difference between the applied H/V ratio and the CoF. The higher the CoF relative to the applied H/V, the greater the level of slip resistance and the lower the risk of slip occurring.

When the applied H/V exceeds the CoF one of two things may happen depending on the level of friction and traction available. If the level of available friction is exceeded, the shoe sole will slide over the surface as happens when a tennis player slips on a wet hard court. If the level of traction is exceeded, then the surface will tear or be otherwise damaged as the footwear cleats plough through the surface as with divots or skid marks in natural grass. On rare occasions, cleats may shear or break off the sole when the attachment is weaker than the playing surface.

### Torsional or rotational resistance

So far we have considered only translational movement, meaning linear motion in a given direction such as during normal walking or running, or sidestepping in lateral racket sports. When a player changes direction, the foot twists or turns on the ground and there is a pivoting, rotational movement between the sole and the surface.

Just as in the case with translational motion, there will be a friction or traction resistance to this rotation which is measured in terms of torque (T) or moment: force x distance measured in Newton metres (Nm). A high torque indicates high torsional slip resistance and the same factors that determine translational slip resistance (vertical load, contact area, pressure) will also affect torsional slip resistance but to different degrees.

Some people calculate what they call a torsional or rotational, friction or traction coefficient by simply dividing torque by the applied vertical load (T/V). Strictly speaking, however, this is not a true coefficient because it has units of metres. True coefficients such as linear CoF are dimensionless and do not have units.

### Performance versus injury

To perform at their highest level, the player needs to be able to react quickly, to stop and start instantly and be able to maintain power and balance under all conditions. To achieve this without risk of slipping, high levels of translational CoF are normally required due to the high ground reaction forces (H/V) exerted. At very high levels of friction, however, foot movement can be impaired and can cause stumbling due to 'foot fixation'. On some indoor



*Slip testing a golf shoe.*

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tennis surfaces, for instance, smooth-soled tennis shoes are recommended to limit the level of traction achieved.

Rotational traction should ideally be relatively low. Foot fixation during turning movements imposes very high torsional strains on the foot, ankle and knee resulting in a high risk of injuries such as anterior cruciate ligament tears. Such injuries were common when artificial grass playing surfaces were first introduced. Players found that cleated shoes designed for natural grass did not provide adequate slip resistance and so changed to more aggressive and longer cleated sole designs. These produced very high rotational traction that led to an increased incidence of knee injuries. Subsequent developments in artificial grass surfaces and complementary footwear design have reduced the problem. While there is little scientific evidence to suggest that low rotational resistance is detrimental to players' performance, one football boot manufacturer did report negative feedback to a design with particularly low rotational resistance.

To maintain an overall balance between performance and injury prevention in sports where turning or rotation is involved, rotational traction should generally be as low as possible and translational slip resistance maintained at a high enough level to prevent slipping. In practice there is probably an optimum comfortable, safe window between maximum and minimum translational and rotational CoF values. These values will vary between individual sports and player preferences.

### How much translational or torsional traction is required?

This is the key question, and to answer it, we need to know the maximum level of ground reaction forces H/V exerted. The CoF between the shoe and surface has to exceed the H/V level in order to maintain traction without slip.

People with differing bodyweight and muscle power will vary in the level of H/V they apply to the ground. The type of activities and movements they perform in a given sport such as stopping, starting, cutting (sidestepping), turning and jumping are also a major factor: So, it is not possible to produce definitive figures, merely best estimates from various studies undertaken on different types of movements in sports.

Starting with normal walking for example, studies at SATRA found that the maximum H/V ratio in both the forward direction at heel strike and backward direction at toe off rarely exceeded 0.3. When walking up or down a 15° incline, H/V increases to about 0.45. During running, levels are even higher though predominantly in the backward direction on the forepart.

Other studies have found that when starting to run, H/V is in the range 0.55 to 0.85, and when stopping abruptly, it can be around 0.7 to 0.8. Sideway direction changes produce lower values at about 0.6. During more acute cutting or shuffling movements sideways forces may equal or exceed an athlete's bodyweight, indicating H/V levels approaching 1.0. A golfer driving off the tee can generate a value of 0.45.

The figures reported are often average results for a number of athletes after repeated trials. By definition of average, this means that half of the trial results exceeded the quoted value. In one study, the average H/V value from a cutting movement on a high friction surface was 0.74, but one-sixth of the results exceeded 0.94. It is partly for this reason that we referred earlier to the CoF only being an indication of the risk of slip occurring. In this example, if the same exercise was carried out on a lower friction surface with a CoF of 0.74, there would have been a 50% risk of slipping on the turn. However on a surface with 0.94 CoF the probable risk would have been reduced to 17%.

With regard to rotational traction, average torque values have been reported for subjects rotating 180° on one foot ranging from 20 Nm to 38 Nm on a range of surfaces and wearing a selection of shoes. The highest individual value was approximately 45 Nm on artificial grass and the lowest about 18 Nm on sand (clay tennis court). Another study looked at 90° rotation and recorded lower torque values of around 17-18 Nm on both artificial grass and a cinder surface. Low rotational traction is desirable to minimise the risk of injury but a minimum level may also be desirable for some sports.

### Measuring shoe-ground traction

To better understand shoe-ground interaction good laboratory tests are required. These enable us to investigate the individual contribution of both footwear and playing surface to the net



*Slip test using an ice tray.*

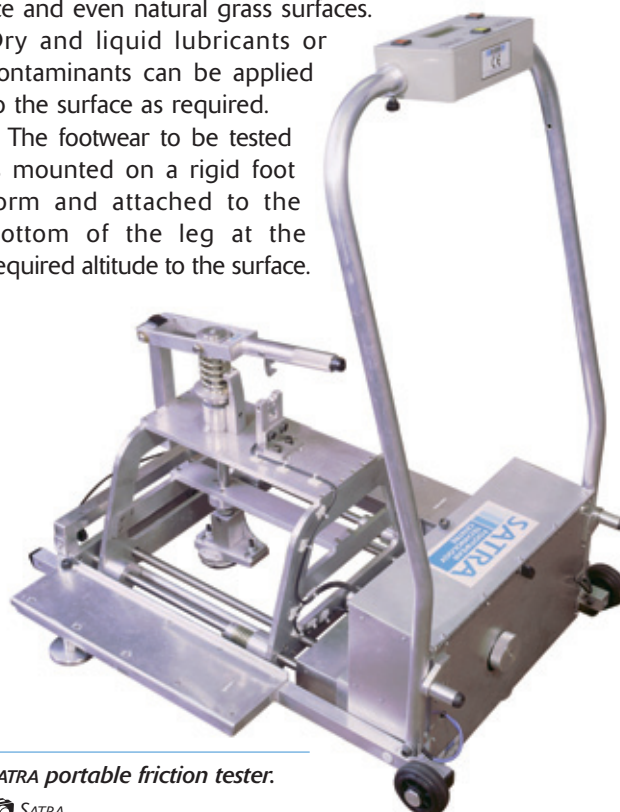
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translational and rotational traction levels more closely.

Due to the dependence of CoF and rotational traction on factors such as vertical load, contact area and velocity, tests should aim to reproduce the biomechanics of the shoe-ground interaction as closely as possible. The SATRA friction tester is one machine that attempts to do this. Originally designed to replicate slip in normal pedestrian gait, it has been developed into a versatile computer-controlled machine capable of applying a wide range of test conditions. Any type of footwear can be tested, from women's sports sandals to men's mountaineering boots and virtually any type of sports surface including man-made rubber, plastic and ceramic tiles to timber, textile, ice and even natural grass surfaces.

Dry and liquid lubricants or contaminants can be applied to the surface as required.

The footwear to be tested is mounted on a rigid foot form and attached to the bottom of the leg at the required altitude to the surface.



*SATRA portable friction tester.*

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### International test standards

At present there are no international standards for testing sports footwear traction. The only published international footwear slip resistance standards are EN13287:2004 and ISO 13287:2006 for safety, protective and occupational footwear. They are identical and very similar to SATRA TM144, which can be used for all translational slip resistance footwear applications.

It is anticipated that the principle of the SATRA/EN/ISO methods will be adopted in due course for routine quality testing of everyday footwear and could equally well be applied to sports footwear. The main difference between testing different types of footwear—apart from adjusting the test conditions appropriately—is in the choice of pass levels or specifications to apply. These should be set at suitable levels that take account of both player performance requirements of the specific sport and injury prevention. This means setting both minimum and maximum specifications.

For research purposes, SATRA TM144 can be used to compare the relative slip resistance merits of different footwear soling compounds. Vulcanised rubber—the most commonly used material for sports footwear—may be compared against other polymers such as PU and PVC/rubber blends which can also provide high levels of friction. Compound hardness and resilience are two physical properties of soling materials which, together with tread pattern design, can be engineered to give the required high or low frictional performance required for translational and rotational traction. 

The angles may be set to simulate forward heel slip for example, and backwards or sideways forepart slip. Once set, the leg—which comprises a pneumatic cylinder and vertical force transducer—lowers the shoe onto the surface and rapidly applies the required vertical load, which is adjustable from 100 to 1,000N depending on the activity being simulated. After a controllable but usually very short contact time, the test surface is pulled from beneath the shoe at a set constant speed of between 0.05 and 0.5 m/s by a powerful electric motor.

The computer print-out records the vertical (V) and horizontal (H) forces during the test, together with an instantaneous H/V trace. From this the static and dynamic CoF can be measured and compared with the biomechanical requirements discussed earlier. The friction tester can be adapted to measure rotational traction by replacing the test bed with a rack and pinion operated turntable. The shoe is then lowered onto the centre of the turntable which rotates at a constant rate and the rotational slip resistance measured.

### Internal shoe friction

We have concentrated exclusively here on shoe-ground interaction, but the fact that the forces acting on the shoe outsole are transmitted to the leg through the rest of the shoe should not be forgotten with respect to footwear design. It is therefore important therefore that the shoe fits securely to the foot and that the internal shoe lining friction levels are suitably specified. A loose fitting shoe with low friction linings will result in undue foot movement within the shoe, leading to instability during play and ultimately foot injury. 

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