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Investigation of the Role of Diminishing Surface Area on Friction-Based Tactile Discrimination of Textures

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ABSTRACT

The ability to discriminate among various tactual elements is crucial to any tactile communication system, such as in assistive technology for those with visual impairment. In previous work, the authors investigated the ability to differentiate textures having a large surface area. In the current work, the objective was to determine how diminishing surface area affects perception, and the extent to which limited area inhibits with the friction-based perception. A perception study in combination with friction measurement was performed to address this issue. Circular texture samples consisting of abrasive papers of P800, P1200 and P2500 grit, respectively, of three different sizes, 38.1 mm, 9.5 mm and 3.2 mm, were used as stimuli. Same size samples were presented in pairwise combinations to determine the mean probabilities of differentiation for an abrasive paper pair at different sizes. Results from the perception measurement indicated that decreasing size of the texture sample resulted in a decrease in the ability to both reliably differentiate different-grit abrasive pairs and reliably identify same-grit abrasive pairs. Finger friction measurements from the participants suggested a possible edge effect on the friction of the samples. Silicone-based probes were also employed for friction measurement of the texture samples to identify friction mechanisms as well as confirm the magnitude of the effect of sample edges on total friction.

1. Introduction

Tactile discrimination of textures involves differentiating surfaces by processing information received through touch, likely involving complex interactions with surface parameters such as roughness, hardness, slipperiness and warmth of the surface. This is relevant because the sense of touch has been shown to be superior to vision for discriminating surfaces, especially of finer textures [1]. Early studies involving discrimination tasks focused on finding texture height detection thresholds and corresponding neural events for a single raised dot, and noticed that the detection thresholds decreased with an increase in the dot diameter [2, 3]. In a discrimination task involving two dot patterned surfaces, the difference in the dot spacing of the surfaces was proportional to the discriminative performance [4]. In fact, in a discrimination study involving gratings of different roughness scales, the spatial period was found to be the most relevant dimension for texture discrimination [5]. These studies were quite informative in identifying the dimensions that were important during a discrimination event, however they were limited to only two types of macro-scale textures (gratings and dot patterns). Discrimination tasks were also used to compare the texture perception ability of blind and sighted observers [1, 6]. Miyaoka et al. measured the discrimination thresholds for fine textured surfaces (sandpapers and gratings as stimuli) and proposed that the perceived roughness amplitude of the surfaces was used for tactile discrimination [7]. A more recent study showed that wrinkled surfaces with feature amplitudes as low as 13 nm could be successfully discriminated from blank surfaces, and proposed that the perceptual dimensions involved could be related to the coefficient of friction and the wavelength of the wrinkles [8]. The literature strongly suggests that topological information about the surface of the texture dictates differentiability of the textures. However, the ability to discriminate between different textures with respect to the size of the texture sample has not been thoroughly explored.

One of the challenges in investigating tactile perception with a goal of understanding fundamental parameters affecting tactual communication, is that many studies have an emphasis of either pure cognitive science, or on tactile deficits in an engineered product resulting from a design requirement or materials change. There has not been a significant amount of work done to bridge the difference in paradigms. However, there have been some efforts to explore this field. Mylon, et al. published a comprehensive review of the work done in medical glove design with some discussion of the tactile impacts for the wearer

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[9]. On the other hand, there has been a great deal of work done in the field of skin friction, but the results thus far have shown that it is difficult to directly predict skin friction unless a number of parameters are controlled such as anatomical location, skin preparation, sliding motion, as well as many other parameters. An excellent summary of this literature was done by Derler, et al. [10]. The knowledge collected in these works is vital for understanding the connection between fundamental tribological phenomena and tactile perception, as is the goal of this work.

In this study, the authors aimed to determine the effect of sample area of micro-scale textures on the tactile differentiability of those textures, and investigate the role of friction on the ability to make such a determination. With this objective, a perception measurement experiment was conducted in combination with friction measurement using participants' fingertips. Friction measurements were also made for two silicone probes sliding against the stimuli used in the perception and finger friction measurement experiments. Topological analysis of the textures surfaces complemented the results from the experiments in order to better understand the factors that impact tactual discrimination.

2. Experimental Methods

2.1. Stimuli

This paper refers to the second of two different classes of textures: a) macro-scale textures, which involve patterns that can be viewed without magnification and often have repeating patterns (e.g., dots, ridges, grids, etc.); and b) micro-scale textures, which involve elements that are not readily visible without magnification, and are often distributed without a fixed pattern. This is a distinction proposed by the researchers to clearly described textures encountered in tactual applications. The current study was focused solely on micro-scale textures. Three fine grit abrasive papers of grits P800, P1200 and P2500 (as specified by the Federation of European Producers of Abrasives, FEPA) were used as the texture samples in this study. In a previous study, these three grit abrasive papers, when provided in 78 × 90 mm sheets to the participants in a sequential manner, were clearly differentiated from each other (mean probabilities of detecting a difference were 0.93, 0.93 and 0.71 for P800-P1200, P800-P2500 and P1200-P2500 pairs respectively). An extensive surface analysis of the abrasive papers can be found in a prior work by the authors [11], with the main difference being the mean size of the abrasive particles for each FEPA grade and the resulting surface roughness. The average roughness (Ra) ranged from 6.00 μm (P800) to 4.22 μm (P1200) to 4.05 μm (P2500), and exhibited no evidence of directional orientation or macro-scale periodicity. Scanning Electron Microscopy (SEM) (FEI Quanta 250 Field SEM) was used to verify that the maximum particle dimensions of the abrasive papers were in agreement with the FEPA standard grain sizes (21.8 μm, 15.3 μm and 8.4 μm respectively for the P800, P1200 and P2500 grits). Circular samples of each of the three abrasive paper grits of three different diameters, 38.1 mm, 9.5 mm and 3.2 mm, respectively, were used for both the perception and friction experiments. The three sample diameters will hence forth be referred to as 'large', 'medium' and 'small' sizes respectively. Fig. 1 shows the large, medium and small samples of P800 grit textures.

In order to prepare the texture samples of different sizes, one of the adhesive sides of double sided adhesive sheets (Silhouette, 8.5-in. by 11-in.) was adhered to the back of the abrasive papers and circle punches (EK tool punches) were used to punch out the circular samples. This process enabled producing circular samples with consistent size and layer thicknesses (of abrasive and adhesive layers) across all sample sizes for all the abrasive grits. The sample diameters were verified by using a digital microscope (Dino-Lite Basic AM2111) and found to be within ± 0.1 mm. SEM was used to ensure that the punched edges were well formed and consistent among samples. The texture samples were

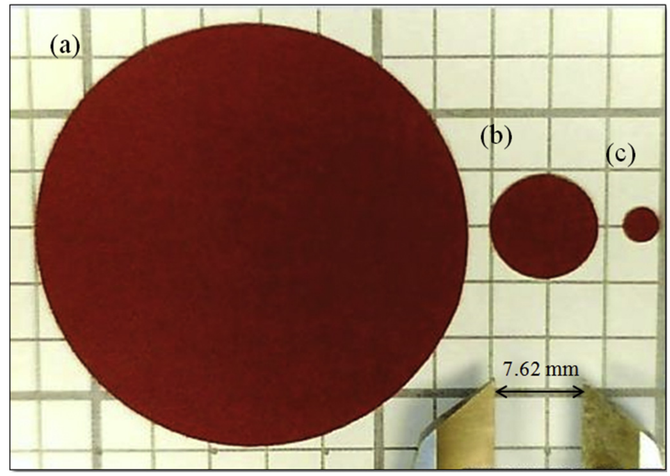

Fig. 1. Circular samples of the abrasive paper grit P800 of the sizes (a) Large, (b) Medium and (c) Small. Scale bar was shown to give an estimate of the relative sizes of the samples.

attached to smooth paper which in-turn was attached to a rectangular magnetic film by using a double sided tape. Texture samples of the same size were presented to the participants in pairwise combinations for the perception and friction measurements. For each size, there were 6 pairwise combinations of the abrasive papers (3 same pair and 3 different pair combinations). Each combination in-turn was repeated 4 times in a randomized order over the size and pairs tested, resulting in a total of 72 measurements (3 sizes × 6 combination × 4 repetitions) per each task (perception and friction) for each of the participants. The sample pairs were attached to the substrate with a constant gap size of 40 mm between the samples for all of the three sizes. The pair of texture discs mounted on the magnetic substrate constituted a complete sample pair for a particular test run. The magnetic backings were of three different sizes (large, medium and small) corresponding to the three different sized abrasive samples as shown in Fig. 2.

2.2. Test Subjects

A total of 23 subjects (12 male and 11 female) participated in the perception and human friction measurement experiment. The participants were recruited through convenience sampling (i.e. from the personal and professional contacts of the researchers, and from

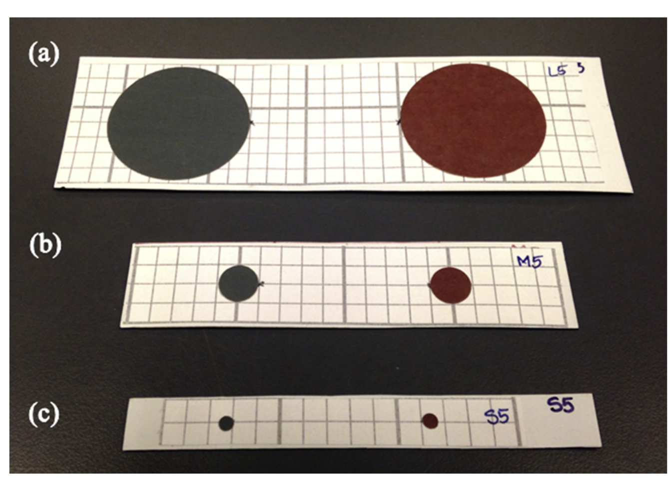

Fig. 2. (a) Large, (b) Medium and (c) Small sample configurations for the abrasive grit pair P1200-P2500 corresponding to the large, medium and small abrasive sample. Different sized paper and magnetic sheets used for each can be seen.