Tribology International 98 (2016) 261–269

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Relation between human perceived friction and finger friction characteristics

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ARTICLE INFO

Article history:
Received 20 November 2015
Received in revised form
21 February 2016
Accepted 22 February 2016
Available online 27 February 2016

Keywords:
Biotribology
Tactile stimulator
Friction perception
Finger

ABSTRACT

The topic of this paper concerns the relation between friction perception and finger friction behaviour. Two experiments were processed for some 20 individuals. The aim of the first experiment was to determine the distribution function of the perceived friction variation detected by the individuals, relating to the friction variation of the touched surface generated with a tactile stimulator. The second experiment was to determine the finger friction criterion correlated with the perceived friction variation analysed from psychophysical techniques. This criterion, called the friction contrast, depends on the individual finger and is influenced by the sliding velocity.

1. Introduction

In tactile perception, the tribological behaviour between the finger and the surface represents an important factor in identifying and perceiving the surface texture. Researchers have investigated the evaluation of the friction between finger and surfaces to better understand the factors influencing the perception. Some factors have an influence on the friction between the surface and the finger. They can be finger or skin features (mechanical or chemical finger properties, as hydrolipid film), environmental features such as temperature and humidity that can modify the finger characteristics, and sliding conditions like normal load and velocity as well as counterpart features (material, roughness or texture of the surface). Moderate moisture increases the friction of the skin [1,2]. Conversely, in wet skin conditions, the film of water formed can act as a lubricant in mixed or hydrodynamic regimes [2–4]. Nevertheless, the relationship between fingertip mechanical properties and friction behaviour is rarely studied. Fingertip impedance or stiffness in the shearing direction, that is, in relation to touch, has been measured [5–7]. Because it is impossible to evaluate the influence of finger softness with the other finger characteristics keeping constant (dimensions, shape, fingerprints), silicone artificial fingers with different softness can be used. It has been highlighted the coefficient of friction (COF) is higher for a softer silicone [8]. The evolution of the COF between the finger and another material decreases with the increase of the normal load. The COF follows the commonly used law from [9]: $\mu \propto W^{n-1}$, where W is the normal force and n a coefficient between two-thirds and one. The COF between the finger and a counterpart seems to increase for very low sliding velocities (0.1–10 mm/s) [10] and decreases for higher velocities (up to 1.5 m/s) [11] in the case of smooth surfaces for both wet and dry fingers [4].

The influence of the rubbing surface features on finger friction has been extensively studied [12]. Depending on the roughness of the counterpart in contact with the finger, the friction regime can be dominated by adhesion for smooth surfaces or by deformation of the fingertip for rough surfaces. Thus, in dry friction, for surface roughness with R_a (the arithmetic average of asperities height's absolute values) in the range of 0.03–11.5 μm [1,12–14] R_z (the average distance between the highest peak and lowest valley) in the range of 0.05–45 μm [3], or R_q (the root mean square of asperities height) in the range of 0.004–2 μm [15], the COF decreases with increasing roughness, because of a decrease of the tangential force owing to adhesion [3]. For R_q up to 90 μm, the COF increases with increasing roughness [16], because of an increase in skin deformation [17]. However, in the case of wet friction, that is, hydrodynamic lubrication, a low R_a has the opposite effect, because it reduces the friction [3]. For a gentle surface roughness compared to fingerprints, the evolution is dependent on the topography of the surface (i.e. shape, height of asperities, and distance between asperities) [18]. The fingertip point of contact when interacting with an object or when

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http://dx.doi.org/10.1016/j.triboint.2016.02.031
0301-679X/

exploring a surface has been studied because of its importance in determining the haptic perception [19].

Material in contact with the finger influences the friction. The COF between the finger and the smooth surface of a homogeneous material can be classified in decreasing order of importance: soft polymers such as rubber, hard polymers (except polytetrafluoroethylene – PTFE) [20], and metals and PTFE [1]. Glass can give a lower or higher friction coefficient than hard polymers [21–23] and metals, probably depending on its state of cleanliness.

The influence of friction between the finger and a surface on the perceived friction, or slipperiness, has been less studied. One probable reason is the difficulty of changing the friction without changing the surface roughness or the material [20,21]. Therefore, other surface characteristics are changed, not only the friction properties. A convenient solution for modifying the friction between the finger and a surface is to use a tactile stimulator to stretch the skin [24] of the fingertip or to modify the friction of a tactile plate used as a touch pad [25]. The effect of skin stretching, simulating friction, on the perception of friction has been highlighted using a force feedback arm and contact location display apparatus [26]. One of the most important solutions is to use a tactile stimulator, which gives the opportunity of changing the friction between the surface and the finger without changing the roughness of the material. The tactile stimulator used in this study allows us to obtain a variable and repeatable friction coefficient quickly, and can be used to simulate real textile fabrics [27].

The principle of the tactile stimulator, called STIMTAC, used in the present study is based on friction coefficient modulation because of the possibility of instantaneously changing the contact conditions between the finger and the plate by acting like a lubricant. In this type of device, the finger has to move back and forth on the tactile plate to feel stimulation. This kind of device can be very interesting for the study of the influence of friction on the perceived friction and/or friction threshold [25]. A change of around 20% in the friction coefficient can be perceived by the human finger [28]. The lubrication effect is obtained by ultrasonic vibrations of the active plate of the stimulator at a well-chosen mechanical resonant frequency [29]. This vibration frequency is not perceptible by human mechanoreceptors.

The purpose of this paper is the find the relation between the finger friction behaviour and the friction perception, i.e. the ability to perceive friction variation. The role of the cutaneous mechanoreceptors, the mechanotransduction and the treatment in the cerebral cortex are not considered in this study.

This paper presents an analysis of the friction between the index finger and the surface of the stimulator excited by different signals. The main goal of analysing the relation between human perceived friction and finger friction characteristics is to design the command programme of the tactile stimulator to simulate the touch sensation of textures [27]. First, the perceived threshold for friction variation is determined; that is, the smallest vibration amplitude perceived as a change of friction by human subjects. Secondly, this threshold is used to evaluate the relation between the psychophysical friction evaluation and the tribological response of the finger grabbing the tactile stimulator surface. A statistical analysis will be undertaken to assess this relation in order to determine one out of three friction criteria correlated best with the perceived friction variation. These criteria are extracted from the friction signal between the surface and the finger. Moreover, the influence of the sliding velocity on friction perception and behaviour is studied.

2. Methods and measurements

2.1. Tactile stimulator

In our experiment, we used an ultrasonic tactile stimulator, described elsewhere [29–35] to produce a tactile stimulus. This device is based on friction reduction by creating an air gap that lubricates the contact between the finger and a plate. The air gap is obtained by ultrasonic vibration of the active plate of the stimulator (Fig. 1). The frequency of the ultrasonic vibration is about 42 kHz, which corresponds to a well-chosen longitudinal mechanical resonant frequency of out of the plane of the stimulator (Fig. 2). Because the human finger is not sensitive to vibrations higher than 1 kHz [36], this vibration cannot be perceived as vibration; it only induces the air gap.

In order to create the ultrasonic vibration of the active surface, piezoelectric ceramics are used as actuators. These actuators are glued under the plate and supplied by a voltage to create vibration by means of the inverse piezoelectric effect. The supply voltage is adjusted in order to reach the desired vibration amplitude [31,32]. Piezo-sensors, which are calibrated by means of a vibrometer (OVF-5000, Polytech, Germany), are also used in order to find the linear relation between the sensor response and the instantaneous vibration amplitude [31]. The vibration amplitude is of the order of a few microns [35]. The modulation of the vibration amplitude influences the tactile feeling of the surface by reducing the friction depending on the finger position or by a temporal modulation [30]. The size of the vibrating surface of the tactile stimulator is $76 \times 41 \times 1.2\ \text{mm}^3$ and the aluminium plate is covered with a PVC film with a roughness R_a of 1.23 μm.

2.2. Friction measurement

A specific tactile tribometer has been developed for the measurement between the stimulator and the volunteer's finger. It is a reciprocating tribometer, as illustrated in Fig. 3. A linear stage is operated in order to guarantee a constant velocity when measuring the friction. (VT75 100 DC HLS, controlled by a one-channel Mercury servo-controller C863, Physik Instruments Gmbh & Co. KG, Karlsruhe, Germany), onto which the sample is affixed. The data acquisition is performed by a Pulse data recorder (Brüel & Kjaer, Mennecy, France). The normal and lateral forces are obtained from a three-axis load cell (model 3A60-20N, Interface Inc., Scottsdale, Arizona), onto which the tactile stimulator is affixed and which provides the components of the force exerted by the finger on the cell along three orthogonal axes (the vertical axis is denoted as z, the axes in the horizontal plane are named as x and y). The load cell is placed on the linear stage and can be translatable along the x axis. To ensure a correct position of the finger relative to the sample and for the comfort of the subject, an adjustable gutter is designed to support the subject's arm. The angle between the finger and the scanned surface was about 25°.

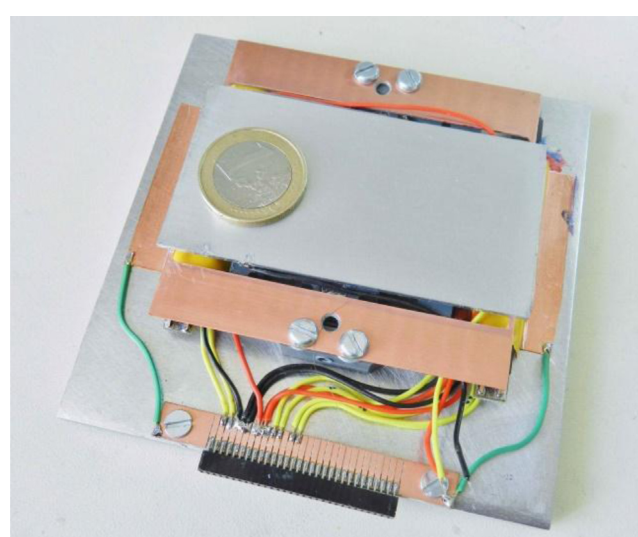

Fig. 1. Photograph of the tactile stimulator used.