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Tennis shoe-court interactions: Examining relationships between contact area, pressure and available friction

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Introduction

In tennis, complex dynamic movements (side jumping, cutting and braking) affect the loading conditions experienced by players (Orendurff et al., 2008). The magnitude of these forces in combination with other variables, e.g. surface roughness (Clarke et al. 2012) and shoe orientation (Ura et al., 2013) affects the friction generated between the shoe and surface. Previous tennis studies have reported peak vertical forces of 1243.9 ± 99.1 and 1680.5 ± 483.7 N on hard court for a side jump and running forehand movements respectively (Damm et al., 2013). Despite the high loading conditions, repeatable mechanical lab-based test devices have been developed to reliably measure shoe-surface friction (Clarke et al. 2013). However, the challenge remains to replicate these for portable friction test devices. Pressure insole data collected in previous tennis studies (Girard et al., 2010; Damm et al., 2014) could be a key source to develop reliable portable test devices more representative of loading conditions during realistic movements. Variables such as shoe-surface contact area, pressure and available friction need to be assessed in order to examine this further.

Purpose of the study

The purpose of this study was to investigate shoe-surface contact area at different vertical loads, relate them to pressures measured in previous biomechanics tennis studies and measure the available dynamic friction force.

Methods

Tennis shoes were pressed against a surface using a bespoke lab-based traction testing device (Clarke et al., 2013). The vertical loads ranged from 600 to 1600 N in intervals of 200 N. Three commercially available hard court tennis shoes of the same design but ranging in size (EU sizes 31, 39 and 49) were tested. The shoe-surface contact area of the forefoot segments was calculated using an ink print protocol developed previously (Clarke et al., 2012). Blank paper was rigidly attached onto a smooth acrylic sheet under the shoes before they were loaded. The ink prints were digitised and analysed with a bespoke Matlab threshold programme to calculate the ink area. This procedure was repeated 4 times for each condition. The paper surface was then replaced with a commercial hard court sample (mean roughness value of Ra= 14) and friction testing was carried out over the same range of vertical loads. The average dynamic coefficient of friction (DCOF) was calculated using the mean dynamic friction force in the direction of movement between 10 mm and 30 mm horizontal displacement (detailed in Clarke et al., 2013).

Results

For this study the results indicated an increase of contact area as the vertical load increases, showing strong and significant linear regressions ($R^2 > 0.81$, $p < 0.05$, where n = 72) with varying gradients, showing differences between each shoe size. Figure 1 exhibits the pressure values calculated from the vertical load and contact area for each shoe.

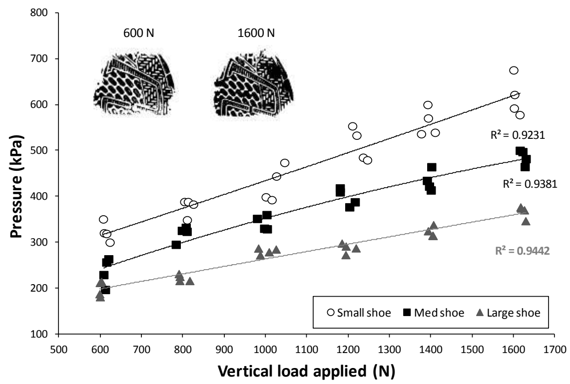

Figure 1. Plot of the pressure against vertical load for each shoe tested. Examples of ink prints are shown for the size EU 31 shoe, at 600 and 1600 N of vertical load.

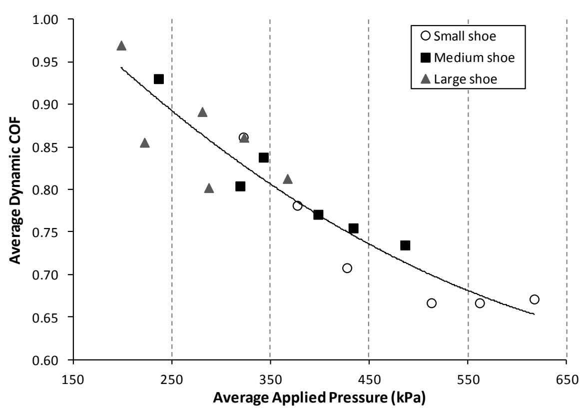

Figure 2. Plot of the pressure against average DCOF for each shoe. Best fit 2nd order polynomial shown to illustrate trend (black line).

Figure 2 shows the results for DCOF against average applied pressure (as predicted from the linear fits in Figure 1). This is assumed to be the average pressure experienced by the shoe before the onset of sliding. As the applied pressure increases, there is a tendency for the DCOF to decrease. Based on the calculated pressure and despite the size of the shoe and the contact area with the surface, similar friction measurements were obtained.

Discussion and conclusion

Significant linear relationships exist between contact area, pressures and normal force investigated in this study. Similar trends are then observed with friction data. By using relatively smaller shoes and scaling down the vertical load applied, it is possible to generate pressures that are comparable to previous biomechanical studies. Damm et al. (2014) reported peak pressure values ranging from 340.4 – 596.6 kPa. It is therefore possible to consider small shoes under small loads that are still capable of maintaining levels of applied pressure that are representative to real-match conditions when considering measuring friction with portable devices.

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