

Fingertip Slip Illusion with an Electrocutaneous Display

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ABSTRACT

Development of an intuitive pointing device is one of the most significant issues at present in the graphical user interface (GUI) field. Current pointing devices are categorized into two types: the force-based type and the position-based type. The force-based devices require a small input area, but require non-intuitive force-position translation. In contrast, position-based devices are easy to manipulate because of the relatively intuitive position-position translation, but require a large input area. To address the trade-offs between the two device types, we propose a pointing-stick-based input device that uses a newly discovered illusory slip sensation. The slip illusion is induced by presenting a tactile flow generated by an electro-tactile stimulus to the fingertip, while also applying a shear force at the fingertip. This enables us to operate the force-based type of pointer as intuitively as the position-based type. In this paper, we investigate the conditions for occurrence of the illusion, focusing on the shear force at the fingertip, the velocity of the tactile flow, and the directional dependence between the shear force and the tactile flow.

KEYWORDS: electrocutaneous display, haptic illusion, pointing device, slip sensation.

INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Input devices and strategies; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 INTRODUCTION

Pointing devices for graphical user interfaces can be categorized into two types. One type of pointing device, such as a mouse or a touchpad, translates the position of the user's finger to the position of a pointer. The other type of pointing device, such as a joystick or a pointing stick, translates the force of the finger to the speed of the pointer.

There is a well-known trade-off between the two device types. In the position-based input devices, position-to-position translation is quite intuitive, but the device requires a relatively large input area for the finger motion. In contrast, the force-based input devices require a small installation area, but the force-to-position translation is somewhat non-intuitive. For example, it can be difficult to draw even a simple circle.

To resolve the trade-off between intuitive operation and area

requirements, Ikeda et al. presented a small touch pad with a fingerprint sensor [1]. This touch pad translates the motion of a fingerprint to the position of a pointer, so that the device requires only a small installation area. It achieved positional type input with small finger movements, but at the same time this small movement may actually make the operation harder.

The other solution is to use haptic illusion. Some researchers have added tactile feedback to a pointing stick [2][3]. Tsuchiya et al. proposed Vib-touch, which added vibration to a force-based pointing device. By controlling the vibrational pattern in accordance with the applied force, the device can reproduce a variety of tactile sensations, such as force, viscosity and elasticity. However, we have found a new haptic illusion of "slip," which occurs when tactile flow is presented at the fingertip, while a shearing force is also applied to the fingertip (Figure 1). By using this illusion, we aim to resolve the trade-off.

In this paper, we investigated the occurrence conditions for the illusion, focusing on the shear force at the fingertip and the velocity of the tactile flow, and the directional dependency between the shear force and the tactile flow.

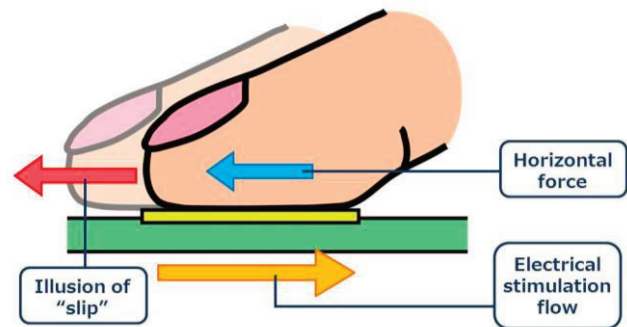


Figure 1. Conceptual image of the slip illusion.

2 SLIP ILLUSION

2.1 Analysis and proposal

To present a subjective feeling of finger motion while the finger does not actually move, we observed the components of haptic sensation related to finger motion. They are divided into two categories. One is the cutaneous sensation, which is because of shear force, frictional vibration, or motion of a pattern on the skin. The other is proprioceptive sensation, which is because of the force and the joint angle. There are therefore roughly five types of cue for finger motion (cutaneous sensation caused by shear force, vibration, and pattern motion; and proprioceptive sensation caused by force and joint angle).

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Our problem here is that we want to present a subjective feeling of finger motion while the finger does not actually move. As we are focusing on the force-based type input device, shear force does exist, and so two of the five cues (cutaneous sensation by shear force and proprioceptive sensation by force) exist. What is essentially lacking is proprioceptive sensation from the joint angle. We must supplement the existing sensation by enhancing the other cues.

One possibility is the addition of vibration as a cue for the subjective feeling of motion, which was done by Tsuchiya et al [2][3]. It is a simple method, but users cannot grasp how far the finger moves accurately, and it requires additional cues such as vision.

Our proposal is to add another cutaneous cue, using the motion of a pattern on the skin. A similar method was proposed by Pasquero and Hayward [4]. They showed that cutaneous motion of a pattern presented on a finger helps in scrolling and task selection. As their main concern was the task completion time, the subjective feeling was not reported. In our case, we focus on inducing an illusory finger motion, which has a larger potential application area.

2.2 Preliminary observations

To represent the cutaneous motion of a pattern, we used an electrocutaneous display (Figure 2, and described in detail in the next section) [5], and a commercially available pin type mechanical tactile display (KGS Corp., DotView DV-2). A single line was presented and moved while participants (the authors) put their finger on the display and generated a shear force.

In this preliminary trial, we found two interesting phenomena. The first was that when we used an electrocutaneous display, a “constant slip” sensation occurred, as we expected. However, when we used a mechanical tactile display, this illusory sensation was not reported. We believe that the flatness of the electrocutaneous display surface helped the illusion, while the non-flat surface of the mechanical tactile display might have hindered the illusion.

The other phenomenon was that when shear force was not applied, the illusion did not occur. The shear force or deformation of the skin by the shear force therefore seems to be a main contributing factor to the illusion.

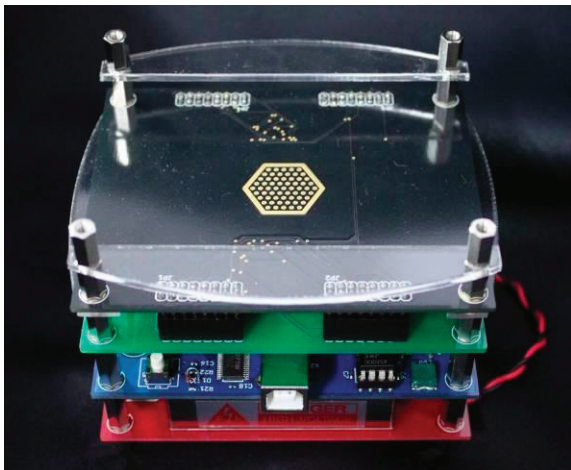


Figure 2. Electrocutaneous display [5]

3 EXPERIMENT 1: SHEAR FORCE MEASUREMENT DURING TACTILE FLOW PRESENTATION

We conducted an experiment to verify that the proposed method can present a pseudo-slip sensation. A moving pattern with variable velocity was presented, and the participants were asked to exert a shear force until they subjectively felt “slip”. Our expectation was that the shear force should decrease because of the slip illusion.

3.1 Experimental system

3.1.1 Electrocutaneous display

We used an electrocutaneous display, as shown in Figure 2. The display has 61 electrodes arranged hexagonally. The distance between each electrode is 2.0 mm, and the electrode diameter is 1.0 mm. The pulse amplitude used was 0.0–3.0 mA, the pulse width was 0.05 ms, and the pulse frequency was 60 pps (pulses per sec).

A moving line pattern with variable speed was presented, as shown in Figure 3. During the experiment, the subjects controlled the pulse amplitude freely, so that the elicited sensation remained clear.

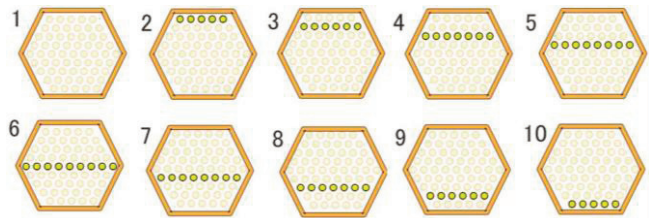


Figure 3. Electrical stimulation flow (1 to 10)

3.1.2 Measurement of shear force

The electrocutaneous display was placed inside a hard case with four pressure sensors (NITTA Corp., FlexiForce), with one placed on each side wall. When the participants applied a shear force, it was measured using the sensors (Figure 4). In this experiment, we used one pressure sensor attached to the front side.

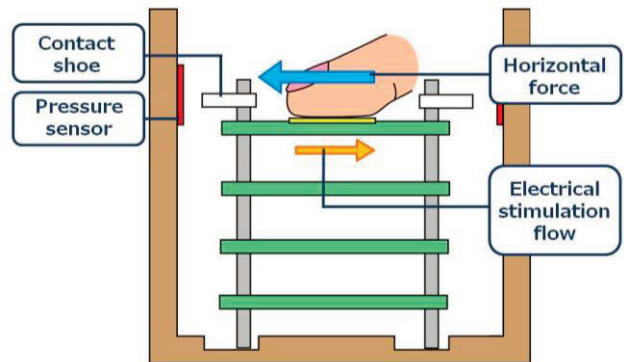


Figure 4. Measurement of shear force

3.2 Experimental conditions

The participants closed their eyes during the measurements. We prepared four velocity conditions (0, 10, 30, and 50 mm/sec). The 0 mm/sec condition required no electrical stimulation. The participants answered 5 times for each condition, and thus the total number of trials was 20 (=4×5). Three participants (2 males, and 1 female, aged 22–23 years old) took part in the experiment.

3.3 Experimental procedure

First, the participants placed their right index fingers on the electrodes. While the display presented electrical stimulation flow to the finger, the participants gradually distorted their fingers forward until they perceived the slip sensation. When the participants perceived the slip sensation, they pressed a button, and the shear force at that moment was recorded. Figure 5 shows the appearance of the experiment.



Figure 5. Appearance of experiment 1

3.4 Results

Figure 6 shows the experimental results. The horizontal axis gives the velocity of the electrical stimulation; and the vertical axis shows the normalized shear force. We subtracted the force at 0 mm/s from all experimental data. For example, under the 10 mm/sec condition, participants perceived a slip sensation with 3.14 N smaller force than in the 0 mm/sec condition. Error bars indicate the standard deviations.

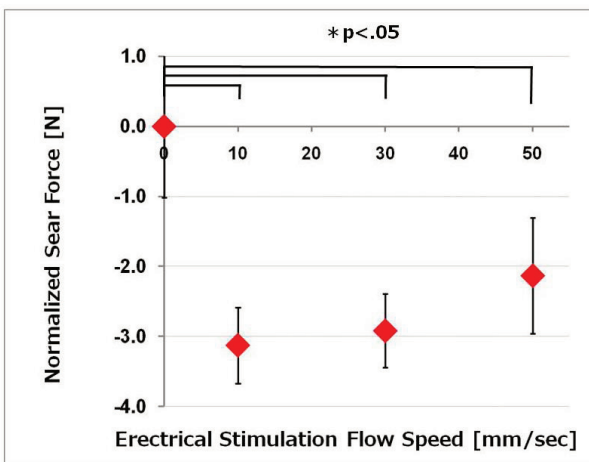


Figure 6. Experimental results

3.5 Discussion

From the results of analysis of variance, the effects of the flow velocity were found to be significant (ANOVA, $F(3, 6)=10.43$; $p<0.01$). For all of the 10, 30 and 50 mm/sec conditions, the required shear force was lower when compared to the 0 mm/sec condition. This result indicates that the participants perceived the illusory slip sensation when they were presented with both a moving electrical stimulation to the fingertip and finger distortion.

All participants also reported that they felt continuous motion of their fingers, although their fingers were actually not moving.

4 EXPERIMENT 2: SHEAR FORCE MEASUREMENT WITH CONSTANT VERTICAL FORCE

The results of experiment 1 imply that a motion speed of around 10 mm/sec is optimal, while speeds of less than 10 mm/sec were not observed. In the next experiment, we observed the details around and below 10 mm/sec.

Also, in experiment 1, we did not control the vertical force of the finger, which in fact greatly affects the slip conditions. Because it is possible that the shear force was reduced simply because the vertical force was attenuated, the next experiment was carried out under constant vertical force conditions.

4.1 Experimental system

To feed back the vertical force information to the participants, we placed the experimental system on an electronic force balance (Figure 7).



Figure 7. Experimental system

4.2 Experimental conditions

Six participants (4 males and 2 females, aged 21–28 years old) took part in the experiment. We presented a moving line as in experiment 1, with 11 different velocities (from 0, 2, 4 ... 20 mm/sec). As before, no electrical stimulation flow was applied for the 0 mm/sec condition. For each speed, the shear force measurement was carried out three times. The total number of trials was 33(=11×3).

4.3 Experimental procedure

First, the participants pushed their right index finger on to the display while watching the value of the electronic force balance. They were asked to maintain a vertical force of between 1 N and 3 N during the measurements. Next, the electrocutaneous display presented the tactile flow to the finger, and the participants gradually distorted their fingers forward until they perceived the slip sensation. When they felt the slip sensation on their fingers, they pressed a button, and the shear force was measured. The participants repeated this trial 3 times for each speed condition. If the vertical force was not kept between 1 N and 3 N, the subject restarted the trial.

4.4 Results

Figure 8 shows the experimental results. The vertical axis, horizontal axis, and error bars are the same as those in Figure 6.

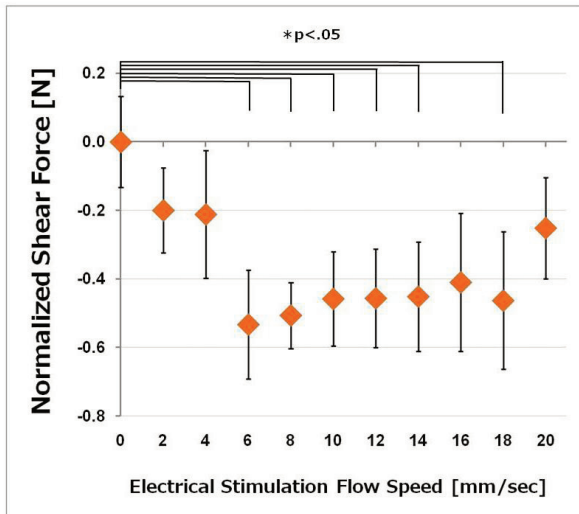


Figure 8. Experimental result 1

4.5 Discussion

The experimental results showed that the shear force was attenuated. Results of analysis of variance showed that the velocity of the tactile flow was significant (ANOVA, $F(11, 55)=1.94$; $p<.05$). The t-test revealed that the results for 0 mm/sec vs. 6,8,10,12,14,18 mm/sec of electrical stimulation flow were significant (independent t-test; $p<0.05$), and the minimum point for the shear force is 6 mm/sec. Therefore, by presenting both a moving tactile flow to the fingertip and the shear force, the required force to perceive the slip sensation was clearly attenuated.

5 EXPERIMENT 3: DIRECTIONAL DEPENDENCY

When considering the application of the illusion to the pointing device, the slip sensation should occur in any direction. In this experiment, we tested whether the slip sensation was evoked in four different directions (up, down, left, right) (Figure 9).

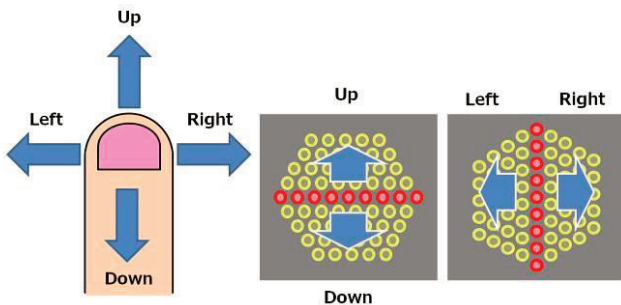


Figure 9. Direction of shearing force (left) and tactile flow by electrical stimulation (Right)

5.1 Experimental device

The experimental device was the same as that in experiment 2. To measure the four-way shear forces, we used four force sensors attached to the inner walls of the case.

5.2 Experimental condition

An electrical stimulation flow at 10 mm/sec was presented with five directional conditions (up, down, left, right, and nothing, i.e. no electrical stimulation). Four directional conditions for the shear force were given (up, down, left, right). For each combination, the measurement was carried out three times. The total number of trials was 60 ($=5 \times 4 \times 3$). Six participants (4 males and 2 females, aged 21–25 years old) participated in the experiment. Figure 10 shows the appearance of experiment 2.



Figure 10. Appearance of experiment 2

5.3 Experimental procedure

The procedure for the experiment was the same as that in experiment 2. After three measurements using the same directional conditions (direction of the flow and direction of the shear force), the participants changed the direction of the shear force. Then, the direction of the tactile flow was changed and the measurements were conducted again in the same way.

5.4 Results

The experimental results are shown in Table 1. The values of each cell show the normalized shear force, in which the test values were reduced by subtraction of the values of the 0 mm/sec case. The force units used are newtons. A negative value (blue cell) means that a lower shear force was required to perceive the slip sensation than with no electrical stimulation flow, indicating that the slip illusion was induced.

Table 1. Experimental results 2

Normalized Shear Force [N]		Direction of Shear Force			
		Up	Down	Left	Right
Direction of Electrical Stimulation	Down	-0.50	-0.24	0.05	0.12
	Up	-0.32	0.27	0.56	-0.43
	Right	0.27	0.24	-0.60	-0.94
	Left	0.03	0.52	-0.67	-0.74

5.5 Discussion

Variance analysis in experiment 3 indicated that interaction between the fingertip shear force and the electrical stimulation flow was significant (ANOVA, $F(12, 60)=6.96$; $p<0.01$).

Looking back at experiments 1 and 2, the slip sensation occurred when the finger was distorted "upwards" and the electrical stimulation flow was presented as "downwards (i.e., opposite direction to the finger shear force)". We therefore expected that the direction of the finger shear force and the electrical stimulation flow must be in opposite directions.

However, the results indicated that when the direction of shear force was "downward", the direction of the electrical stimulation flow was better in the "downward (same direction)" case than in the "upward (opposite direction)" case. However, when the direction of the shear force was left or right, the direction of the electrical stimulation may be either right or left.

These results may indicate that the tactile flow direction was sometimes misinterpreted as being in the opposite direction when combined with the shear force. Further study is necessary for this experiment.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we observed a new tactile illusion of slip, where a combination of electrical stimulation flow and finger shear force was applied. The sensation is continuous while the finger remains stationary.

We conducted two experiments to validate the illusion. The results clearly showed that the user felt the slip sensation with less shear force than under the actual slip conditions, suggesting the existence of a slip illusion.

We also conducted an experiment to see if the illusion occurs in other directions. The results remain unclear, but seem to indicate that the tactile flow direction was sometimes misinterpreted as being in the opposite direction when combined with the shear force. Further study is necessary to explore this point.

Our future work includes an in-depth study of the last experiment, and fabrication of the pointing device and its evaluation.

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