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Understanding the traction of tennis surfaces

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Abstract

The traction provided by a footwear-surface interaction can have an impact on player safety, performance and overall enjoyment of sport. Mechanical test methods used for the testing and categorisation of safe playing surfaces do not tend to simulate loads occurring during participation on the surface, and thus are unlikely to predict human response to the surface. For example, the pendulum system routinely employed by the International Tennis Federation (I.T.F.) utilises a standard rubber 'foot', rather than a shoe sole, and does not apply forces comparable to those in real play. There is a requirement for an improved scientific understanding of the tribological interactions at the shoe surface interface and the effects footwear and surface parameters have on the traction mechanism developed. The relationship between normal force and the coefficient of traction for the forefoot of a tennis shoe in contact with different tennis surfaces was examined using a bespoke traction rig. The effects of surface roughness were also examined. A power relationship was found between normal force and traction. As normal force increased differences in surface traction were found. The normal force, stiffness, and roughness of the surfaces affected the adhesive and hysteresis friction mechanisms that contribute to the overall traction force.

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Keywords: Traction; sport surfaces; friction mechanisms; tennis.

1. Introduction

Traction can be defined as the ratio of the horizontal traction force and the normal force, termed the coefficient of traction (COT). In sport the traction generated at the shoe-surface interface is critical to a

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player's performance and injury risk [1]. The overall traction will be dependent on the friction mechanisms developed between the footwear and the playing surface. There is a requirement for improved scientific understanding of the tribological interactions at the shoe-surface interface in sport [2]. Understanding how traction is developed will aid the improvement of playing surfaces and footwear constructions. Once traction mechanisms are understood, surface properties and/or footwear can be effectively changed to maximise performance. This paper presents initial data from a wide-ranging study currently being conducted. The aim of the current paper is to understand the parameters likely to affect the traction experienced by tennis players.

Nomenclature

COT	coefficient of traction
m	arbitrary constant
n	arbitrary exponent
F_N	normal force (N)
R_a	average roughness (μm)

2. Method

Seven tennis surface samples (summarised in Table 1) were tested with a bespoke traction tester, an impact hammer, and a profilometer. Traction tests were conducted using a bespoke traction testing device [2]. A hydraulic ram provides a controlled normal force to a test foot. A high-pressure pneumatic ram provides a controlled driving force in the horizontal direction. A solenoid valve is opened, opening the pneumatic cylinder, to provide a controlled dynamic horizontal force. Load cells (Vishay, model 615) in the horizontal and vertical direction and a horizontal linear displacement voltage transducer (LDVT) provide the necessary measurements to describe traction behaviour. Voltage signals from the load cells and LDVT are sampled simultaneously, via bespoke signal amplifiers and a data acquisition device (National Instruments model number NI USB6008) and displayed in real time using LabView (version 8.2 National Instruments). The respective signals are sampled at 200 Hz and transformed into force and displacement measurements. A 12 mm thick forefoot segment of a commercially available tennis shoe was glued onto the device for use during traction testing (Figure 1). Traction tests were conducted at a mean velocity of 0.1 m/s under a range of normal forces (100 N – 800 N). Tests were repeated six times on each surface and each repeat was conducted on a different section of the surface. Traction was taken as the mean dynamic coefficient of traction in the longitudinal direction between 40 mm and 100 mm horizontal displacement.

Table 1. Summary of surfaces used in testing.

Surface Reference	Sample Description
1	‘Dynaflex Center Court’ Acrylic paint surface coating on a wood backing. 6 mm in total.
2	‘Latex-ite Super Cushion II’ Acrylic paint surface coating on a wood backing. 4-5 mm wood backing, 6-7 mm in total.
3	‘Synpave Rebound Ace’ Acrylic paint surface coating on cushion and wood backing. 5 mm wood backing, 12 mm in total
4	Polymeric tennis surface. 7 mm in total.
5	Acrylic paint surface coating on cushion and wood backing. 5 mm wood backing, 10 mm in total.
6	Acrylic paint surface coating with small particle sand mix. 6 mm Perspex backing.
7	Acrylic paint surface coating with large particle sand mix. 6 mm Perspex backing.

Fig. 1. Forefoot segment of the tennis shoe used for traction testing.

Surface roughness was measured with a laboratory based Mitutoyo profilometer. The profilometer was used to measure the mean roughness average (R_a) of each tennis surface. An impact hammer, detailed in Carré *et al*. [3], was used to assess the mean normal impact stiffness of each surface.

3. Results

3.1. Effect of normal force on traction

A typical plot of horizontal displacement against COT is shown in Figure 2. The COT remains relatively constant during the horizontal movement of the test foot. This was observed throughout all traction tests.

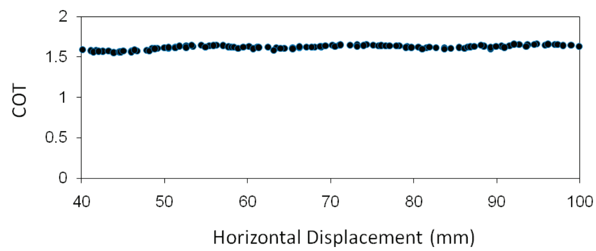


Fig. 2. Typical plot of horizontal displacement against COT.

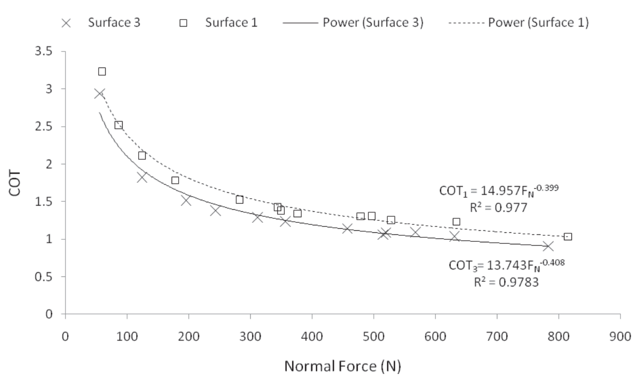
Typical plots of normal force against COT are shown in Figure 3(a). Power relationships were found between between COT and normal force and can be described by Equation 1:

$$COT = m(F_N)^n \tag{1}$$

where F_N is the normal force and m and n are arbitrary constants.

The corresponding equations for each surface, as described by Equation 1, were used to assess the relationship between normal force and traction, Figure 3(b). As the normal force increases, trends showing differences in traction between surfaces appear to form in the data.

a



b

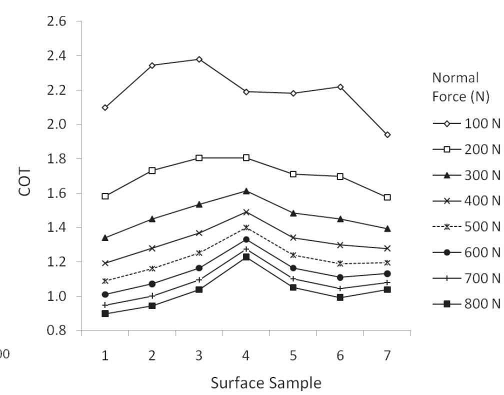


Fig. 3. (a) Typical plots of normal force against mean coefficient of traction (COT); (b) Plot of the coefficient of traction (COT) of the 7 surfaces under a range of normal forces.

3.2. Surface roughness

Figure 4 shows the mean roughness (R_a) ($\pm$ 1 standard deviation) of each surface. No significant linear relationships were found between surface roughness and traction under the various normal forces.

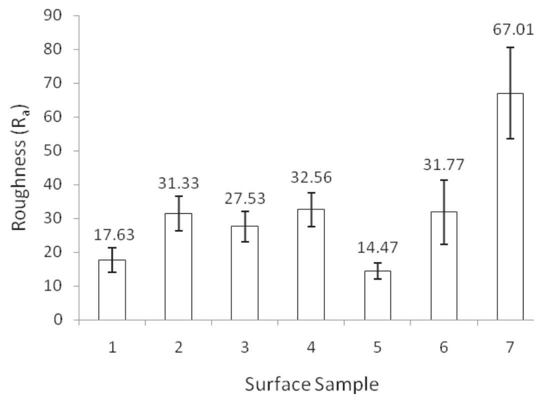


Fig. 4. Plot of mean surface roughness (R_a) for each surface sample.

3.3. Surface stiffness

The mean surface stiffness (± 1 standard deviation) as measured by the impact hammer is shown in Figure 5. As expected surfaces 3, 4, and 5 demonstrate relatively low stiffness. These surfaces have either a cushioned backing (surfaces 3 and 5) or are polymeric (surface 4).

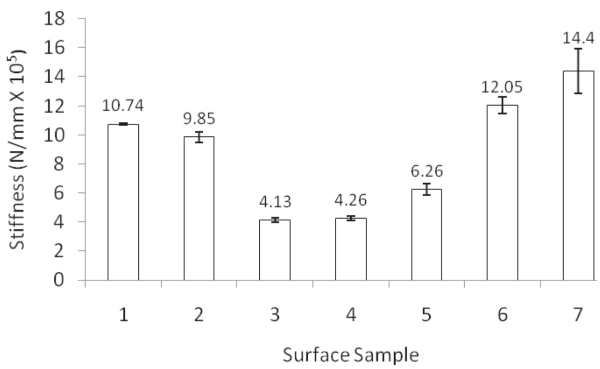


Fig. 5. Plot of mean surface stiffness for each surface sample.

4. Discussion

4.1. Influence of surface roughness on traction

No significant linear relationships were found between surface roughness and traction. However, traction mechanisms are complex and dependent on other surface parameters. Surfaces 6 and 7 only differed in the sand particle size within their acrylic paint surface coating and are therefore worth closer examining. It is interesting to note that as the normal force is increased, the comparative COT of surface 7 increases. It can be hypothesised that at a low normal force the high surface roughness of surface 7 results in lower real contact area; and hence a lower adhesive friction force. However, as the normal force increases, a transition occurs as the real contact area increases and a combination of adhesive and hysteresis friction mechanisms cause the relative traction to increase. The hysteresis friction associated with overcoming the roughness during sliding will become an increasingly dominant component of the overall traction force as normal force increases due to increased loading of the visco-elastic tennis shoe sole.

4.2. Influence of surface stiffness on traction

It is hypothesised that the deformation of the playing surface affected the traction mechanisms observed. A deformable surface dissipates energy during sliding due to its elastic properties. Surface 4 was a deformable polymeric surface. Under increasing normal force the traction of surface 4 becomes greater in comparison with the other playing surfaces (see Figure 3(b)). The lower stiffness of surface 4 results in its deformation. It is hypothesised that the energy dissipated during the deformation and recovery of the surface results in the high traction forces measured. Friction resulting from deformation is caused by the surfaces visco-elastic hysteresis, the partial recovery of energy results in friction losses and hence increases the traction force. Although surface 3 has a similarly low stiffness as surface 4 its deformation-recovery cycle will have been affected by its different construction.

4.3. Influence of normal force on traction

The findings highlight the requirement to conduct traction tests under relevant loading conditions. Currently tennis surface dynamic friction tests are conducted with a portable pendulum device in line with the standardised method of operation detailed in BS 7976-2:2002 [4]. The pendulum test foot assembly applies a normal static force of 24.5 N [4]. Lewis *et al.* [5] found the average normal force applied by the pendulum to be 12 N when conducting dynamic tests with a pendulum of identical specification. These forces are well below the forces found during dynamic athletic movements by a tennis player during play [6] and therefore will not be sensitive enough to consider the friction mechanisms discussed.

5. Conclusions

Traction was found to be a function of the normal force applied to a surface. A power relationship was found between normal force and dynamic coefficient of traction, at forces greater than 100 N.

Surface roughness and surface deformation have a significant affect on traction. As normal force increases, the effect surface roughness has on traction will change. At low forces, a rough surface will have relatively low traction. However, at higher loads the relative traction will increase as hysteresis friction becomes increasingly dominant. A deformable surface will provide increased traction as energy is dissipated during the deforming and recovery of the surface.

Future experiments are required to simultaneously measure surface deformation and traction to understand the effects of friction associated with deformation. Measuring contact area will also aid understanding the effects of adhesive and hysteresis friction mechanisms on surface traction.

Acknowledgements

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