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Chapter 22

RAISED-DOT SLIPPAGE PERCEPTION ON A FINGERPAD USING AN ACTIVE WHEEL DEVICE

Yoshihiko Nomura, DrEng* and Hirotsugu Kato, MsEng
Department of Mechanical Engineering,
Mie University, Japan

ABSTRACT

To improve the slippage perceptual characteristics with the fingertip cutaneous sensation, raised dots were introduced on the surface of a rotating wheel. As a result of psychophysical experiments, we obtained factor effects on the perception; statistical tests showed a significant difference among the three surfaces: the 3.2 mm and 12.8 mm periods of raised dot surfaces, and the without-raised-dot surface.

INTRODUCTION

A prototype of a 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; concatenating the motions, they can further perceive line drawings such as the multi-stroke characters. It would be helpful for visually impaired persons to perceive line drawing in such the way. 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 (1).

Sarada et al. also reported some perceptual characteristics with slip velocities and directions (2). 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-

* Correspondence: Professor Yoshihiko Nomura, Dr Eng, Department of Mechanical Engineering, Mie University, Kurimamachiyacho, Tsu, 514-8507, Japan. E-mail: nomura@mach.mie-u.ac.jp.

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 extended perceptual tasks from the velocity to the length (3). It was also found that a speed perception scheme worked for the high-speed condition or the multiple dot contact condition, while a dot counting scheme did so for the low-speed and single dot contact condition (3). In this work, the mechanical configuration was extended from the linear actuator-based translation to servomotor-based rotation towards the development of mouse type tactile devices (3).

As with the mouse type fingertip tactile devices, Kyung et al. (4) proposed a multi-functional mouse providing 1-D grabbing force and 2-D translational force together with pin array tactile patterns. Gleeso et al. (5) proposed a device providing a 2-D tangential skin displacement. Tsagarakis et al. (6) 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. (7) 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 with non-bumpy surfaces, the authors introduce raised dots to enhance the slippage perceptual performance in this work.

METHODS

Three kinds of films were introduced: (i) a surface with a dot spacing interval of 3.2 mm, see Figure 1(a), referred as the “3.2mm-dot surface”; (ii) a surface with a dot spacing interval of 12.8 mm, referred as the “12.8mm-dot surface”; and (iii) a non-bumpy flat surface, referred to as the “flat surface.”

The flat surface was introduced to clarify the advantages of the raised dots. 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 film that is commercially available (#2000, grain size of 9μm, 3M Corp.) to make the experimental results general. The films were affixed to the cylindrical surface of a wheel. The wheel was 65 mm in diameter, and was 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 Figure 1(b), (c)).

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, facing to the front (see Figure 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 touched the wheel surface using their fingerpad through a hole (12.8 mm diameter) made in a polyester film (100μ thick); the wheel was activated after arbitrary waiting times: the wheel was swivelled to a direction, and 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 an interval of 30° in the counterclockwise direction. The speed was set at 60 mm/s because the speed of 60 mm/s is considered to be natural in ordinary active touches. The 6 lengths and 12 directions made a combination of 72 line segments which were ordered in a pseudo random way, and were presented twice for each of the three surface types. Consequently, the total number of 432 (6×12×2×3) runs of line segment were presented 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 answered the perceived lengths and directions in the following way: just after the wheel stopped, they opened their eyes, looked at the answer board (see Figure 1(d)), and phonated a code number that represents the length and the direction.

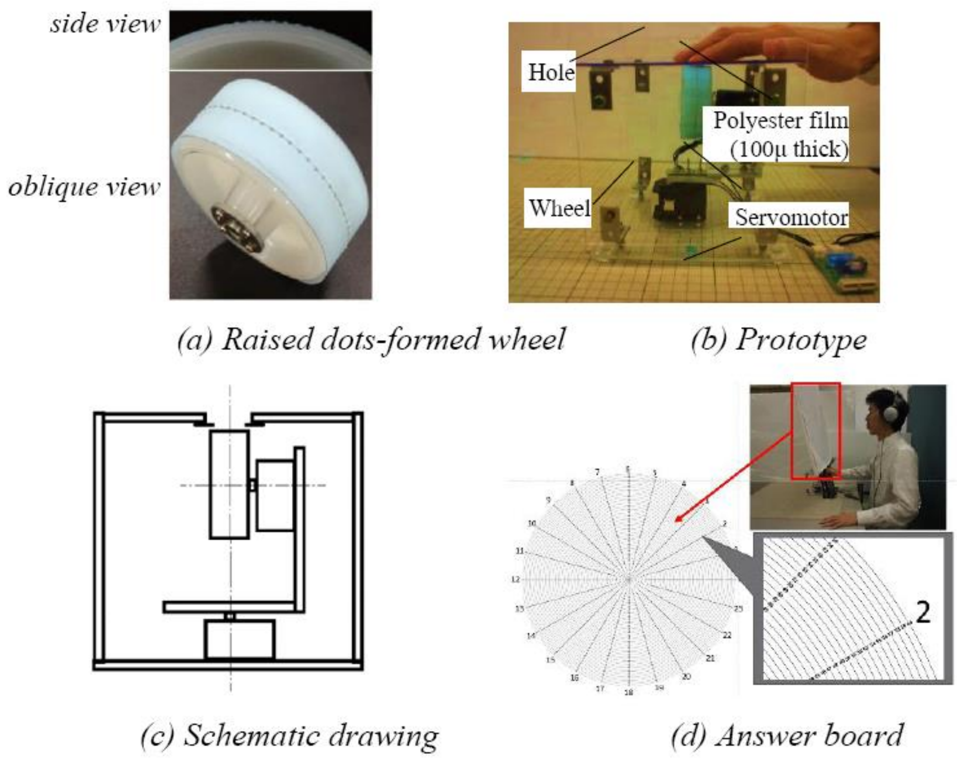
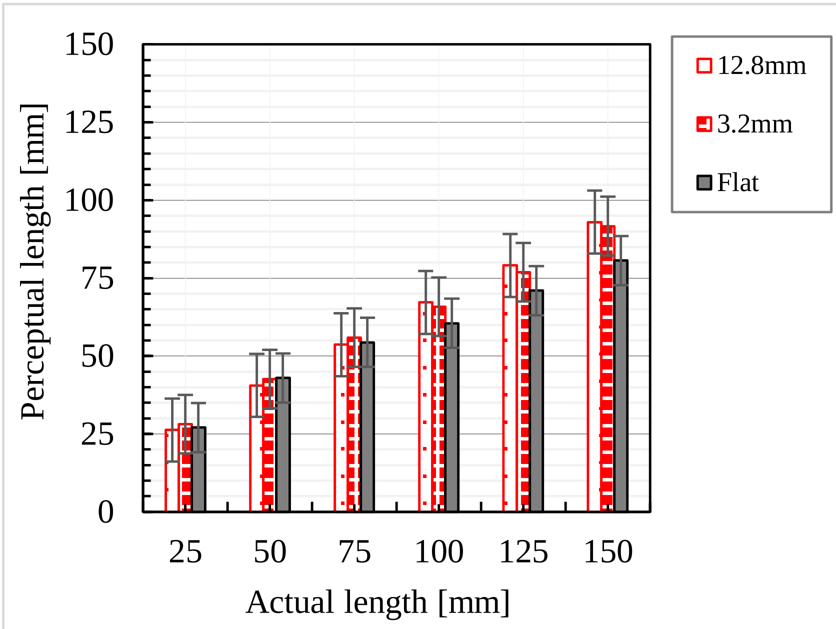


Figure 1. Experimental device.

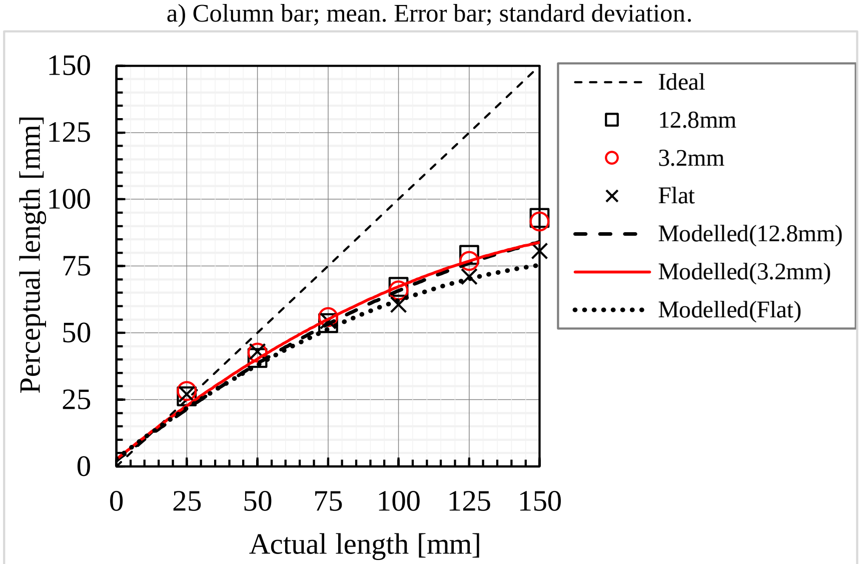
RESULTS

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

The relationships between the perceptual angle errors and the actual angles are shown in Figure 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.



a) Column bar; mean. Error bar; standard deviation.



(b) Symbol; mean. Line; modelled.

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

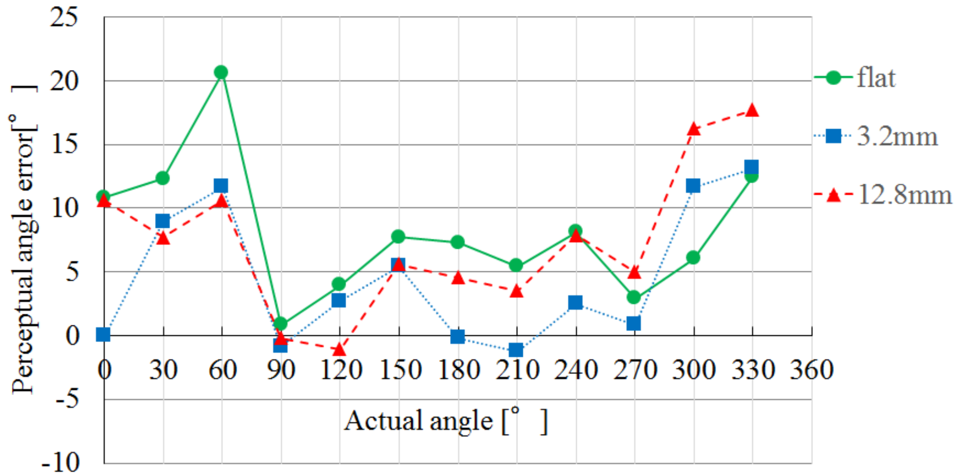


Figure 3. Mean deviation of the perceptual direction for the three surfaces with respect to the directions.

Discussion on perceptual lengths

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

$$l_{model} = \alpha L^{\beta} \tag{1}$$

The length-related nonlinearity can be expressed by parameters β: the further away from the ideal value of 1 the value of β is, the larger the nonlinearity effect is. After taking logarithms of Eq. (1)

$$\ln l_{model} = \ln\alpha + \beta \ln L, \tag{2}$$

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

Next, an ANOVA test was applied to the estimated coefficients (see Table 1(a), (b)). It was concluded that there were significant differences among the three surface levels for each of the coefficients, ln α and β, with the significant level of 0.1%, 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 (see Figure 3). We can conclude from Table 1(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.

Table 1. ANOVA tables

(a) ln α (α, proportional coefficient wrt perceived lengths)

Factor	Level	Mean	Factor effect	Stand. dev.	DOF	Test stats. F-value	Dicision
Surface	12.8mm	0.94	-0.18	0.76			
	3.2mm	1.16	0.03	0.96			
	Flat	1.28	0.15	0.86			
					2	4.1	*
Direction					11	0.79	NS
Interaction					22	0.49	NS
Error				1.01	396		
Global		1.12		1.11	431		

(b) β (exponential coefficient wrt perceived lengths)

Factor	Level	Mean	Factor	Stand.	DOF	Test	Dicision
Surface	12.8mm	0.7	0.044	0.18			
	3.2mm	0.657	0.001	0.21			
	Flat	0.612	0.044	0.17			
					2	4.68	**
Direction					11	1.14	NS
Interaction					22	0.76	NS
Error				0.19	396		
Global		0.656		0.21	431		

(c) Perceived directional errors

Factor	Level	Mean	Factor effect	Stand. dev.	DOF	Test stats. F-value	Dicision
	12.8mm	7.36	0.53	16.05			
Surface	3.2mm	5.12	−1. 71	13.28			
	Flat	8.00	1.17	20.52			
					2	7.75	***
Length					5	0.18	NS
	0°	9.44	2.62	16.7			
	30°	9.65	2.82	18.29			
	60°	13.47	6.64	16.3			
	90°	-0.07	-6.9	12.4			
	120°	1.88	-4.95	19.4			
Direction	150°	6.25	-0.58	18.37			
	180°	3.89	-2.94	13.63			
	210°	2.57	-4.26	17.56			
	240°	6.18	-0.65	16.57			
	270°	2.92	-3.91	10.72			
	300°	11.32	4.49	16.68			
	330°	14.44	7.62	16.99			
					11	19.39	***
Interaction					10	1.93	***
Error				15.98	2579		
Global		6.9		16.92	2591		

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

CONCLUSION

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 a human fingerpad. By integrating the perceived velocities over duration times, line segments can be perceived. The sample size was not enough to conclude definitely, and further examinations are necessary. The followings were tentatively obtained as a pilot study.

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

The experimental equipment used in this study was not compact enough to make use of mouse-interface, and 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 blindness.

In the future, embedding the much smaller size of the wheel into a mouse, the authors would like to construct a prototype of active wheel mice.

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