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Quantitative assessment of friction perception for fingertip touching with different roughness surface

W. Li, M.L. Zhan, Q.Y. Yu, B.Y. Zhang, Z.R. Zhou*

Tribology Research Institute, Key Laboratory for Advanced Technology of Materials of Ministry of Education, Southwest Jiaotong University, Chengdu 610031, China

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Abstract

There are many mechanical stimulation receptors and sensory nerve endings in human skin, which are the important tools in tactile perception. It is a complex process for human to perceive objects and friction relative motion plays an important role during this process. When human's fingertips friction against objects, they will produce compression and tensile mechanical deformation, which can stimulate the mechanical stimulation receptors in fingertip skin to produce corresponding action potentials and impulses signals. The signals which contain object's physical properties are transmitted to cerebral cortex by nervous system, thus the shape and surface texture of objects are perceived. Thus the friction between the fingertip and object is an important factor to perceive objects. There exist positive connection between friction and tactile perception. However, limited quantitative parameters can be used to evaluate the perception, and they have rarely been studied scientifically. In this paper, the friction perceptions of fingertip skin rubbing against different roughness sandpapers were studied by biofeedback of frictional signals, physiological and psychological responses. An UMT-II tribometer was used to measure tribological parameters of the fingertip, and corresponding physiological response of electroencephalogram (EEG) signals were monitored by using a Physiological Monitoring and Feedback Instrument (NeXus-10) with BioTrace+software. The psychological responses were scored according to the volunteer's perception during friction tests. The correlation models among the perception of fingertip, friction coefficient and EEG signals were established by applying regression analysis method. Results showed that the friction coefficient, amplitudes of EEG signals and psychological responses increased with the roughness of sandpapers increasing. There existed a significant correlation among the friction perception of different surface roughness, friction coefficient and amplitudes of EEG signals. By using this method, the perception of fingertip skin for different roughness surface during friction can be evaluated quantitatively.

Keywords: Fingertip skin; Friction perception; Roughness; Ridge regression; Quantitative evaluation

1 Introduction

Tactile sense of skin is produced by contacting with the external environment, which is a response to mechanical stimulations such as contact, sliding, pressure, etc [1]. There are many mechanical stimulation receptors and sensory nerve endings embedded in human skin, which are the important tools in tactile perception. It is a complex process for human to perceive objects and friction relative motion plays an important role during this process [2,3]. Finger skin is the most frequent contact with the external environment, and it is also the most sensitive parts of tactile sense. When fingertips friction contact against objects, they will produce compression and tensile mechanical deformation due to friction relative motion, which can stimulate the mechanical stimulation receptors in fingertip skin to produce corresponding action potentials and impulses signals. The signals which contain object's physical properties are transmitted to cerebral cortex by nervous system, thus the shape and surface texture of objects are perceived. Therefore, the friction between the fingertip and object is an important factor to perceive objects. There exist positive connection between friction and tactile perception.

*Corresponding author. Tel.: +86 28 87600971; fax: +86 28 87603142.
E-mail address: zrzhou@home.swjtu.edu.cn (Z.R. Zhou).
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In recent years, a lot of experimental studies focused on the friction between finger and objects. For dry finger pads, the dynamic friction coefficients between the human finger and flat materials surfaces typically range from 0.2 to 1.75, measured by means of force plates or analogous measurement systems [4–10]. In the majority of the studies, finger friction was measured at normal forces below 5 N, covering the typical range which is used for the tactile assessment of surfaces. As we have considered, the surface properties of materials and objects are essential for the tactile properties of skin. Lisa skedung [11] inquired the feeling judgments of the participants by touching 21 different kinds of printing paper and found the surface roughness played a dominant role in tactile sense. The friction and thermal conductivity were much more important to identify the good hand feelings for printing paper. Xavier [12] examined the relationship between the tactile roughness discrimination threshold (TRDT) and the tactile spatial resolution threshold (TSRT) at the index fingertip contacting with two sets of six different sandpaper grits and found there was no significant correlation between TRDT and TRST performance. The results supported the theory that the neural mechanisms underlying the perception of tactile roughness discrimination for fine textures differ from those involved in spatial resolution acuity. Miyashita [13] measured the physical properties of thermal conductivity, surface energy and roughness parameters of different materials and pointed out that these physical properties could affect the warm feeling in the process of touch. Kim [14] studied the relationship among the human tactile sensitivity, the vibration amplitude and frequency and reported that the changes of skin vibration amplitude and frequency will affect subjects' resolution degree on the roughness of hard texture surface. Ramona [15] also found that the friction induced vibrations of surface roughness can affect the tactile perception. On the investigation of the tactile sensation during friction contact, some studies reported that soft and smooth materials were regarded as comfortable, those that were stiff, rough, or coarse as uncomfortable [16–18]. Cadoret [19] reported the generally unpleasant sensations associated with manipulation of sticky or greasy surfaces may be due to the unusually strong or weak tangential force signals, which would ultimately interfere with estimating the frictional properties of manipulated object. In our previous study [20], the tactile sensations of human volar forearm skin have been assessed quantitatively during friction testing by using the friction signals and physiological signals of conductance, temperature, and electroencephalography (EEG). The friction force, amplitudes of EEG signals, skin conductance, skin temperature and psychological responses increased with the normal force increasing. The results indicated the discomfort sensations of human skin were strongly related to friction conditions, which intensified under the large normal force and long friction time, and gradually weakened with the number of tests increasing. We also investigated the discomfort perceptions among different gender and found that the discomfort sensations of female were stronger than those of male during the same friction testing [21]. In order to evaluate the discomfort perception more accurately, we constructed a model equation based on the partial least-squares regression, which illustrated the relationship of human discomfort sensation versus physiological indices and tribological stimulus and could assess quantitatively the tactile sensations of skin to a certain extent [22].

The perception of roughness is very important in our life, which is directly related to people's comfort sensations for the objects with different roughness. Although we have done a lot of research on the skin friction, the quantitative evaluation of skin tactile perception has not been solved. Consequently, in this paper, the friction perceptions of fingertip skin rubbing against different roughness sandpapers were studied by biofeedback of frictional signals, physiological and psychological responses. An UMT-II tribometer was used to measure tribological parameters of the fingertip, and corresponding physiological response of electroencephalogram (EEG) signals were monitored by using a Physiological Monitoring and Feedback Instrument (NeXus-10) with BioTrace+software. The psychological responses were scored according to the volunteer's perception during friction tests. The correlation models among the perception of fingertip, friction coefficient and EEG signals were established by applying regression analysis method. The purpose was to explore a new method to evaluate quantitatively the perception of fingertip skin contacting with different roughness surface.

2 Materials and methods

2.1 Skin samples and counterpart material

Considering that the index finger skin is the most frequent contact site with the external environment in daily life, it was chosen for the tests. Six adult volunteers who have healthy and normal index finger skin took part in the experiment. The volunteers' profiles are listed in Table 1. All volunteers approved the experimental protocols. For each volunteer, the right index fingertip was selected as test site, which was not applied any chemical/cosmetic substances one day before testing in order to retain natural skin conditions. The test site was cleaned with conventional shampoo followed by water rinse, then was wiped dry with a lint-free towel and cleaned again with alcohol. The volunteers were physically inactive for at least 20 min before each friction and physiological testing.

The counterpart materials were sandpapers with four kinds of surface roughness. All sandpaper samples was a square with length of the side of 10 cm. The typical surface morphologies of the sandpapers examined by using a laser confocal scanning microscope (OLYMPUS OLS 1100) are shown in Fig. 1, and their 3-D surface morphology and roughness parameters of skin surface

Table 1
Volunteer profile.

Gender	Number	Age (year)	Weight (kg)	Height (cm)
Male	3	25 ± 2	61.5 ± 4	173 ± 2
Female	3	25 ± 1	51.2 ± 2	160 ± 2