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Influence of clay properties on shoe-kinematics and friction during tennis movements

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Abstract

Tennis is a sport characterised by being played on different surfaces: hard court, grass and clay. These surfaces influence the style of play and tennis specific movements. Specifically on clay, most of the common movements performed by players (e.g. accelerating, side stepping and braking), are performed with some level of controlled sliding. In order to reduce the player's injury risk, and assess the shoe-surface requirements on clay surfaces, there is a need for a scientific understanding of the player's kinematics and tribological mechanisms occurring at the shoe-surface interface. The purpose of this study was to identify the kinematics of the shoe during the sliding phase, and to assess the friction that is present. Baseline areas of both ends of a clay court were prepared with two different mixes of clay, varying the particle size. Eight experienced clay players participated in this study which took place during the Conde de Godó tennis tournament in Barcelona, Spain. 3D kinematic data data was collected using two synchronised high speed video cameras, and after the tests, perception questionnaires were applied to the players. Additionally, three different mechanical devices were utilised to measure the friction of the two clay surfaces. Displacement and velocity data of the shoe in contact with the surface were correlated with the friction measurements from both clay surfaces. Results indicated that significant differences occurred between the two clay surfaces for some shoe kinematic data, and mechanical friction. However, the perception scores suggest the opposite behaviour stated by the mechanical test and shoe-kinematic data. The present study has provided evidence that shoe kinematics and friction of the shoe-surface interaction are affected by the surface conditions, specifically particle size.

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Keywords:Tennis; clay; friction; kinematic; perception

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1. Introduction

In professional tennis, clay courts surfaces are widely used for tournaments. Most of the common movements performed by players (e.g. accelerating, side stepping and braking), are performed with some level of controlled sliding. There are no regulations on the optimal parameters (e.g. particle size) for the preparation of clay courts, so in consequence the players need to adapt their biomechanics to the different clay courts around the world. Although these surfaces have been reported to have lower risk of injuries because of their ability to allow players to slide (Nigg 2003), there is little research on how clay particle size, affects the player's ability to slide in a controlled movement (Clarke *et al*. 2013). Previous studies have been successful in showing that humans are able to identify friction parameters which coincide with mechanical measures (Stiles and Dixon, 2007). However, perception of clay tennis courts and the relationship between kinematics and friction have not been reported.

Therefore, the aim of this study is to investigate in the field, the effect of clay properties, specifically the particle size, on the shoe-kinematics and friction during the performance of some tennis movements during the sliding phase; and then attempt to validate the results through player perception.

Nomenclature

CC1	clay court 1
CC2	clay court 2
SCOF	static coefficient of friction
DCOF	dynamic coefficient of friction
ITF	International Tennis Federation

2. Method

2.1. Biomechanics trial

Velocity and displacement data focusing on one shoe were collected on an assigned tennis clay court, as part of a biomechanics trial, at the Real Club de Polo, Barcelona, Spain. The data was collected for a change of direction movement and a sliding forehand. After the trials, a questionnaire was applied to the participants in order to obtain perception data.

Eight experienced clay players (1 female and 7 male) volunteered to participate in the trial which took place during the Conde de Godó tennis tournament in Barcelona, Spain.

Prior to the testing, the original clay of the two base-line areas of both ends of a clay court was removed and replaced with the clay described in Table 1. The clay used was the same, only the particle size varied. The preparation, performed by the members of INCOTEC, consisted on passing the clay particles through sieves of different finesses to allow a controlled mix of particle size.

Table 1. Clay court surfaces description

Surface reference name	Particle size distribution
CC1	30% > 0.5mm and 70% < 0.5mm
CC2	100% > 0.5mm

Two dynamic movements were assessed within two separate drills (Figure 1). For both drills, the participants began at the right side of the baseline in a ready position. In drill (a), the participants were asked to perform a sliding forehand foot plant. The ball was sent to the centre of the baseline and the participant was required to run from point (1) to (2) and slide whilst simultaneously hitting the ball with the racket. In drill (b) the participants performed a change of direction movement. The participant was required to run at speed from point (1) to point (2) and then a ball was sent to point (3) allowing the player to perform a change of direction movement. Three successful trials for each drill were required. Participants had adequate time to familiarise themselves with the court, drill and warm up before testing.

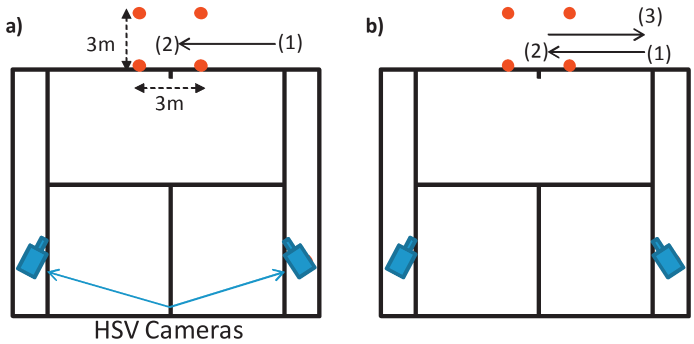

Fig. 1. A schematic diagram for: a) sliding drill: (1) participants starting position, (2) sliding position; b) turning drill: (1) starting position, (2) turning position, (3) return to starting position.

3D Kinematic data was collected for both movements skills using two synchronised high speed video cameras (Phantom 4.1) recording at 300 fps. A 3 x 3 x 1 m calibrated volume was situated at the centre of the baseline (Figure 2). The two cameras were positioned close to the net to record within the volume. The footage recorded for each drill was triggered manually when the player made the movement inside the defined volume. One marker was placed upon the tip of the shoe of the dominant leg that carried out the sliding movement. The number of markers was limited to one to allow quick testing within the short time period allowed with the players. It was felt that this was adequate to gain useful measurements for comparison between the two surfaces. If time and circumstances had allowed, more markers would have been used. A checkerboard () was used to perform the calibration to define the 3D space (Choppin *et al.* 2005 & 2007). The calibration was performed before the players arrived, avoiding any intrusion during the filming. All the footage was digitised with the help of the software Check 3D (developed by the Centre for Sports Engineering Research at Sheffield Hallam University, Sheffield, UK. Check 3D allows the calculation of three dimensional positions of markers in a specific volume. Shoe kinematic data, initial and final velocities, and total displacement during the sliding and change of direction movements, were all obtained from the digitised footage. An absolute test of calibration and digitisation process was assessed by measuring the size of the squares of the calibration checkerboard on the footage recorded, and next, were compared to the same squares measured physically from the checkerboard. It was found that the measurement could be reconstructed to within ±2.5 mm on average.

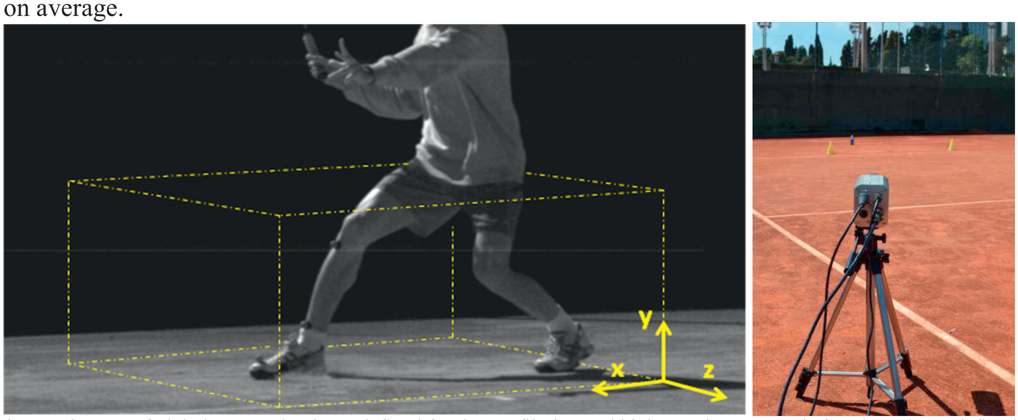

Fig. 2. Diagram of global axes and volume defined for the 3D filming and high speed camera pointing the volume defined.

2.2. Perception data

A short questionnaire was used to collect perception data after the testing on each base-line areas of both ends. Players were asked to rate their perception of slipperiness on both surfaces drills. The scales values were from 1 to 5, being 1 “excessive grip” and 5 being “excessive slipperiness”.

2.3. Mechanical data

A number of mechanical tests were conducted with three different devices on the two different clay surfaces prepared: the pendulum test (British Standard), Crab III test and a bespoke sled friction test device were used to examine static and dynamic friction from the base-line areas of both ends previously described. All mechanical data was collected in conjunction with colleagues from INCOTEC and IBV. The pendulum device (Figure 3b), was conducted according to BS 7976-1-3: 2002 (The Pendulum Method). When released, a rectangular spring loaded rubber slider comes into contact with the surface. The rebound height is measured giving a PTV value. This PTV value is then converted to a mean coefficient of friction. The Crab III (bottom of figure 3a), developed by the ITF (Miller & Capel-Davies, 2006), runs on three wheels and has a rubber sphere attached to the frame via a cantilever beam. As the device is pushed along the surface (approximately 300 mm) the sphere and the surface interact causing the cantilever beam to be deflected horizontally. This deflection is measured via a transducer and is related to the friction between the surface and the sphere. The bespoke sled test (top of figure 3a), an established and simple device, was designed for this project by INCOTEC, to simulate contact conditions during footwear-surface. The device is composed of a shoe outsole mounted on a plate that supports a set of weights; and works in conjunction with a force gauge connected to a laptop with an acquisition programme. All testing was carried out with a total sled weight of 13.78 kg. The testing procedure consisted of attaching the force gauge to the sled and dragging the device for an established distance of 350 mm. The force gauge measured the horizontal force applied during the movement of the sled at a rate of 1000 samples/s. The shoe outsole was brushed before each trial to maintain the same conditions throughout. The SCOF and DCOF are calculated from the force gauge values.

a) b)

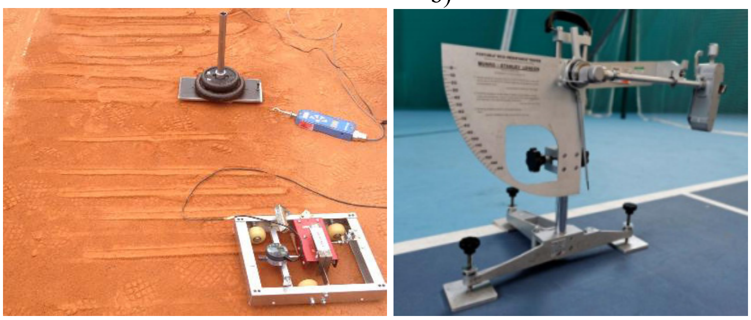

Fig. 3. (a) The Crab III and the sled friction tester (b) Pendulum device

3. Results

Table 2 provides means and standard deviations from the the mechanical data collected on both base-line areas. A one-way ANOVA with repeated measures was used to examine SCOF and DCOF between the surfaces and the devices. For the Crab III and sled device CC2 had significantly lower static and dynamic coefficients of friction compared to CC1 ($p < 0.05$). In contrast, the pendulum was not able to find significant differences ($p = 0.529$) between the surfaces. Between devices, the Crab III and the sled device showed no significance ($p = 0.732$) in the measurements for the CC2 surface, meaning good agreement between the devices. However for the CC1 surface statistical differences ($p < 0.05$) were found. The same behaviour occurred for the Crab III and the pendulum, with no significant differences ($p = 0.174$) being found between the devices for the CC1 surface. However for the CC2 surface, statistical differences ($p < 0.05$) were found.

Table 2. Means and SD for mechanical data

Mechanical test	CC1 surface		CC2 surface	
Frictional measures	*SCOF*	*DCOF*	*SCOF*	*DCOF*
Pendulum	n/a	0.602 ± 0.126	n/a	0.558 ± 0.107[1]
Crab III	0.675 ± 0.116*[1]	0.516 ± 0.070*	0.472 ± 0.054*	0.375 ± 0.012*[1]
Sled Device	0.462 ± 0.053*[1]	n/a	0.428 ± 0.031*	n/a

*denotes significant difference between surfaces (same device)
[1] denotes significant difference between devices

Table 3 shows the shoe-kinematic for the two drills performed by the players on the two surfaces. A one-way ANOVA with repeated measures was used to examine the different variables between the surfaces and the forehand and change of direction movements. For the sliding forehand movement, only the total sliding displacement showed a significant difference between the two surfaces ($p < 0.05$). No statistical differences were found for the initial and final sliding velocities ($p = 0.668$; $p = 0.527$). However, for the change of direction movement, the final sliding velocity showed a significant difference ($p < 0.05$). The initial sliding velocity and total sliding displacement movements showed no statistical difference ($p = 0.399$; $p = 0.195$).

Table 3. Means and SD for shoe-kinematic data for the sliding forehand and change of direction movements on both surfaces.

Variable	CC1 surface	CC2 surface
Sliding Forehand		
Initial sliding velocity (m/s)	4.16 ± 1.22	4.09 ± 1.11
Final sliding velocity (m/s)	1.54 ± 1.15	1.96 ± 0.57
Total sliding displacement (m)	0.48 ± 0.16	0.74 ± 0.13*
Change of direction		
Initial sliding velocity (m/s)	3.06 ± 1.08	3.76 ± 0.83
Final sliding velocity (m/s)	0.40 ± 0.21	1.03 ± 0.28*
Total sliding displacement (m)	0.51 ± 0.18	0.87 ± 0.44

*denotes significant difference between surfaces

For the perception data, no significant effects were revealed for the two drills on the two surfaces previously described (Table 1). However Figure 4 shows that the CC1 surface was rated by the players, to be slippery for perceived grip compared to the CC2 surface. For the change of direction movement the difference between surfaces was close to be significant (p=0.090), however, not sufficient to be statistically different. This suggests that further investigation is needed.

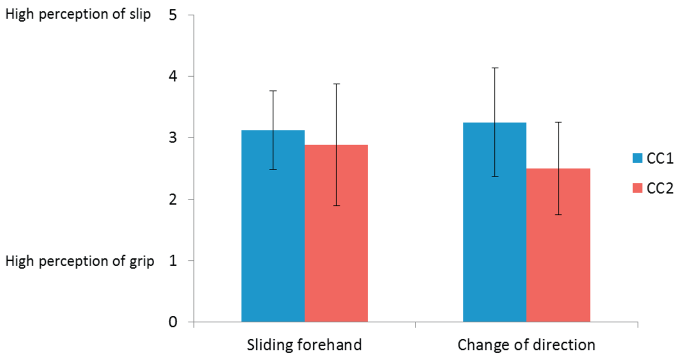

Fig 4. Mean and SD for the grip perception parameter and comparison between the two surfaces tested.

4. Discussion

The present study aimed to examine the influence of clay particle size upon shoe-kinematics response and perception. A further aim was to investigate the friction on the different clay surfaces prepared which the particle size was varied.

Sliding displacement was 64% further on the CC2 surface compared to the CC1 surface. Our results suggest that the mix of size particles of the CC1 surface affects the friction during the sliding movement. The mechanical testing performed with the three devices (Figure 2) confirms that the lower friction from the CC2 surface allows the players to slide more, compared to the friction from the CC1 surface. A study by Mills *et al.* (2009), where the effect of size particle on shoe-floor contact friction was analysed, pointed that particle size below 0.06 mm, under a compression force, behave as a thin layer, predominating a sliding friction. However, the particles greater than 0.06 mm are less likely to join and act as single entities, predominating a rolling friction. In relationship to our study, this suggests that the CC1 surface which was pretty made up of smaller particles (particle size: 30% > 0.5mm and 70% < 0.5mm), during a shoe-surface contact, may produce a more balanced behaviour between sliding and rolling particle friction. The mechanical test and shoe-kinematic data suggest that CC1 provides more grip than CC2. However, the average perception scores rated CC1 as being more "slippery" than CC2, but this was not statistically significant. This suggests that more perception parameters need to be assessed in order to find a correlation between the mechanical and biomechanical data with player perception.

5. Conclusions

The experimental results reported in this paper demonstrate that a change in particle size has a significant effect on kinematics of the shoe-surface interactions, backed up by friction testing. In order to gain a better understanding of these areas, further testing need to be performed on a wider range of samples. Once the tribological mechanisms are better understood, the results could help to develop the optimal parameters for clay courts.

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