Line-Drawing Presentation Strategy with an Active-Wheel Mouse
After-Recognition-Go Strategy vs. While-Perceiving-Go Strategy

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Abstract—**The objective of this study is to examine presentation strategies for line-drawing recognition by using a finger-tactile interface, i.e., an "*active-wheel mouse*," which can present slippages to users via users' fingertip skin. The interface embodies an active wheel being rotatable in any direction, with any speed and for any time-duration. Through the slippage stimuli, the interface can present stroke motions with any direction, velocity and length to users. In this paper, we proposed two kinds of presentation strategies, called an "*after-recognition-go strategy*" and a "*while-perceiving-go strategy*" for single-stroke line-drawings. The former strategy employs an open-loop control scheme with no-feedback, and the latter one does a closed-loop control scheme with online-feedback. Next, the perceptual performances were compared between the two strategies via a psychophysical experiment, in which single-stroke line-drawing consisting of up to three straight-line segments were recognized. In the experiment, the length, direction, and velocity were randomly chosen within 50 - 150 mm, 0 - 359 deg, and 12 - 50 mm/s, respectively. In order to examine performance, we introduced objective and subjective evaluation values. As for the objective evaluation variables, the mean and the variance were calculated for (root mean squared errors (RSMEs) of the motion-related variables such as lengths, angles, and mean-velocities and for RSMEs of the time-durations, while, as for the subjective evaluation variable, questionnaire survey was conducted. As a result of the experiment, in comparison with the while-perceiving-go strategy, the after-recognition-go strategy was recommended for further development of the finger-tactile interface, based on the significant reduction of time-duration and on no mental-fatigue reports in a questionnaire: in the case of for the after-recognition-go strategy, the means and the standard deviations of RSMEs were -19.3 ± 40.7 mm (for length), 5.0 ± 15.9 degree (for angle), and 9.2 ± 22.3 mm/s (for mean-velocity).**

Keywords-fingerpad; tactile sensation; slippage; interface; multiple strokes; presentation and recognition strategy.

I. INTRODUCTION

Human beings get a large amount of information via vision from the surroundings. Therefore, once we lose our vision, we shall suffer inconveniences in daily life. Many assistive devices were developed as an alternative. Visually impaired persons utilize sensations other than the vision such as skin-sensations and proprioceptive sensations.

This paper describes an extended version of the previous paper by Nomura et al. [1], and the objective is to develop an operational strategy by utilizing our developed tactile-device, i.e., an active-wheel mouse by Nomura et al. [2] [3].

Some handy-and-portable devices have also been proposed for character presentation and walking route guidance. Tsuda et al. [4] and Causo et al. [5] proposed vibrotactile stimulations-based interface for instructing arm motions. Norman et al. [6] and Gleeson et al. [7] proposed skin-stretch-based interface for instructing planar hand motion guidance. Ion et al. [8] proposed a tactile display that drags a physical tactor across the skin in 2D for instructing geometric shapes or characters. Tsagarakis et al. [9] proposed a slippage display composed of two cone-shaped rollers for instructing 2D directions. Moscatelli et al. [10] and Webster et al. [11] proposed a ball rotation-based mechanism for instructing 2D slippages. Provancher et al. [12] proposed a skin stretch-based 1D directional interface. Gwilliam et al. [13] proposed a skin stretch-based tactile display in conjunction of a joystick-based force feedback system. Koslover et al. [14] combined a skin stretch-based tactile display with vibrotactile and voice guidance system. They can present motion information by using tactors, and, yet, there are some tasks to be solved: ① the number of physical properties to be presented was restricted in such a way that only motion direction can be presented, ② the working area was also restricted to several millimeters.

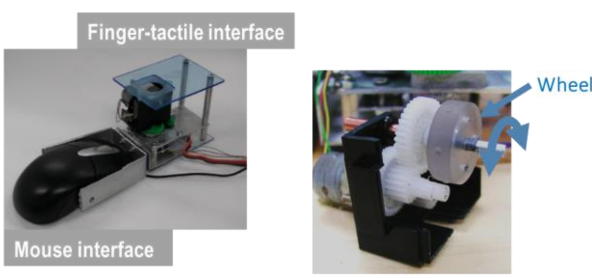
The remainder of the paper is structured as follows. Section II outlines our developed active-wheel mouse, and Section III introduces two line-drawing-stroke presenting strategies to be compared: one is an after-recognition-go strategy, and the other a while-perceiving-go strategy. Next, two experiments follow the system descriptions. Practically, in Section IV, perceptual characteristics of simple patterns of 1-, 2-, and 3-strokes are presented as a basic study, and, in Section V, those for complicated patterns of 5-strokes are presented as an example of practical applications. The paper closes with a conclusion and remarks for further developments.

II. Active-Wheel Mouse, a Finger-Tactile Interface

A. Apparatus

We have previously presented an active-wheel mouse [2][3]: a specific mouse interface, at the front of which a finger-tactile interface is attached as shown in Figure 1. A wheel is embedded in the finger-tactile interface, and the diameter and thickness of the wheel are 20 mm and 6 mm, respectively (see Figure 2). In particular, it is noted that raised dots in this work are formed on the wheel peripheral surface to enhance slippage perceptual performance as well as Nomura et al. [2][3]: as for the raised dots, the height is 0.5 mm, and the diameter of the bottom circle is 1.7 mm. The dot interval was designed as 10.5 mm so that the dots appear one by one on the finger-pad: it was concluded that the one-by-one appearance made the slippage perception easier as in Nomura et al. [15][16]. The finger-tactile interface rotates a wheel around the wheel central axis in any horizontal direction by two stepping motors (M15SP-2N and M25SP-6NK (Mitsumi Electric Co., LTD., Tokyo, Japan) (see Figure 3). Installed in a wheel rotating part, the former stepping motor rotates the wheel, while the latter stepping motor swivels the wheel rotating part. The rotation and swivel result in a velocity and direction of wheel slippage on finger-pad, respectively. The velocity together with the time duration decides slippage length.

Holding the mouse body and touching their finger-pad on the rotating wheel periphery from above, users accept slippage stimulus (see Figure 3). Here, note that the circumference of the wheel is circular, and the shape of the slippage itself is not a straight line, but an arc. Since it is not easy for us to perceive the arc-shaped slippages, users were instructed not to perceive the slippage as an arc segment, but as a straight-line segment.



(a) Active-wheel mouse (b) Wheel-rotating part.

Figure 1. Active-wheel mouse.

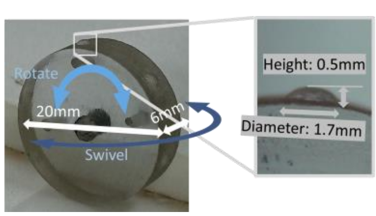
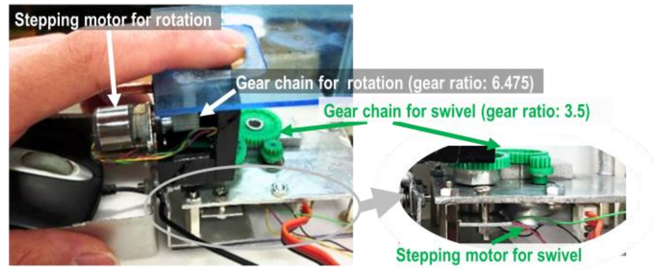
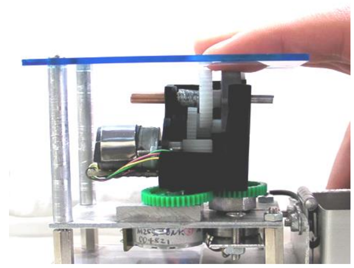


Figure 2. Configuration of wheel: raised dots are formed on the wheel periphery.



(a) Stepping motor and gear chain for rotation and those for swivel.



(b) Side view of the finger-tactile interface.

Figure 3. Fnger-tactile interface in use.

III. Line-Drawing-Stroke Presenting Strategies

Two control schemes were applied as line-drawing-stroke presenting strategies: one is off-line control scheme and the other is on-line control scheme. The off-line control scheme is represented by a line-drawing-stroke presenting strategy called “after-recognition-go strategy”, and the on-line one by that called “while-perceiving-go strategy.” The two strategies will be explained in the following. In the following, the word “a line drawing” represents a kinked line consisting of straight-line segments, and the word “a stroke” represent a dynamic motion corresponding to each of the straight line-segments.

A. After-Recognition-Go Strategy

The first strategy for presenting line-drawing-strokes, that is, the after-recognition-go strategy, is carried out in the following procedure.

[Step 1] Subjects hold the mouse in their right hand. Then, they touch their index finger-pad on the wheel from above.

[Step 2] Finger-tactile interface swivels the rotating unit in a given direction. Next, it rotates the wheel with a given velocity and angle. While accepting the slippage stimulus during the rotation (see Figure 4①), the subjects recognize the stimulus as a straight line motion (see Figure 4 ②.)

[Step 3] Just after the wheel rotation finished, the subjects drag the active-wheel mouse so as to reproduce their recognized motion (see Figure 4 ③).

[Step 4] The subjects memorize the drag motion as a stroke (see Figure 4 ④).

[Step 5] Just after memorizing the stroke, the subjects send a signal by pressing a button with the left hand.
[Step 6] Return to [Step 2] till all the strokes are memorized.

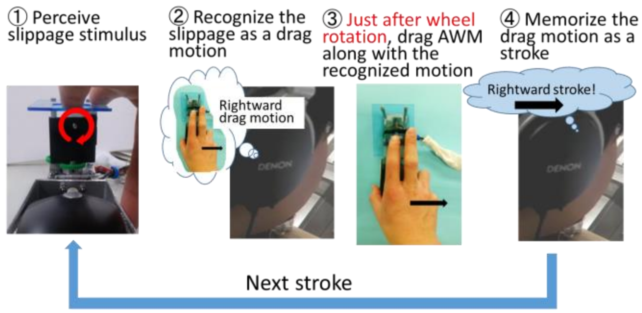


Figure 4. "*After-recognition-go strategy*" for line-drawing-stroke teaching & learning: the acronym, AWM, represents the active-wheel mouse.

B. *While-Perceiving-Go Strategy*

In this section, the second presenting strategy for line-drawing-strokes, i.e., the while-perceiving-go strategy, is explained.

[Step 1] Subjects hold the mouth in their right hand. Then, he touches their index finger-pad on the wheel.
[Step 2] The finger-tactile interface swivels in a specific direction. At a time, the wheel rotates with another specific velocity under a positional feedback control scheme. That is, as shown in Figure 5, the direction is given by the direction from the present position to a sub-goal (the point between two consecutive segments) of a desired locus. The velocity is given by the desired velocity at the proximal point on a desired trajectory.
[Step 3] While accepting the slippage stimulus, the subjects recognize the stimulus as a straight line motion not of the desired stroke, but that of a stroke to be headed for the sub-goal, and drag the active-wheel mouse along with the recognized motion (see Figure 6 ① and ②).
[Step 4] The subjects memorize the motion from the starting to the arrival point as a stroke (see Figure 6 ③).
[Step 5] Just after memorizing the stroke, the subjects send a signal by pressing a button with their left hand.
[Step 6] Return to [Step 2] till all the strokes are presented.

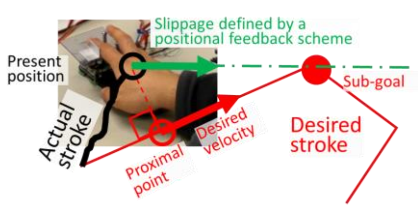


Figure 5. A positional feedback scheme employed in "*while-perceiving-go strategy* " as a stroke presentation method. The slippage velocity is given as the desired velocity at the proximal point on a desired trajectory.

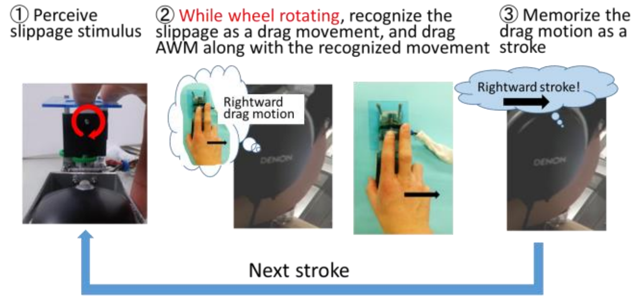


Figure 6. "*While-perceiving-go strategy"* for stroke presentation. The step ② in this figure can be regarded as an on-line integration of the steps ② and ③ in Figure 4, i.e., the "*after-recognition-go strategy."*

IV. Basic Experiment

A. *Experimental Method*

1) *Experimental conditions*

In order to confirm a potential of the "after-recognition-go strategy" as a drawing presentation, a line drawing learning experiment was carried out.

Five healthy right handed males in their 20s (22~24, 22.6 (mean) ± 0.9 (SD)) participated in the experiment. We have prepared six line-drawings that consisted of straight lines from single stroke to three strokes as shown in Figure 7. All the strokes were of the uniform motion, i.e., constant-velocity straight line motion. The factors and the factor levels are shown in Table I, and, in the trials, the levels for each of the presentation-strategy factor and the stroke-number factor were given by a pseudo-random order.

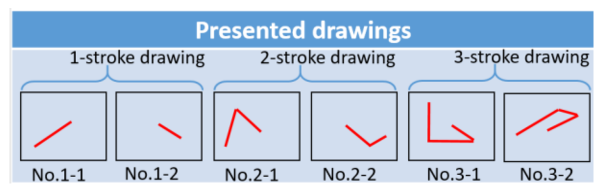


Figure 7. Presented drawings used for a line drawing learning experiment.

TABLE I. Factors and factor levels in Basic Experiment.

Factor	Level
Subject	5 males
Presentation strategy	While-perceiving go, After-recognition go
Presented line drawing	6 in total: 2 patterns with 1-stroke, 2-strokes, and 3-strokes, respectively
Length	Randomly chosen between 50 - 150 mm
Speed	Randomly chosen between 12 - 50 mm/s
Direction	Randomly chosen between 0 - 359 deg.

2) *Procedure of while-perceiving-go strategy*

In the case of the while-perceiving-go strategy, targeted *n*-stroke line-drawings were presented through the locus and the velocity block. Each of the blocks is conducted, stroke by stroke, along with the order of a stroke of a target line-drawing (see Figure 8 (a)).

[1st half: locus block]

① Perception & reproduction process: in the order of a stroke of a target line-drawing, while accepting a slippage and recognizing a locus, subjects reproduce their recognized locus (see Figure 6).

② Reproduction process: they reproduce all their recognized *n*-stroke loci.

The pair of ① and ② is called "a locus sub-block," and is iterated *n*-times for the *n*-stroke line-drawing.

[2nd half: velocity block]

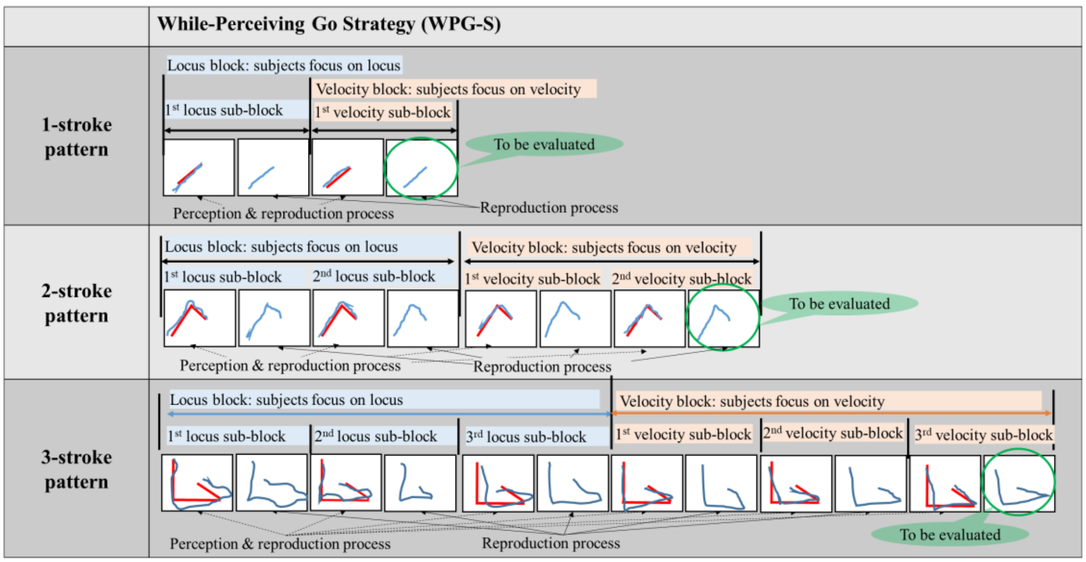
① Perception & reproduction process: in the order of a stroke, while accepting a slippage and recognizing a velocity, subjects reproduce a stroke with their recognized velocity, remembering the corresponding locus memorized in the 1st half.

② Reproduction process: they reproduce all their recognized multi-strokes.

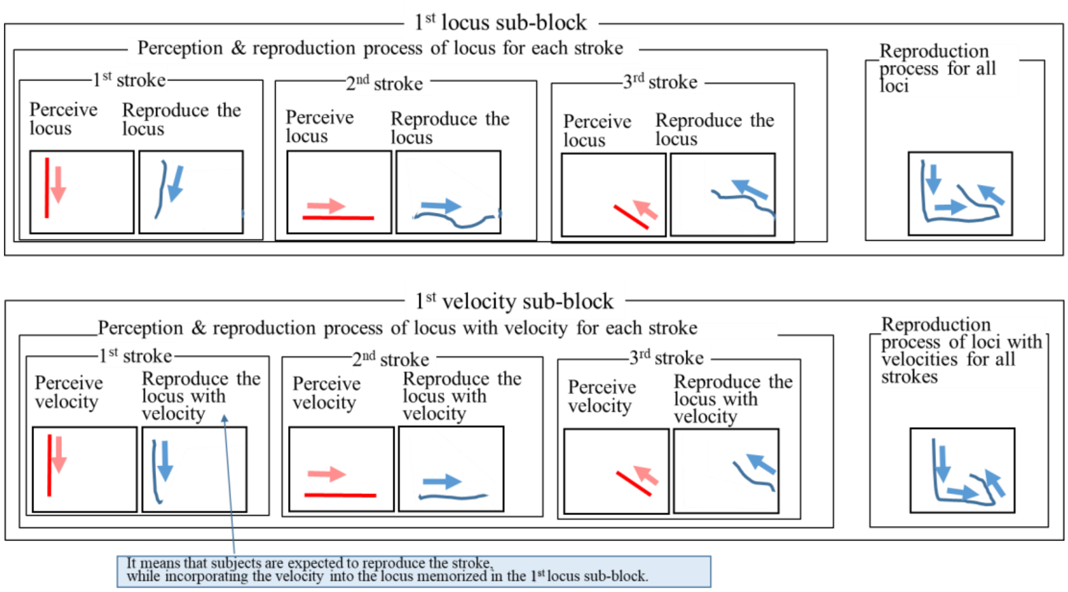
The pair of ① and ② is called "a velocity sub-block," and is iterated *n*-times for the *n*-stroke line-drawing.

3) Procedure of after-recognition-go strategy

In this strategy, targeted *n*-stroke line-drawings were similarly presented by the above explained procedure except for the perception & reproduction process. Figure 8 (b) shows an example of the process. Just after a locus and velocity have been presented for each stroke, subjects reproduce the locus and velocity (see Figure 4).



(a) Procedure of while-perceiving-go strategy for the three line-drawings of 1-, 2-, and 3-strokes: red lines show desired loci; blue lines do reproduced loci.



(b) Detail of the 1st locus subprocess and the 1st velocity subprocess for a line drawing of 3-strokes in the after-recognition-go strategy.
Figure 8. Organization of experimental procedure.

4) *Evaluation values*

We obtained secants from actual strokes: the word “secant” represents the line segment connected from a start to an end point. Next, we defined evaluation values by the differences of the lengths as well as the angles between the desired strokes and the secants of the actual strokes for each of the strokes (see Figure 9). That is,

$$\Delta l = l_{secant} - l_{desired} \tag{1}$$

$$\Delta \theta = \theta_{secant} - \theta_{desired} \tag{2}$$

In addition, the velocity difference of v_{mean} from $v_{desired}$ was also introduced as the other evaluation value:

$$\Delta v = v_{mean} - v_{desired} \tag{3}$$

where v_{mean} is the mean velocity of the varying actual velocity, and $v_{desired}$ is the desired velocity.

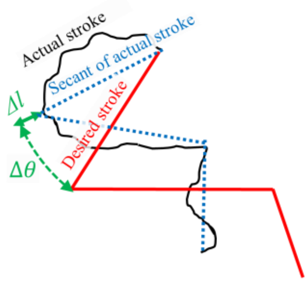
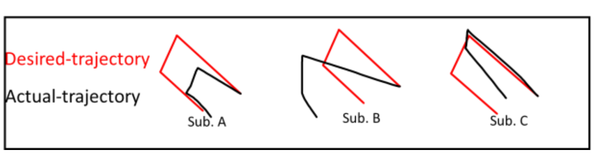


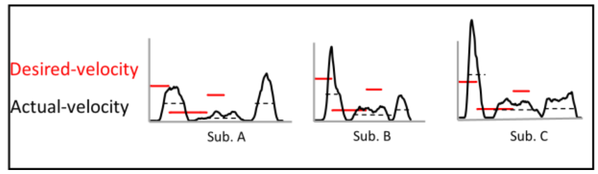
Figure 9. Evaluation values: the differences of lengths and angles between the secants of actual trajectory and the desired trajectory.

B. *Experimental Results*

Taking examples of the three-stroke drawings, loci and time-varying velocities by the after-recognition-go strategy are shown in Figure 10 (a) and (b), respectively. As other examples, loci using either the after-recognition-go strategy or the while-perceiving-go strategy are shown in Figure 11 (a) and (b), respectively. It can be seen that the reproduced lengths and angles as well as the velocities fairly differ from the presented ones, but, yet, rough geometrical features were reproduced. The distortion is considered to mainly come from individual differences in the relationship between the presented and reproduced lengths. The errors of lengths, angles, velocities were evaluated by the root mean squared errors (RSME) and are shown in Figure 12. These are discussed in the following subsection.



(a) Some recognized loci.



(b) Some recognized velocity variations in relationship to time.
Figure 10. Some examples of the recognition with three-stroke drawings.

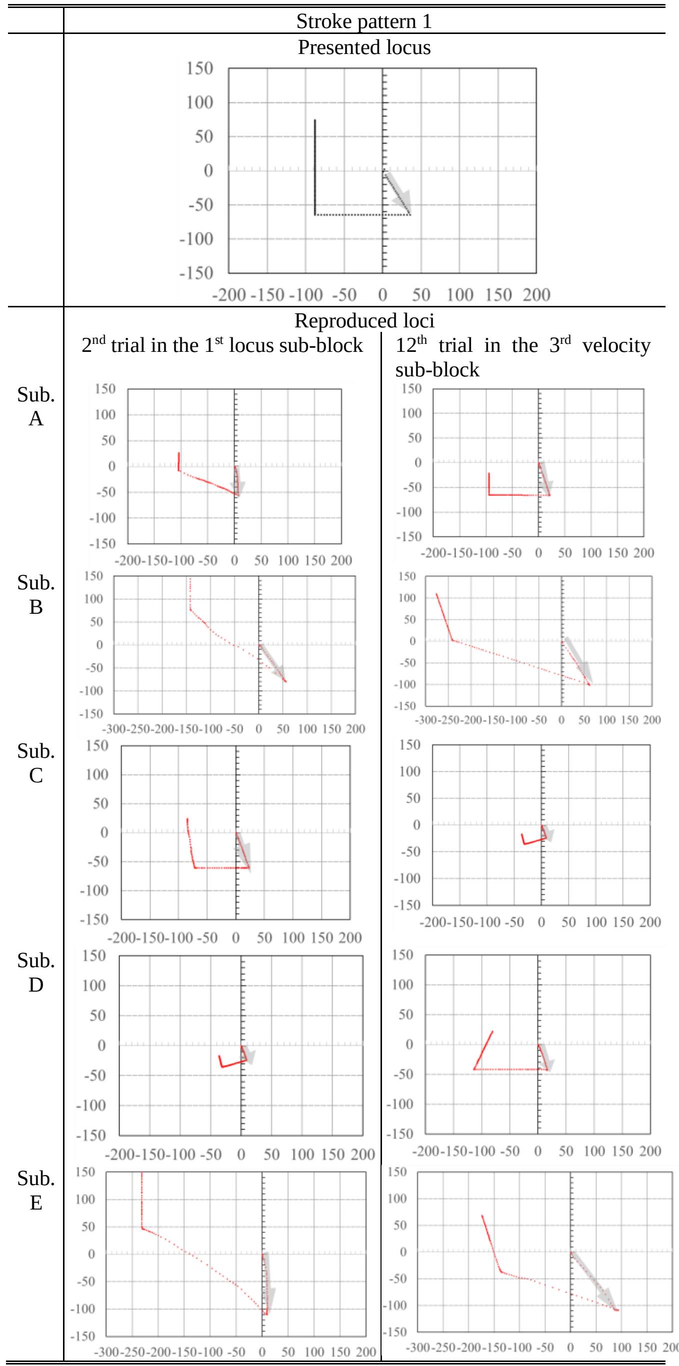


Figure 11. (a) Loci reproduced by the five subjects for the stroke pattern 1. using after-recognition-go strategy. The light gray-colored arrows show the locus is of the first stroke.

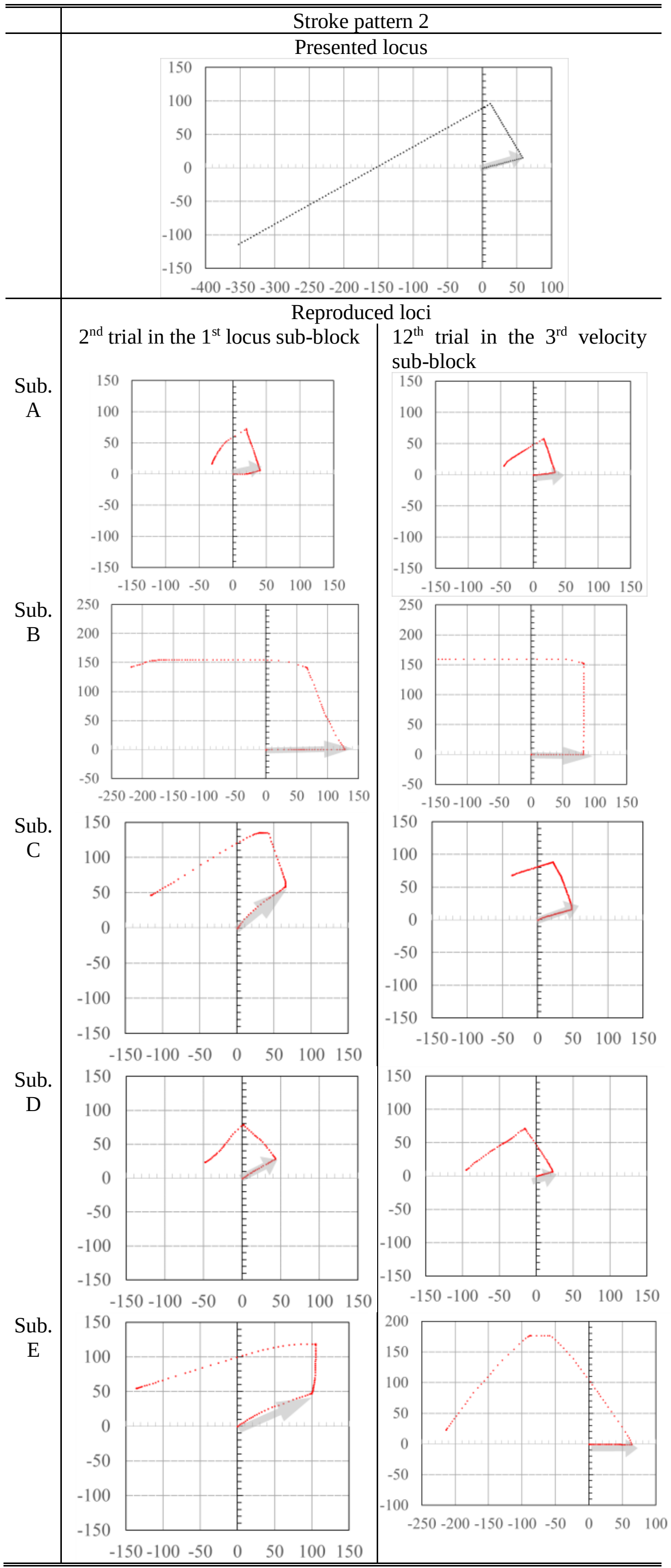


Figure 11. (b) Loci reproduced by the five subjects for the stroke pattern 2. using after-recognition-go strategy.

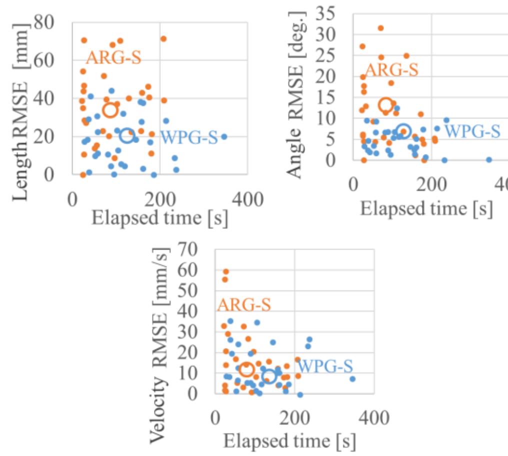


Figure 12. Root mean squared errors with respect to the recognized length, angles, and velocities for multi-stroke drawings: the acronym, ARG-S, represents the after-recognition-go strategy, and WPG-S does the while-perceiving-go strategy.

C. *Discussion*

1) *Statistical t-test on population means of the errors*

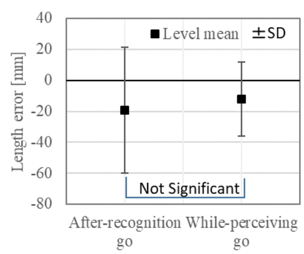
First, based on a statistical *t*-test, the population means of the errors of the lengths, angles, and velocities from the presented ones, as well as those of the time duration of the reproduced strokes are compared between the after-recognition-go strategy and the while-perceiving-go strategy: the population means of the errors are regarded as systematic errors. As a result, we cannot find significant differences between the after-recognition-go strategy and the while-perceiving-go strategy (see Figure 13 (a-1), (b), and (c), respectively, and Table II). On the other hand, with respect to the per-stroke time duration, the after-recognition-go strategy was superior to the while-perceiving-go strategy by a significant level of 1 %: "a test statistic t of 2.70" > "a critical value $T^{29,28}_{0.01}$ of 2.00" as shown in Figure 13 (d): $T^{29,28}_{0.01}$ and $F^{59,58}_{0.001}$ in the following subsection represent $T^{DOF1,DOF2}_{significant\ level}$ and $F^{DOF1,DOF2}_{significant\ level}$, respectively.

2) *Statistical F-test on variance ratios of the errors*

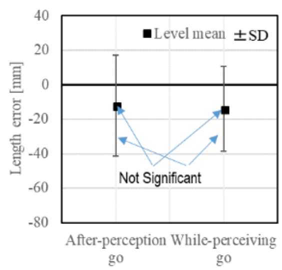
Second, in order to examine random errors, the variances of the errors between the after-recognition-go strategy and the while-perceiving-go strategy were tested by using another statistical *F*-test for variance ratios. The after-recognition-go strategy was inferior to the while-perceiving-go strategy by a significant level of 0.1 % with respect to the variances of the reproduced lengths and angles: "a test statistic F of 2.94" > "a critical value $F^{59,58}_{0.001}$ of 2.40 with respect to the reproduced lengths"; "a test statistic F of 3.03" > "a critical value $F^{59,58}_{0.001}$ of 2.40 with respect to the reproduced angles". Yet, there was no significant difference between the variances of the reproduced velocities.

Here, taking notice of a personal variation in the slippage-perception characteristics, i.e., a nonlinear relationship between the perceived and presented slippage length [3][15][16] (see Figure 14), we have introduced a correction measure to compensate the nonlinear relationship. That is, the relationships between the presented and mean-perceived length were preliminarily calibrated for each of the subjects. Then, based on the calibrated relationships, the reproduced lengths were corrected, subject by subject (see Figure 13 (a-2) and Table III). Consequently, the errors in the after-recognition-go strategy were more effectively reduced than those in the while-perceiving-go strategy, and the significant difference in the length error variances between both strategies has disappeared. As a result, there was no significant difference in the length errors not only for means but also for variances.

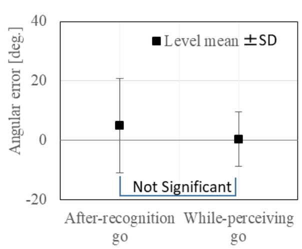
Incidentally, with respect to the per-stroke time-duration, the after-recognition-go strategy was, vice versa, superior to the while-perceiving-go strategy by a significant level of 0.1 %: a test statistic F of 5.57 > a critical value $F^{29,28}_{0.001}$ of 3.34.



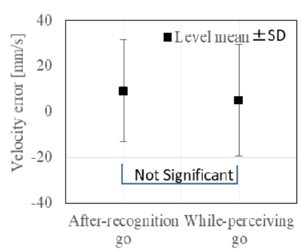
(a-1) Raw length data.



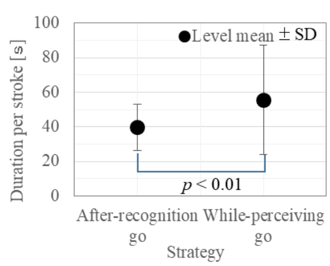
(a-2) Length data corrected by personal relation between perceived and presented length.



(b) Raw angle data.



(c) Raw velocity data.



(d) Raw time-duration per stroke data.

Figure 13. Root mean squared errors with respect to the recognized length, angles, and velocities for multi-stroke drawings.

TABLE II. MEAN AND STAN. DEVI. OF RAW LENGTH DATA.

	After-Recognition Go Strategy		While-perceiving Go Strategy	
	Mean	Stan. devi.	Mean	Stan. devi.
Length [mm]	-19.3	40.7	-12.2	23.7
Angle [deg]	5.0	15.9	0.4	9.1
Velocity [mm/s]	9.2	22.3	5.0	24.3

TABLE III. MEAN AND STAN. DEVI. FOR LENGTH DATA CORRECTED BY PERSONAL RELATIONS BETWEEN PERCEIVED AND PRESENTED LENGTH..

	After-Recognition Go Strategy		While-perceiving Go Strategy	
	Mean	Stan. devi.	Mean	Stan. devi.
Length [mm]	-12.1	29.3	-13.9	24.5

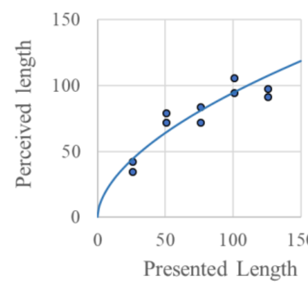


Figure 14. A nonlinear relationship between the perceived and presented slippage length. We have a tendency: when longer slippages are presented, we perceived shorter; while when shorter slippages are presented, we perceived longer. The relationship differs from person by person.

3) *Subjects' report*

We collected opinions with how subjects felt the experiment from a viewpoint of mental impression: all the subjects reported that they felt much more exhausted in the while-perceiving-go strategy than in the after-recognition-go strategy near the sub-goals. It suggests that humans are not able to catch up with the closed-loop feedback-control scheme.

4) *Comprehensive evaluation*

The performances described in the preceding subsections are comprehensively summarized as follows. First, the errors of the corrected lengths showed no significant difference both in means and in variances. Second, the errors of the angles showed no significant difference in means, although they showed significant difference in variances. Third, the errors of the velocities showed no significant difference both in means and in variances. Thus, from the viewpoint of motion, there was almost no significant difference. On the other hand, with respect to the time-duration per stroke, the after-recognition-go strategy showed significant superiority to those in the while-perceiving-go strategy. In addition, the subjects reported that they felt much less exhausted in the after-recognition-go strategy than in the while-perceiving-go strategy. Comprehensively, the after-recognition-go strategy was recommended for further studies.

V. Practical Experiment

A. Experimental Method: Conditions and Procedures

We carried out a practical experiment in order to confirm the effectiveness of the selected stroke-presentation strategy, i.e., the after-recognition-go strategy. As a practical experiment, the number of strokes was increased to five, and stroke-length variations in a line drawing were enlarged. The experimental conditions are shown in Table IV.

The procedure was almost the same as that in Section IV.A.2) except that each stroke pattern was presented only once, and no repetition was allowed. In addition, the presented lengths were individually adjusted to cancel individual nonlinear relationships of perceived lengths.

TABLE IV. Factors and Levels in Practical Experiment.

Factor	Level
Subject	3 males (around age 23)
Presentation strategy	After-recognition-go strategy
Presented stroke pattern	2 patterns of 5-strokes
Length	Randomly chosen between 10 - 150 mm
Speed	Randomly chosen between 12.5 - 70 mm/s
Direction	Randomly chosen between 0 - 359 deg.

B. Experimental Results

Experimental results are shown in Figure 15. Although it leaves much to be improved, the perceived patterns capture the essential geometrical features of such complicate presented patterns. It shows a potential of the proposed finger tactile interface and the stroke presentation strategy.

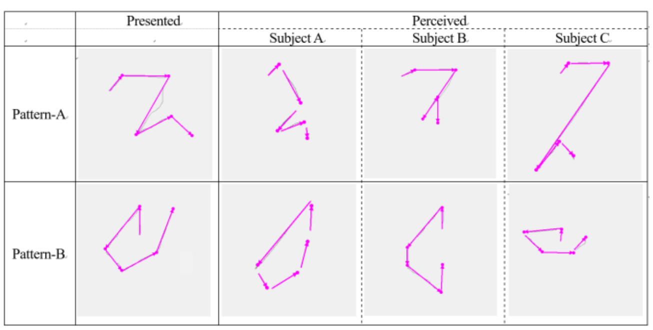


Figure 15. Experimental results of multi-stroke line drawing perception by using the active-wheel mouse.

VI. Conclusion and Future Work

Two multiple-stroke presenting strategies using a finger tactile interface, i.e., an active-wheel mouse, were presented: one is an after-recognition-go strategy, and the other is a while-perceiving-go strategy. Multiple-stroke recognition experiments confirmed the following conclusions.

Although there were almost no significant differences between both of the strategies in terms of error means and variances with respect to lengths, angles, velocities, the after-recognition-go strategy was superior to the while-perceiving-go strategy in terms of means and variances with respect to the time-duration. In addition, all the subjects reported that they were much less exhausted in the after-recognition-go strategy than in the while-perceiving-go strategy. As a result, it can be said that the while-perceiving-go strategy that employs a closed-loop on-line positional feedback scheme does not work well, while the after-recognition-go strategy that employs an open-loop control scheme does work better.

In the future, accuracy and efficiency will need to be furthermore improved. Applicable scope is expected, to be extended for such strokes as curved and accelerated strokes.

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