

Raised-dot slippage perception on fingerpad using active wheel device

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ABSTRACT

To improve the slippage perceptual characteristics with the fingertip cutaneous sensation, we have introduced raised dots on the surface of a wheel rotating on an index fingerpad. Examining the perceptual characteristics of the raised-dot slippages by psychophysical experiments, we obtained factor effects on the perception. As a result of ANOVA, it was confirmed there was a significant difference among the three surfaces: the 3.2 mm period of raised dots, the 12.8 mm periods of raised dots, and the without-raised-dots smooth surface.

1. INTRODUCTION

A prototype of the slippage-displaying device that embodied a wheel rotating on an index fingerpad was studied in this paper. Perceiving velocities for some periods, subjects can continuously move their hand: integrating the motions, they can further perceive line drawings such as the multi-stroke characters. It would be helpful for visually impaired persons. To improve the slippage perceptual characteristics via cutaneous sensation, we have introduced raised dots on the sliding surfaces of the wheel. The raised dots give subjects distinct stimuli of concave deformations moving on the fingerpad skin surface the distinctiveness is expected to enhance the slippage perceptual characteristics. As for the use of the raised dot, Dépeault et al. (2008) studied perceptual characteristics with raised-dot sliding-speed scaling. Sarada et al. (2004) also reported some characteristics with slip velocities and directions: together with a sandblasted homogeneous rough surfaces, they employed a specific dot surface made of small circular bulging edges: the Weber fraction with the slip-speed perception was improved from 0.25 to 0.04, and the difference thresholds between slip-directions were also improved from 11.7 to 3.6 degrees. Taking notice of not only the velocity, but also the perceptual time period, the authors extend perceptual tasks from the velocity to the length (Nomura et al, 2013): a speed perception scheme worked for the high-speed condition or the multiple dot contact condition, while a dot counting scheme did for the low-speed and single dot contact condition. The mechanical configuration was extended from the linear actuator-based translation to servomotor-based rotation towards mouse type tactile devices in this work.

As with the mouse type fingertip tactile devices, Kyung et al. (2004) proposed a multi-functional mouse providing 1-D grabbing force as well as 2-D translation force, together with pin array tactile patterns. Gleeso et al. (2010) proposed a device providing a 2-D tangential skin displacement. Tsagarakis et al. (2005) used a V-configuration of frustum cones to provide the 2-D tangential slip/stretch as the velocity vector by the form of producing a vector sum: the discrimination angle was 15 degrees with about 70 % correct answer rate. Webster et al. (2005) produced the sliding contact through the rotation of a ball: values relating to just noticeable differences (JNDs) with directional differences were given as 20–25°. Contrasting to these being forced to use non-bumpy surface, the authors introduced raised dots to enhance the slippage perceptual performance in this work.

2. EXPERIMENTAL METHOD

2.1 Experimental Equipment

Two kinds of bumpy films were introduced together with a non-bumpy film to clarify the advantages of the raised dots: (1) the surface with the dot interval of 3.2 mm as in Fig. 1 (a) (referred as “3.2mm-dot surface”), (2) the other one with the dot interval of 12.8 mm (referred as “12.8mm-dot surface”), and (3) the non-bumpy flat surface (referred as “flat surface”). Considering Japanese Standard with raised dots for tactile graphics, the raised dot size were 1.5 mm in diameter, and 0.4 mm in height. In addition, All the three films were made of a lapping film (#2000, grain size of 9µm, 3M Corp.) to make the experimental results general. The films were adhered to the cylindrical surface of a wheel. The wheel was 65 mm in diameter, and was able to be rotated with respect to

orthogonal two axes by a couple of servomotors. One servomotor was connected to the other base-fixed servomotor via a swivel joint. This mechanism made the wheel possible to rotate in 2-DOF (see Fig. 1 (b), (c)).

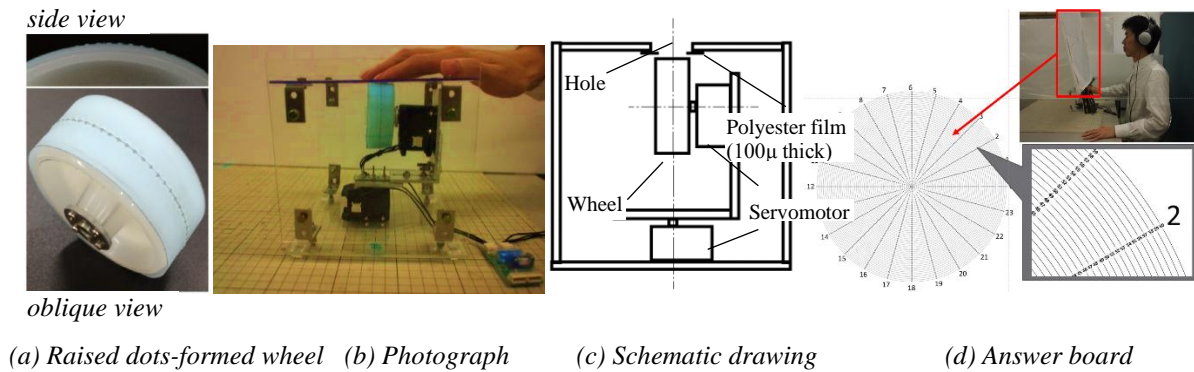


Figure 1. Experimental device.

2.2 Experimental Procedure

Six right-handed male subjects aged 22 to 59 years, voluntarily participated in the experiment. Twisting neither their body at the waist nor their head at the neck, subjects were seated on a chair, and faced his front (see Fig.1 (d)). Setting their elbow flexion angle at about 90° , their forearm was set parallel to the table base, and was also set parallel to the direction in the sagittal plane. A white noise sound was applied to the subjects via headphones for avoiding any side effects on the slippage perception. Subjects touching the wheel surface on their fingerpad through a hole (12.8 mm diameter) of a polyester film (100 μ thick), and the wheel was activated in arbitrary waiting times: it was swivelled to a direction, and was rotated by a specific angle where the servomotors drove the wheel in rectangular velocity patterns. The presented line lengths were 25, 50, 75, 100, 125, and 150 mm. The line directions were 0° (right) to 330° with the interval of 30° in the counterclockwise direction. The speed was set at 60 mm/s that is considered to be natural in ordinary active touches. The 8 lengths and the 12 directions made combinations of 64 line segment patterns, and they were ordered in a pseudo random way, and were presented twice for each of the three surfaces. Consequently, the total number of 432 ($6 \times 12 \times 2 \times 3$) runs of line segment presenting experiment was carried out for each subject. The experiment took about 2 hours per subject. During experiments, the subjects were instructed to relax, and to focus on perceiving the presented linear sliding lengths via their index fingerpad. They were asked to answer the perceived lengths and directions by the following way. Just after the wheel stopped, they opened their eyes, looked at the answer board (see Fig. 1 (d)), and phonated a code number that represents the length and the direction.

3. EXPERIMENTAL RESULTS WITH THE PERCEIVED SLIPPAGES

3.1 Experimental Results

The relationships between the perceptual and actual lengths are shown in Fig.2 for each of the three surfaces: (1) 3.2mm-dot, (2) 12.8mm-dot, and (3) flat. Although a length-related nonlinearity occurred for all the three surfaces, the nonlinearity in both the dot surfaces was seemed to be much smaller than that in the non-bumpy surface.

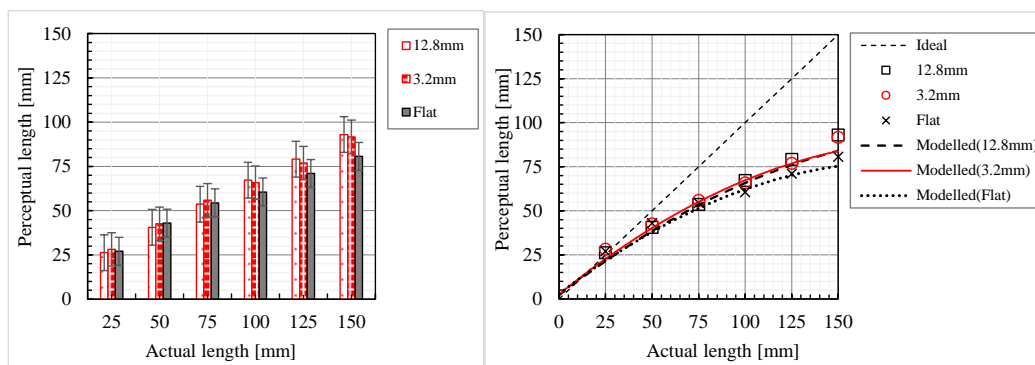


Figure 2. Perceptual length characteristics for the 12.8mm-dot, 3.2 mm-dot, and flat surfaces

The relationships between the perceptual angle errors and the actual angles are shown in Fig.3 for each of the three surfaces. There can be seen a trigonometric function patterns with approximately the same amount of biases of several degrees in the counterclockwise direction.

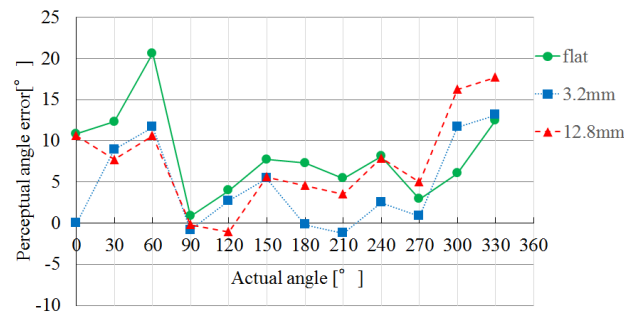


Figure 3. Mean deviation of the perceptual direction for the three surfaces wrt the directions

3.2 Discussion on Perceptual lengths

After applying a curve fitting to the above explained data, a statistical test, ANOVA, was applied. That is, a model value l_{model} of the perceived length l_{perc} was assumed to be given by a power function with the actual length L as in

$$l_{model} = \alpha L^{\beta} \quad (1)$$

The length-related nonlinearity can be expressed by parameters β : the less than 1 the value of β is, the larger the nonlinearity effect is. After taking logarithms of Eq. (1) as in

$$\ln l_{model} = \ln \alpha + \beta \ln L, \quad (2)$$

a linear least squares method was applied to the data for each combinations of the 3 surfaces, 12 directions, 6 subjects and 2 iterations. Then, the 432 pieces of the coefficient pair of $\ln \alpha$ and β were estimated. Averages of the estimated $\ln \alpha$ and β for each of the three surfaces were shown in Fig. 2 together with the modelled values.

Next, ANOVA test was applied to the estimated coefficients (see Table 1 (a), (b)). It can be concluded that there were significant differences among the three surface levels for each of the coefficients of $\ln \alpha$ and β with the significant level of 0.01%, and that the 12.8mm dot showed a bit better performance than the others. While there was no significant difference with respect to the direction factor and the interaction factor.

ANOVA was also applied to the perceived angle errors as in Fig.3. We can conclude from Table1 (c) that there were significant differences of a 0.1 % level among the three surface levels and that the 3.2 mm dot showed much better performance than the others from the viewpoints of both the mean error and the random error (standard deviation). Although there were also significant differences with respect to the direction factor and the interaction factor besides the surface factor, the direction factor effect was the largest among them.

4. CONCLUSIONS

Introducing raised-dots for enhancing slide-length perceptual characteristics, the authors made a prototype of wheel-type slippage presentation device which was able to display velocity vectors via tactile sensation on human fingerpad. By integrating the perceived velocities over duration times, line segments can be perceived. Although the sample size was not enough to conclude definitely, and further examinations are necessary, the followings were tentatively obtained as a pilot study.

1. Based on the Steven's power law, the perceived lengths were modelled.
2. Perception of length: the 12.8 mm dot surface showed a bit better performance than the other 3.2 mm dot and flat surfaces.
3. Perception of angle the 3.2 mm dot surface showed much better performance than the other 12.8 mm dot and flat surfaces.

The experimental equipment used in this study was not enough compact to make use of mouse-interface, further development of miniaturization would also be needed in the future studies. In addition, since the experiments were conducted by sighted persons, the results should be applied to acquired blindness, and further studies shall be necessary for congenital blindnesses.

In the future the authors will embed the much smaller size of the wheel into a mouse as an active wheel mouse.

Table 1. ANOVA tables

| (a) $\ln \alpha$ (α , proportional coefficient wrt perceived lengths) | | | | | | | (c) Perceived directional errors | | | | | | | | | |
|---|--------|-------|---------------|-------------|-------|---------------------|----------------------------------|-------------|--------|------|---------------|-------------|-------|---------------------|----------|--|
| Factor | Level | Mean | Factor effect | Stand. dev. | DOF | Test stats. F-value | Decision | Factor | Level | Mean | Factor effect | Stand. dev. | DOF | Test stats. F-value | Decision | |
| Surface | 12.8mm | 0.94 | -0.18 | 0.76 | 2 | 4.1 | * | Surface | 12.8mm | 7.36 | 0.53 | 16.05 | 5 | 7.75 | *** | |
| | 3.2mm | 1.16 | 0.03 | 0.96 | | | | | 3.2mm | 5.12 | -1.71 | 13.28 | | | | |
| | Flat | 1.28 | 0.15 | 0.86 | | | | | Flat | 8.00 | 1.17 | 20.52 | | | | |
| Direction | | | | | 11 | 0.79 | NS | Length | | | | | 0.18 | NS | | |
| Interaction | | | | | 22 | 0.49 | NS | Direction | | | | | 11 | 19.39 | *** | |
| Error | | | | | 1.01 | 396 | | Interaction | | | | | 10 | 1.93 | *** | |
| Global | | | | | 1.12 | 1.11 | 431 | Error | | | | | 15.98 | 2579 | | |
| (b) β (exponential coefficient wrt perceived lengths) | | | | | | | | | | | | | | | | |
| Factor | Level | Mean | Factor effect | Stand. dev. | DOF | Test stats. F-value | Decision | | | | | | | | | |
| Surface | 12.8mm | 0.7 | 0.044 | 0.18 | 2 | 4.68 | ** | | | | | | | | | |
| | 3.2mm | 0.657 | 0.001 | 0.21 | | | | | | | | | | | | |
| | Flat | 0.612 | 0.044 | 0.17 | | | | | | | | | | | | |
| Direction | | | | | 11 | 1.14 | NS | | | | | | | | | |
| Interaction | | | | | 22 | 0.76 | NS | | | | | | | | | |
| Error | | | | | 0.19 | 396 | | | | | | | | | | |
| Global | | | | | 0.656 | 0.21 | 431 | Global | | | | | 6.9 | 16.92 | 2591 | |

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

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