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Frictional behaviour of running sock textiles against plantar skin

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Abstract

Friction blisters on feet are a common dermatological injury among long-distance runners which can result from repeated shearing of the skin. Previous studies have shown that an increase in moisture level between the sock - skin interface tends to increase the friction and hence the likelihood of blister formation. For the past few decades, many new sock technologies have been developed based on the principle of friction reduction to prevent blisters such as ‘friction-free’ and double layer running socks. However, there have been very few published results on their frictional performance.

Five different running sock materials were selected based on the variations of their knit pattern and fibre composition. The frictional behaviour of these sock materials against whole plantar skin was then assessed in dry condition. All tests were conducted using a bespoke rig that was developed at the University of Sheffield for studies on foot friction. 26 subjects were recruited for this purpose and friction was measured for a range of normal loads. Subjects’ feet were kept at their natural level of hydration, monitored at specific intervals using the Corneometer® CM 825 device.

It was observed that there was a positive correlation ($p<0.05$) between foot hydration and friction force. However, no particular trend can be seen in the friction coefficient values between the tested sock types. This suggests that the properties of the subject’s foot had more prominent effect on the friction levels than the knit pattern and composition of sock materials under dry contact conditions.

Outcomes from this study indicate that the natural variations in the plantar skin and level of moisture present had a more substantial impact on friction behaviour than any changes in knit pattern or sock material, suggesting the control of moisture levels within the shoe environment is a key factor of concern.

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Keywords: Friction blisters; running socks; moisture; feet; plantar skin.

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1. Introduction

The plantar aspect of the foot is one of the areas in the body where the thickest skin is found, along with the back and palms [1]. It is subjected to four main factors during walking and running: impact forces, pressure, friction and shear [2]. This can eventually lead to various skin injuries as investigated by many previous publications including friction blisters [3, 4]. Friction blisters are one of the most common skin injuries among long-distance runners with incidence levels as high as 39%, as reported by Mailler and Adams [4]. In other sports, friction blisters can also impede athletic performance and have an adverse effect on success, as experienced previously by Roger Federer (2005 Australian Open) and Maria Sharapova (2006 Australian Open) [5].

Impact forces occur when the foot makes initial contact with the ground and these forces can lie in the region of two to three times body weight for running motion [6, 7]. During this contact phase, the pressure distribution, normal to the plantar skin in contact, is affected by the fit and design of the shoe. The contact force is partly translated into a shear component, causing a cyclic shear stress to be applied to the foot surface. The level of shear that can be applied is limited in part by the available friction between the foot-sock interface and is also dependent on the normal pressure distribution. Initially the stratum corneum will just be abraded due to desquamation (shedding). However, as the repeated cycles of shearing continue during prolonged running, the forces are transmitted to the deeper epidermal layer. Once the surrounding tissues are unable to withstand the amount of forces which have intensified beyond the tolerable point, micro-tears start to occur within the stratum spinosum resulting in friction blisters [8, 9]. The size of blisters varies depending on the skin location, the magnitude of the forces, contact parameters and the environment as observed by Herring and Richie [10]. The authors also found that 60.2% of the blister incidences occur in the forefoot region compared to the midfoot and rearfoot regions with 33.3% and 6.5% respectively.

Another critical factor that poses additional risks to developing blisters is increased moisture levels within the shoe which could be due to high level of perspiration and humid environment. Moisture content in the stratum corneum [11] and presence of water in the skin-fabric interface could strongly influence the friction of skin. Rubbing wet skin against dry fabrics has been shown to result in a significant increase in friction with larger increases being found for hairy skin compared to glabrous skin [12]. A recent work by Tomlinson et al. [13] (not using textiles), found an increase in skin-surface friction coefficients in a humid environment and attributed them to physical mechanisms including water absorption and capillary adhesion due to meniscus formation. The authors also concluded that there was negligible effect due to the viscous shearing of liquid bridges formed between the skin and the interacting surface. Elevated temperature at the skin surface during rigorous sport activities where the feet are subjected to repeated rubbing could also increase the skin moisture levels through sweating. This is more prominent for shoes with poor air-permeability that represent a barrier to heat transfer. Moisture present in the contact could also increase friction due to changes in the properties of the sock fibres [2].

Most of the previous blister studies were conducted on the palm, forearm, thighs, abdomen and back of the heel [14] and not on the plantar aspect of the foot. Our present study is specifically aimed to address this gap and further improve the understanding of frictional behavior of sock textiles against plantar skin in dry condition. The friction coefficients of the plantar skin against five running sock materials were evaluated and the foot hydration level was also monitored using a standardized protocol.

2. Materials and methods

2.1. *Study participants*

Twenty-six healthy participants were recruited from the University of Sheffield, UK. All participants (19 males and 7 females; age: 24.8±4.9 years) took part voluntarily and provided their written informed consent for the study purpose. Exclusion criteria of the study were skin with acute and chronic wounds, any history of skin disorders, allergies that could be triggered by latex, surgical spirit or any alcohol-based topical preparations. Ethical approval was obtained from the Ethics Committee at the University of Sheffield.

2.2. Sock materials

Five different types of commercially available running socks were selected due to their differing fabric composition and knit patterns. The characteristics of these socks are provided in Table 1.

Table 1: Characteristics of socks used for the friction experiments.

Sock	Material compositions	Knit pattern
A	75% cotton, 17% polyester, 6% nylon, 2% elastane	Terry jersey
B	100% cotton	Simple jersey
C	40% wool, 31% cotton, 19% nylon, 8% elastane	Terry jersey
D	99% nylon, 1% elastane	Simple jersey
E	100% synthetic nylon	Simple jersey

2.3. Foot hydration analysis

The hydration level of the plantar skin was monitored throughout testing using a capacitance-based device, the Corneometer® CM 825 (Courage and Khazaka, Germany). Skin surface hydration changes the dielectric constant which alters the capacitance of a measuring capacitor. The measurement depth of this device is between 10 to 20 μm, hence ensuring that the epidermal hydration is not influenced by the skin dermis. Previous studies have shown that the Corneometer® is capable of detecting the differences in the moisture levels between normal and dry skins[15] . The Corneometer measurements were given in arbitrary units (AU) ranging from 0 to 120 AU.

Three sets of hydration measurements were carried out on each participant: 1) immediately after removing their footwear and before cleaning; 2) after cleaning and acclimatisation, which is also prior to the friction tests and 3) immediately after the friction tests to monitor if any large changes had taken place during testing. Each set of hydration measurements included 18 data: three separate measurements taken at six different plantar regions, as shown in Figure 1, to allow for an average hydration value of each region to be calculated. The foot which was to be tested was cleaned with water (at room temperature) to remove any contaminants. Upon removal from the foot bath the foot was dried with paper towels and allowed to acclimatise to the room conditions for 10 minutes. All testing was undertaken in a lab with a temperature of between 20 to 22°C and a relative humidity of 40 to 60%.

Fig. 1. Division of plantar regions for hydration testing: 1- hallux; 2- first metatarsal head; 3- between the second and third metatarsal heads; 4- between the fourth and fifth metatarsal heads; 5- arch and 6- heel.

2.4. Friction experiments

Friction measurements were conducted in dry condition using a bespoke friction rig – adapted from a previous study [13]. The rig consists of two 50 kg rated S-shaped load cells; one is placed vertically under a sliding test plate to measure the normal force and one is fixed horizontally to the plate to measure the applied shear force (acting against friction). The sock materials were cut into rectangular samples of approximate size 150 mm × 400 mm and initially clamped at either end onto the plate to maintain a consistent level of pre-strain. They were then securely attached to the plate using double-sided adhesive tape to ensure no movement during testing.

Pilot testing revealed that there was no significant effect of sample strain on measured friction, with no significant differences between minimum and maximum strains applied. For the purpose of this study and to ensure consistency, all the sock samples were pre-strained to their maximum level before being secured on the test plate. Participants were instructed to slide their foot against the sock material in a forward direction whilst keeping the sliding velocity fairly consistent by counting to 5 during each test (a protocol adapted from [13]). A range of five different vertical loads were applied by the participants for each sock material, starting with the lowest before increasing incrementally. The maximum loads that could be applied by the participants were measured to be as high as 500 N. This is more representative of the real-world foot-loading scenarios, than values used in previous skin research [16-18]. All five sock materials were tested under dry conditions and the order of testing was randomised for each participant.

3. Experimental results and discussions

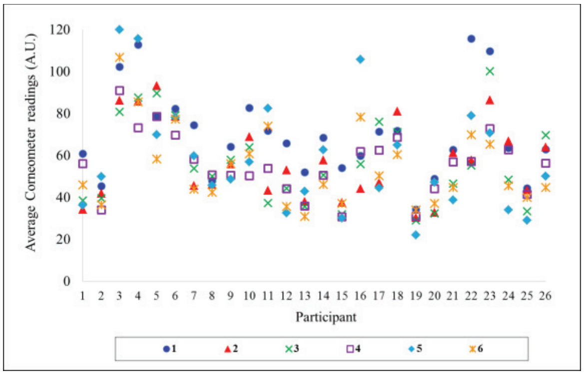

Fig. 2. The Corneometer readings measured after cleaning and acclimatization across six plantar regions (n=26). 1- hallux; 2- first metatarsal head; 3- between the second and third metatarsal heads; 4- between the fourth and fifth metatarsal heads; 5- arch and 6- heel.

3.1. Skin hydration analysis

The hydration values obtained after foot cleaning and acclimatisation were selected as baseline readings and the average hydration values measured across six plantar regions for all participants are shown in Figure 2. The data did not show any consistent trend in hydration level at different locations. This could be attributed to various other participant-specific factors having influence such as skin condition, gait mechanisms, and skin care regimen. A recent study by Laing et al. [19] also suggested that the variablity in the skin hydration could be associated with the physical structure of the feet.

3.2. Evaluating friction coefficient of sock materials against human plantar skin.

Example force data from one participant is shown in Figure 3(a). Similar trends were found for all participants with friction force found to increase linearly with normal force. A value of predicted friction force for a 100 N normal force was then interpolated for each sock material and this data was collated for further analysis.

The friction data obtained from the tests was shown to be widely dispersed across the tested sock materials, as seen in Figure 3(b). The ANOVA test comparing the differences between the sock materials showed no statistically significant differences ($p>0.05$), suggesting that the individual properties of the plantar skin had more of a prominent effect on friction than the knit pattern and composition of sock materials, when tested under dry conditions. This did not concur with the findings obtained by Baussan et al. [16] which showed that the inside of the a terry jersey knitted sock had a higher friction coefficient than that of a simple jersey knitted sock.

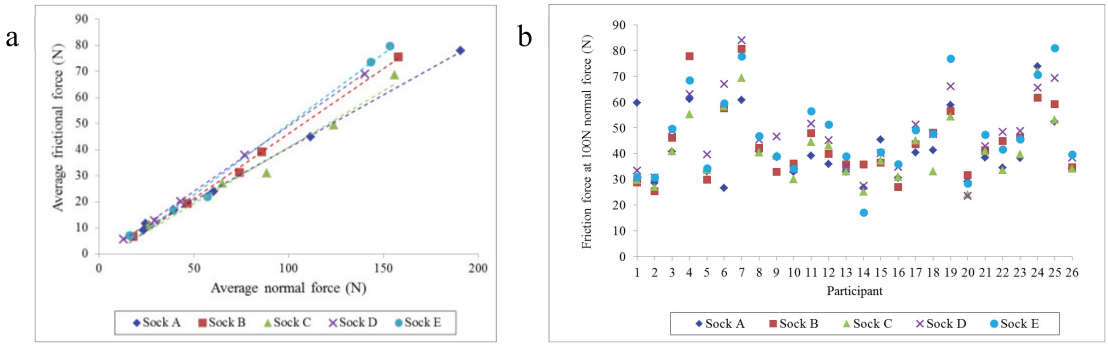

Fig. 3. (a) Force data for the five sock materials from one of the participants (Subject 6); (b) The friction force produced against five sock materials (n = 26, p > 0.05).

3.3. Relationship between friction force and average foot hydration level

The friction values for the five socks were averaged for each participant and compared with their average foot hydration level as shown in Figure 4. There was a moderate positive correlation between the average friction force and hydration level (r = 0.661, p<0.05). Higher foot hydration level tended to produce much higher friction force when interacted with sock materials. This is in agreement with many previous investigations that showed similar outcome when moist skin interacts with other surfaces [13]. Other studies reported that skin surface hydration affects the mechanical properties of the skin resulting in an increased skin tissue flexibility [17] which could lead to this trend.

In the current study, the friction tests were conducted in dry condition whilst keeping the foot hydration level fairly similar to the baselines prior to each test. However, this does not eliminate the possibility that the foot hydration level could fluctuate throughout each test run due to perspiration and increased absorption of moisture from high load application. This is reflected in the Corneometer readings taken immediately after friction test where the foot hydration values increased slightly than the baselines. In order to acquire good comparisons between the data, it is therefore crucial to consistently monitor the foot hydration level in friction experiments.

Measurements of skin elasticity and skin surface temperature may be considered in future experimental work which would provide better insights into the effects of changes in plantar skin hydration.

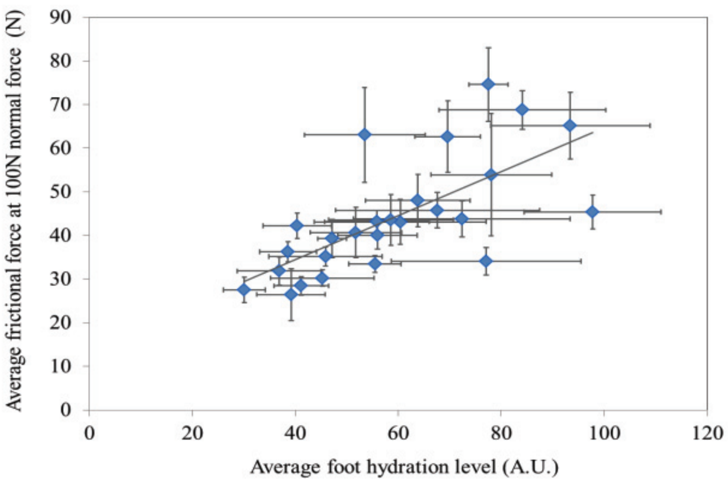

Fig. 4. Positive correlation between friction force at 100N normal force and varying foot hydration level (n = 26, r = 0.661, p < 0.05).

4. Conclusions

This study has established a standard protocol to assess the frictional behaviour of sock materials against human plantar skin in dry conditions. No consistent differences were found between the different socks tested. A relationship was found between friction and foot hydration, indicating that the control of skin moisture levels within the shoe environment could be a key factor to control blisters. Other factors such as the contact area, skin roughness and deformation may also influence the friction of plantar skin and this warrants further investigation. A similar protocol could also be implemented in the future to examine moist contact conditions.

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