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Perceiving slipperiness and grip: A meaningful relationship of the shoe-ground interface

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ABSTRACT

The present study investigated the relationship between objective measurements of the available (CoF_A), the utilized (CoF_U) coefficient of friction and subjective perception of grip or slipperiness. It was hypothesized that significant correlations exist between the perception of grip or slip and the CoF during sports movement and that a minimum CoF was needed to ensure an optimal grip/slipperiness perception. Eighteen healthy active females performed forward and backward cutting tasks onto a forceplate. Six shoes and two floors were used to induce different grip conditions. Subjective ratings and CoF_U were assessed for each shoe-floor combination, and mechanical CoF_A was also measured in a specific test bed. Significant relationships ($p < 0.001$) were found between grip, slipperiness ratings or CoF_A with the CoF_U ($r = 0.98$, $r = -0.97$, $r = 0.88$, respectively). Individual sensory thresholds of the minimum required CoF_U were also determined using probit models between the CoF_U and the grip acceptability. The mean threshold defined in the present study was 0.70 ± 0.11. This meant that below this threshold, the grip perception was not acceptable, whereas above this threshold, the grip was felt good enough to perform the task. In conclusion, strong relationships between subjective perceptions and objective measurements of friction were found in sports-like movements. Moreover, a minimum friction requirement was defined for indoor dry shoe-floor conditions. The present study gives new insights of the shoe-floor interaction and outlines friction requirements for the manufacturers of sports floor or footwear.

1. Introduction

Footwear has been studied from different perspectives, mainly regarding shoe performance [1], fit and comfort [2], or protective function [3]. Thereby the shoe traction (or friction) is a key factor. Improving traction of soccer shoes can enhance players' performances [4], however it increased joint loading which can also lead to an increase in injury risk [5,6]. In contrast, slippery shoes are not acceptable, therefore it can be assumed that an optimal of traction can be preferred. The recent literature has investigated either on traction for field sports shoes or on friction for court sports [7], there is limited information regarding the optimal amount of friction needed for indoor sports shoes.

Other aspects of footwear friction have been widely studied in the field of occupational ergonomics. In order to prevent slips and falls, previous studies have investigated the relationship between available and utilized coefficient of friction (CoF_A and CoF_U, respectively) in different situations and environments [8–12]. CoF_A refers to the maximum friction available for a given shoe-floor interface and it is measured mechanically with either laboratory devices [9,13] or in-field portable devices [8,10,11]. CoF_U refers to the biomechanically measured friction of the shoe-floor interface during gait [8–11,14,15]. These studies showed that slips were associated with low CoF_A whereas the required CoF_U was similar or greater for a safe gait [9,11]. It was proposed that the difference between CoF_A and CoF_U would be a good criterion to evaluate slip for contaminated surfaces [10]. Indeed most of these previous studies investigated walking on wet or contaminated floors. For that reason their CoF_U was measured as the dynamic CoF (also called kinetic CoF) during slip. On the contrary, for dry conditions in sports-like movements, the static CoF was proposed as a better descriptor of the grip and the slipperiness [16].

Interestingly, shoe-floor interface has also been studied through both objective and subjective assessments of slipperiness [17]. Previous studies found significant relationships between the

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slipperiness perception and the CoF measurements [8,18–21]. A similar relationship was found between the CoF_U and the perceived grip of a sports shoe-floor interface [16]. Some of these previous investigations tried to determine a CoF_A or CoF_U threshold beyond which the participant would slip. The older works did not present sufficient interface conditions to get a clear threshold (0.22–0.41 of CoF_A) [8,18]. In their study, Hanson and colleagues [9] used a greater number of flooring conditions which allowed them to define specific slip and fall thresholds based on a logistic regression model between the perceived slips and the CoF measurements. These authors predicted that slips would have a 50% probability of occurring for a 0.16 difference between CoF_A and CoF_U, and a safe gait would be achieved when the CoF_A minus CoF_U difference would be above 0.52.

The aim of this present study is threefold. Firstly, the relationship between CoF_U and CoF_A has to be highlighted during sports-like movements. It is hypothesized that although the two parameters should be correlated, the relationship may not be similar between low and high shoe-floor friction conditions. Secondly, the relationship between the perception and the measurement of grip or slip previously observed in the literature is questioned for sports-like movements. It is hypothesized that significant correlations exist between the perception of grip or slip and the utilised coefficient of friction (CoF_U) during simulated sports movements. Thirdly, a sensory threshold of the minimum friction required for indoor sports activities could be determined using the forced choice paradigm and probit statistical analyses. It is hypothesized that the minimum of CoF_U needed to ensure a good grip perception will be greater than in previous studies on walking.

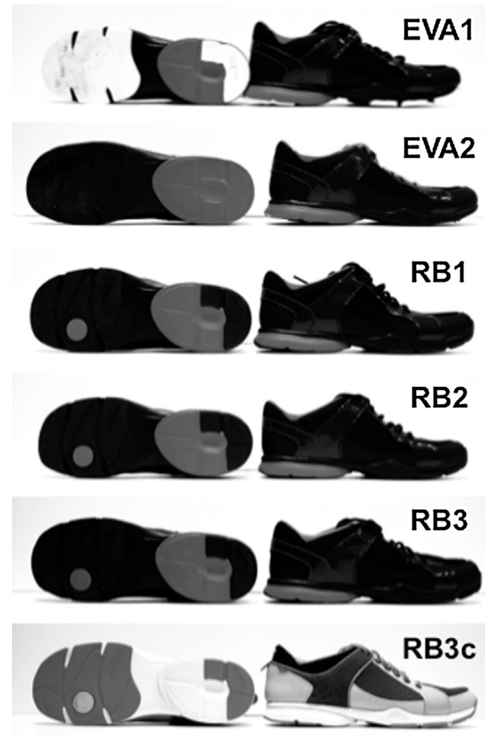

Fig. 1. The six pairs of shoes had the same design and were made of the same materials, excepted for the outsole material which consisted of two different EVA foams (EVA1 and 2), three different rubbers (RB1, 2 and 3) and one last pair of shoes (RB3c) which had the same materials characteristics as the RB3 but with different colors.

2. Materials and methods

2.1. Participants

Eighteen healthy active females (age: 27.0 ± 4.5 years, height: 168 ± 4.6 cm, weight: 61.0 ± 8.1 kg, crotch height: 79 ± 3.5 cm) volunteered to participate in this study. They were free from lower-limb injury and wore a shoe size of 39 (EU). All the participants gave informed consent, in compliance with the ethical rules and laws which regulate human experimentation in France.

2.2. Procedure

Every participant wore six different pairs of shoes on two floor conditions. Five pairs of shoes were identical in size, geometry, midsole foam, colour, with differences only in the outsole (Fig. 1). The outsoles did not differ in geometry but they differed in material properties, with two different ethyl-vinyl-acetate materials (thereafter called EVA1 and EVA2) and three different rubber materials (thereafter called RB1, RB2 and RB3). The sixth pair of shoes was identical to RB3 (thereafter called RB3c). The first floor condition corresponded to the bare force plate (steel) and the second floor condition corresponded to a wooden floor of 4 mm thickness fixed on the top of the force plate. Vertical and shear components of the ground reaction force (Kistler, Switzerland) were recorded at 2000 Hz with a custom made Labview program (National Instruments, USA).

First, the participants performed a warm-up and practice period with a seventh pair of shoes that was not included in the study analyses. During the experiment, the participants tested each of the 12 combinations of shoe-floor interface in a pseudo-randomized order. The shoe conditions were randomized for both floor conditions, and half of the participants started with the steel floor whereas the other half started with the wooden floor. The participants completed a specific frontal cutting task. This task consisted of going forward and backward onto the force platform with a four-step approach. The step on the forceplate stopped the forward approach and initiated the reverse movement back to the starting point with the participant always oriented in the same direction. This "blocking" step was chosen to represent a recurrent sports-like movement and to be easily reproduced in the mechanical footwear test. This movement was repeated continuously for 30 s. Marks on the ground helped to check that the steps were separated by a minimum distance corresponding to each participants' crotch height. Meanwhile a metronome helped to maintain a constant step rate of 110 steps per minute. Before every 30 s trial, the lab floor and the steel or wooden surface of the force plate were cleaned. The shoes outsoles were also cleaned between each trial using an alcohol brush and pulsed air.

After each 30 s trial, the participants were asked to answer a binary forced choice question as 'whether the shoes gave them enough grip to perform the task (coded: 1) or not (coded: 0)'. Then, they gave their perceived grip and perceived slipperiness of the shoe-floor interaction onto two separate Likert scales, from 0 'no grip at all' to 10 'extremely grippy' and from 0 'not slippery at all' to 10 'extremely slippery', respectively.

Prior to the experimentation, static mechanical coefficients of friction had been measured using a slip resistance testing machine (STM603 Satra, UK) for each 12 combinations of shoe-floor interfaces, according to the established Satra standard method TM144. First, the footwear was attached to a foot last and a normal force of 500N was applied on the foot last with a plantarflexion of 10°. Then the floor was moved at a 0.3 m.s^{-1} and the resulting traction force was measured (based on ASTM F2913-11). This measurement corresponded to the available coefficient of friction (CoF_A). The plantarflexion position and the movement speed were chosen to get CoF_A values comparable with the biomechanical measurements.