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Expanding Texture Perception in the "Velvet Hand Illusion" Through Added Vibration

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I. Introduction

We perceive the texture of various objects, such as the soft feel of clothing, the warmth of wood, and the uneven and hard texture of concrete roads, and use these to make cognitions and judgments necessary for our lives. The relationship between the physical properties of an object's surface and the perception of its textures has been the subject of extensive study and is gradually being elucidated [1]. These insights have been applied to texture reproduction technologies for providing realistic haptic experiences in fields such as VR and remote operations. Many methods have been proposed to recreate texture, and haptic illusions have attracted considerable attention.

Among these illusions, the Velvet Hand Illusion (VHI) is well-known. VHI is a phenomenon in which moving two or more wires sandwiched between the hands creates the illusion of a velvet-like texture, even though such a texture is not actually present [2-4]. It has been reported that the closer the ratio of the movement speed to the wire interval is to one, the stronger the intensity of VHI [5]. Also, a related study compared actual VHI textures to material samples and found that the texture changes depending on the wire interval, and movement speed and direction [6].

However, the texture reproduction range revealed in that study has been limited. We hypothesized that adding other controllable stimuli to the VHI is necessary to reproduce richer textures, but there were no related studies. Therefore, in this study, we focused on vibration, which is widely used in haptic research, and introduced micro-vibration to the wire using actuators, exploring to broaden the range of textures that can be perceived through VHI.

II. Methods

The experiments were conducted in two steps. First, an evaluation of VHI perception with added vibration was performed, followed by an evaluation of tactile textures of material samples. Each experiment involved 14 participants. In the first experiment, we initially let the participants understand what VHI is. Then, using the developed VHI presentation device, which was visually obscured by a curtain, we randomly presented 12 wire conditions consisting of wire intervals (25, 50, and 100 mm) and vibration frequencies added to the wires (0, 50, 100, and 250 Hz). The reciprocating movement speed of the wire was fixed at 100 mm/s. The device was composed of an outer frame made of an aluminum frame, two piano wires, actuators attached above and below each wire, and a linear drive stage attached to the bottom of the frame. By controlling the drive speed of the stage, the wire interval, and the actuator output, we can present VHI to participants under various conditions (Fig. 1). For each condition, the participants evaluated seven perceptions, which included VHI intensity (seven scales in the category rating method) and six well-known to be major components of tactile texture (seven scales in the semantic differential method), that is, "soft/hard", "dry/wet", "cold/warm", "rough/smooth", "sticky/slippery," and "bumpy/flat" [1].

In the second experiment, we used 14 material samples (cardboard, suede, genuine leather, felt, copy paper, wool, cotton, cork, linen, velvet, artificial leather, wood, and acrylic resin) to have participants evaluate the same six tactile textures. The samples were standardized to a length of 100 mm and reciprocated at the same speed of 100 mm/s as the first experiment. The participants sandwiched the samples between their hands while wearing gloves on the non-dominant hand and evaluated the perceived textures with their dominant hand.

III. Results and Discussions

Fig. 2 shows the results of two experiments. First, we confirmed the average VHI intensity score of participants in the 12 wire conditions, including a comparison with previous studies (Fig. 2a). The results of the three conditions without vibration were consistent with previous studies. That is, the VHI intensity increased as the ratio of the movement speed (100 mm/s) and the wire interval approached one. Based on this, we determined that the device used in this experiment was able to allow participants to appropriately perceive the VHI. We also found that the VHI intensity increased with vibration applied to the wire regardless of the wire interval conditions. In particular, we confirmed that the 25 mm wire interval conditions, where the intensity was low, were significantly increased compared to that at 0 Hz ($p < 0.05$ in the Dunnett's test). In the 50 and 100 mm wire interval conditions, the VHI intensities at 0 Hz were originally high, so the increase in intensity might have been underestimated using the scale used in this experiment.

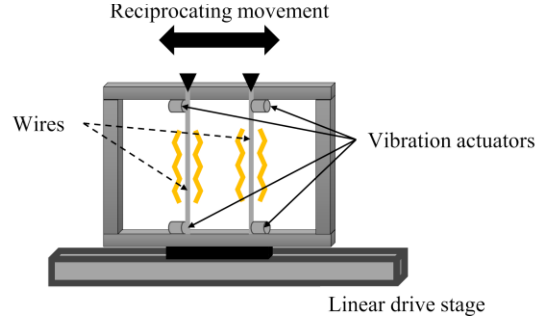

Figure 1. Developed VHI presentation device.

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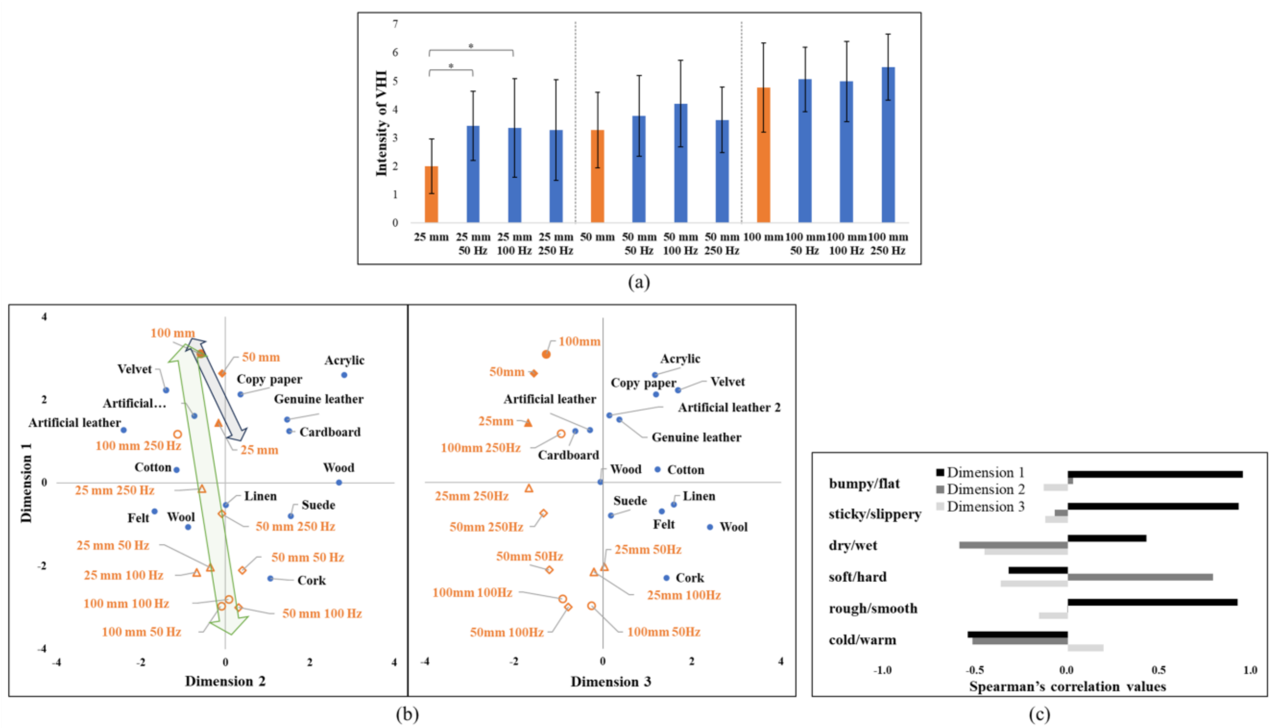

Figure 2. (a) VHI intensity for 12 wire conditions, Orange bar indicates the conditions without vibration. (b) Results of multidimensional scaling. Orange plots denote the wire conditions. The black and green arrow indicates the tactile range for the conditions without vibration, and the range including the conditions with vibration. (c) Spearman's correlation values between each dimension and texture.

Next, to investigate whether the wire conditions with vibration expanded the texture range reproduced by the VHI, we mapped the 12 wire conditions and 14 material samples into a space composed of six texture scores and then performed multidimensional scaling using the Euclidean distances between the plots. Stress values showed that three-dimensional space was sufficient to represent the original space. Fig. 2b shows the result plotted in three-dimensional space. We first found that genuine leather, artificial leather, and copy paper were close materials to the texture of wire conditions without vibration. Also, the three conditions were arranged in order of the width of the wire interval. Furthermore, we found that the range of arrangements in space is greatly expanded, becoming also close to cork, suede, and linen when the wire conditions with vibration were included. Also, as shown in Fig. 2c, through the Spearman correlation values between each dimension and texture, we found that the results of this study showed that the range of representation was expanded in the directions specifically related to dimension 1, that is, "bumpy/flat," "sticky/slippery," and "rough/smooth." On the other hand, small extensions were observed in the directions of dimensions 2 and 3. This suggests that other controllable stimuli are required to expand the representation range in directions such as "soft/hard" and "dry/wet".

The results indicated that adding vibration to general VHI stimuli may enable us to perceive stronger VHI intensity and a wider variety of textures. As to why the addition of vibration obtained these results, combined with a previous study indicating that general VHI is perceived through the responses of Merkel cells and Meissner corpuscles [7], it was hypothesized that the addition of vibration may have prompted further responses of Pacinian corpuscles, resulting in an expansion of the range. Also, it was possible that the vibration itself directly affected texture perception. Future work directions include further investigation of vibration-induced VHI, including higher-resolution frequency conditions (e.g., 50–300 Hz in 25 Hz steps) and additional amplitude conditions, confirmation of the above hypothesis, and exploring the extension of texture to different dimensions by incorporating vibration and other stimuli for applications in VR gloves and telehaptics.

References

[1] S. Okamoto, H. Nagano, and Y. Yamada, "Psychophysical dimensions of tactile perception of textures," *IEEE Trans. Haptics*, vol. 6 (1), pp. 81-93, 2013.

[2] A. Pasqualotto, C. C. J. Yin, M. Ohka, et al., "The Effect of Object Compliance on the Velvet Hand Illusion," *IEEE Trans. Haptics*, vol. 13 (3), pp. 571-577, 2020.

[3] H. Mochiyama, A. Sano, N. Takesue, et al., "Haptic illusions induced by moving line stimuli," *Proc. of World Haptic Conference*, pp. 645-648, 2005.

[4] H. Komura, T. Mochizuki, K. Yamashita, et al., "Basic investigation of velvet hand illusion using a dot matrix for haptic display development," *J. Adv. Mech. Des. Syst. Manuf.*, vol. 19 (1), 2025.

[5] N. Rajaei, Y. Kawabe, M. Ohka, et al., "Psychophysical Experiments on Velvet Hand Illusion Toward Presenting Virtual Feeling of Material," *Int. J. of Soc. Robotics*, vol. 4, pp. 77-84, 2012.

[6] T. Yokosaka, S. Kuroki, and S. Nishida, "Describing the Sensation of the 'Velvet Hand Illusion' in Terms of Common Materials," *IEEE Trans. Haptics*, vol. 14 (3), pp. 680-685, 2020.

[7] N. Rajaei, M. Ohka, T. Miyaoka, et al., "Investigation of VHI Affected by the Density of Mechanoreceptive units for Virtual Sensation," *Int. J. Smart Sens. Intell. Syst.*, vol. 6 (4), pp. 1515–1532, 2013.