Perceptual and Reproductive Learning for Line Drawing Strokes Using Active Wheel-Based Finger Tactile Interface

Yoshihiko Nomura, Shinichi Inagaki, Norihiko Kato
Graduate School of Engineering
Mie University
Tsu, Japan
e-mails: {nomura, inagaki-s} @ int.mach.mie-u.ac.jp
nori @ robot.mach.mie-u.ac.jp

Tokuhiro Sugiura
Center for Information Technologies and Networks
Mie University
Tsu, Japan
e-mail: sugiura @ cc.mie-u.ac.jp

Abstract—**The goal of this paper is to establish an intensive training procedure for improving subjects' tactile-motor performance for an active wheel-based finger tactile interface. The methodology for achieving the goal is to propose a training procedure, and to show perceptual learning characteristic improvements as a result of the intensive training. Concretely, subjects repeated a tactile-motor learning trial composed of a slippage perception and a stroke reproduction. That is, a learning trial is constituted of four steps: (1) a target hand-stroke, i.e., a uniform motion, is presented as a slippage by the active-wheel-based finger-tactile interface, (2) a subject reproduces the slippage as a hand-stroke, (3) accepting the slippage corresponding to the subject-reproduced stroke, the subject improves their slippage sensitivity, (3) accepting the initial slippage corresponding to the target hand-stroke, the subject furthermore improves their slippage sensitivity. The training had been conducted for eight days, three sessions a day, 16 learning trial a session. As a result of a psychophysical experiment with eight subjects involving an intensive eight-day training, the subjects significantly improved their slippage-perception and stroke-reproduction ability. The 1st day training doubled the perceptual sensitivities: the sensitivities were defined by a ratio of an estimated slope to the standard error with respect to the reproduced stroke speed, by another ratio with respect to the time-duration, and by the standard deviations with respect to the reproduced stroke angular error. Furthermore, the intensive eight-day training made the speed-perceptual sensitivity two-times better than that after the 1st day training. Thus, a learning effect was significantly observed, and, consequently, the effectiveness of the proposed training procedure was confirmed.**

Keywords—slippage perception; tactile interface; stroke reproduction; training and learning; dominant and non-dominat hand assignment.

I. INTRODUCTION

In the previous paper by Nomura et al. [1], a line drawing perceptual characteristic using an active-wheel mouse (AWM) was presented on the relationship to the number of strokes: the AWM was a mouse interface to which active wheel-based finger tactile (AWFT) interface was attached. [2] [3] [4] [5] [6]. This paper is an extended version of the previous paper. In this paper, the AWFT interface was not attached to a mouse, but was used in a stand-alone as a static interface. Moreover, an intensive training protocol for perceptual learning with the AWFT interface was proposed.

Once we lose our vision, we shall suffer inconveniences in daily life. Visually impaired persons utilize their sensations other than the vision such as skin-sensations and proprioceptive sensations. Similarly, many assistive devices have been developed as an alternative for vision.

Some handy-and-portable tactile devices have also been proposed for character presentation and walking route guidance. For instructing arm motions, Tsuda et al. [7] and Causo et al. [8] proposed a vibrotactile device. Norman et al. [9] proposed a skin-stretch device. Gleeson et al. [10] proposed a skin stretch-based tactile display in conjunction of a joystick-based force feedback, and Koslover et al. [11] combined a skin stretch-based tactile display with vibrotactile and voice guidance. Ion et al. [12] proposed a tactile display to drag a physical tactor across the skin for instructing geometrical shapes. Tsagarakis et al. [13] proposed a slippage display to rotate two cones for instructing 2D directions. Moscatelli et al. [14] proposed another slippage display to rotate a ball for instructing 2D slippages.

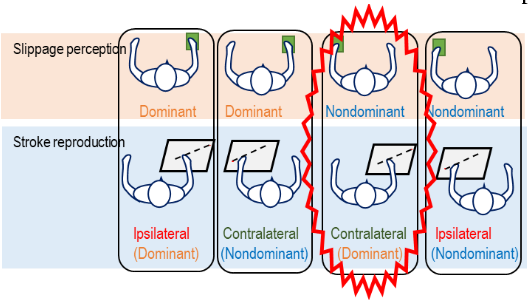
They provided motion information with tactors. However, they could not solve the following problems: ① the number of physical properties to be presented was restricted in such way that only a motion direction can be presented, ②the operating range was restricted in several millimeters. As a solution for the problems, the authors have presented the AWFT interface [4] [5]" and an "After-Recognition Go (ARG)" presentation strategy [2] [3].

Recently, based on the ARG presentation strategy, the reproduction performances, i.e., the accuracies in the speed, time-duration, and direction of the reproduced strokes, were compared between four kinds of hand assignments on perception-and-reproduction task. That is, while the AWFT interface presented slippages to an index finger pad of either a dominant or non-dominant hand, users perceived the slippages and recognized them as strokes. Next, the users reproduced the recognized strokes with either a dominant or non-dominant hand. As a result, a hand-assignment by the non-dominant for perception and dominant for reproduction (NDP&DR hand-assignment) was found to be superior to the other three hand assignments because the proportional coefficient of the reproduced stroke speed against the presented stroke speed by the NDP&DR hand-assignment was nearest to the ideal value of one than the other three hand-assignments as shown in Figure 1—in the NDP&DR hand-assignment, users perceived the slippages by their index finger pad of their non-dominant hand, and reproduced the recognized strokes by their dominant hand.

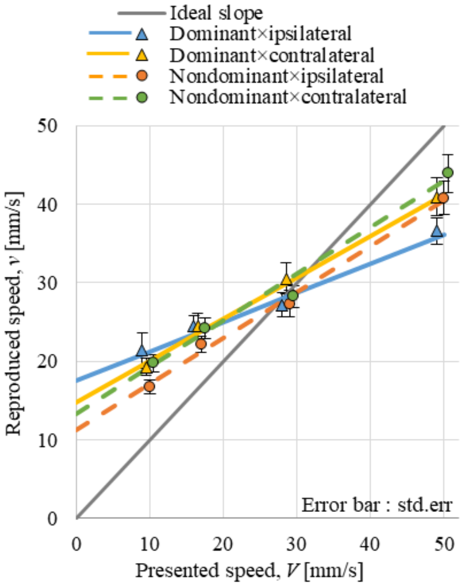
In this experiment, the NDP&DR hand-assignment and the ARG presentation-strategy were employed as elementary procedures that are repeated in an intensive learning protocol.

Some studies on perceptual learning were carried out as follows. Wong et al. reported a learning effect with respect to a tactile interface that presents square-wave gratings as horizontal or vertical stimuli on a small area of fingerpad and lip [15]. They confirmed a tactile experience-based hypothesis that blind participants who have a lot of tactile experience would outperform the sighted participants on the fingers, and that Braille reading would correlate with the tactile acuity. Using the same apparatus, they furthermore, conducted an experiment involving an intensive training where participants completed 1900 training trials (38 blocks ×50 trials) during four days [16]. As a result, they concluded a hypothesis that tactile perceptual learning is limited by finger size. That is, participants' tactile spatial acuity improved toward a theoretical optimum value defined by their finger size: participants with worse initial performance relative to that corresponding to their finger size improved more with training, and post training performance was better correlated than pre-training performance. Harrar et al. reported an interesting result on the so-called transfer learning regarding the extent to which tactile perceptual learning was generalized across fingers [17]. They measured tactile orientation discrimination abilities in each of the four fingers (index and middle fingers of both hands) before and after a training procedure. In the training procedure, 4 tactile gratings were chosen, based on the threshold calculated from the first testing session, and based on performance in the previous training sessions (Sessions 2 through 4) thereafter. Participants completed 576 trials (4 day-sessions × 12 blocks (4 gratings widths × 3 block repetitions) × 12 trials). As a result, following training, performance was improved not only for the trained fingers, but also for its adjacent and homologous fingers. These findings gave us a motivation of taking up to confirm the learning effect on improving perceptual sensitivities with an intensive training for the author-developed AWFT interface as in this paper.

The remainder of the paper is structured as follows. Section II outlines a brief mechanical design of our developed AWFT interface and some methodologies for the interface, i.e., the ARG presentation-strategy and the NDP&DR hand-assignment. Section III introduces a protocol for perceptual learning with the AWFT interface. Next, in Section IV, an experiment follows the system descriptions. The paper closes with a conclusion and remarks for further developments.



(a) Four kinds of assignments of either dominant or non-dominant hand to perception and reproduction task.



(b) The nondominant×contralateral assignment, i.e., non-dominant-for-perception and dominant-for-reproduction, shown by the yellowish green-colored broken line was concluded to be best in the four assignments, achieving the highest slope of the reproduced speed to the presented one.

Figure 1. Characteristics of reproduced speed for the four kinds of perception×reproduction assignments [6]

II. ACTIVE WHEEL-BASED FINGER TACTILE INTERFACE

In this section, a brief mechanical design of the AWFT interface is first described. Nest, methodologies for utilizing the interface, i.e., the ARG presentation-strategy and the NDP&DR hand-assignment, are introduced.

A. *Apparatus*

We have previously presented an AWFT interface [5]: a specific tactile interface as shown in Figure 2. A wheel is embedded in the tactile interface, and the diameter and thickness of the wheel are 20 mm and 6 mm, respectively (see Figure 3). Raised dots are formed on the wheel peripheral surface to enhance slippage perception: the height of the raised dots is 0.5 mm, and the diameter of the bottom circle is 1.7 mm. The dot interval was 10.5 mm so that the dots appear one by one on the fingerpad because one-by-one appearance made the slippage perception easier as in Nomura et al. [18][19]. The 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 4). 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 fingerpad, respectively. The velocity together with the time duration decides slippage length.

B. *ARG Line-Drawing-Stroke Presenting Strategy*

The ARG presentation-strategy for presenting line-drawing strokes was employed as in the following [3].

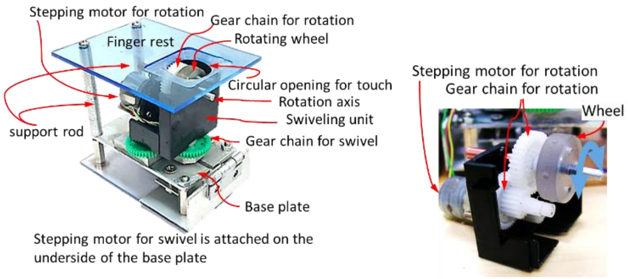
[Step 1] Subjects put the wrist of their non-dominant hand on a resting stage —as was recommended by the result that a NDP&DR hand-assignment was superior to the other hand-assignments [6]: users perceived the slippages by their index finger-pad of their non-dominant hand, and reproduced the recognized strokes by their dominant hand. Since all the subjects were right-handers in this experiment, the non-dominant and dominant hand correspond to the left and right hand.

[Step 2] The AWFT interface swivels the swiveling unit in a given direction.

[Step 3] The subjects touch their index finger-pad of their non-dominant hand on the wheel periphery.

[Step 4] The AWFT interface rotates the wheel with a uniform angular velocity and in a time-duration. While accepting the slippage stimulus induced by the rotation (see Figure 5 (a)), the subjects recognize the stimulus as a stroke with a uniform-velocity straight-line motion. In particular, the subjects focus their attention to the speed, time-duration, and angle of the presented slippage. Here, note that the circumference of the wheel is circular, and the actual locus of the slippage is an arc. Yet, 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.

[Step 5] Just after the wheel rotation finished, the subjects draw a straight line on a touch panel display (TPD) using a stylus pen held by the dominant hand (see Figures 5 (b) and (c)).



(a) AWFT tactile interface. (b) Swiveling unit (Wheel-rotating part).

Figure 2. General view of AWFT interface

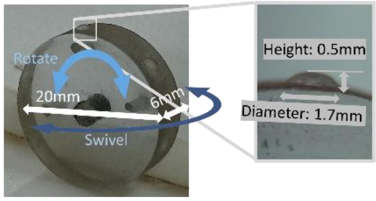


Figure 3. Wheel configuration: raised dots are formed on wheel periphery.

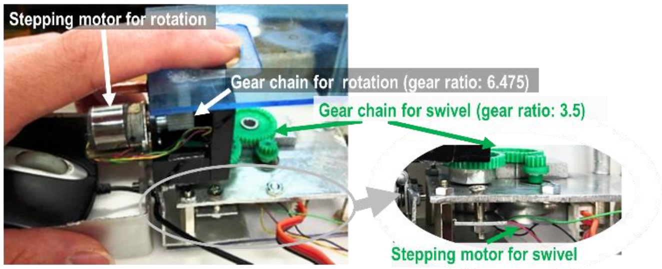
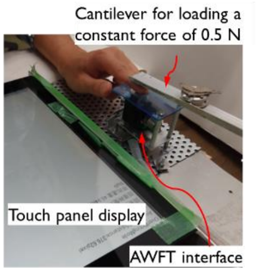
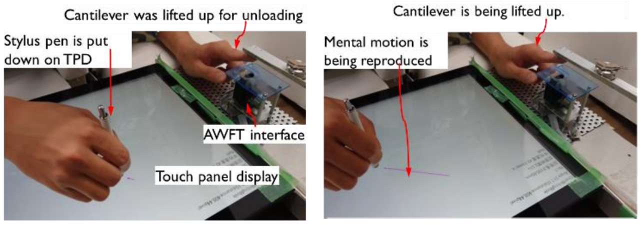


Figure 4. Stepping motor and gear-chain units for rotation and for swivel.



(a) Accepting wheel rotation, a subject creates a mental image of a presented slippage.



(b) Subject puts down a stylus pen on a TPD screen.

(c) Subject traces the mental image on the TPD with the stylus pen.

Figure 5. ARG presentation-strategy for line drawing stroke learning.

III. PROTOCOL FOR PERCEPTUAL-AND-REPRODUCTIVE LEARNING WITH AWFT INTERFACE

A representative application of the slippage presentation by the AWFT interface is to instruct users on line-drawing strokes. In making line-drawing strokes, there are two processes: one is a slippage-perceiving process and the other is a handstroke-making process based on the perceived slippages. Therefore, in order to improve the performance of making line-drawing strokes, the sensitivity of slippage perception and stroke reproduction is to be enhanced in a combined form.

The perceptual-and-reproductive learning with the AWFT interface was carried out in eight days as shown in Figure 6: the eight days are concentrated, but consecutive, and a few days of breaks were involved in a schedule being different from subject to subject. In order to make the learning effect explicit, the period of eight days was designed, based on a preliminary experiment employing three subjects other than the subjects in this paper.

In the first day, before learning, the experimenter explained the task to the participants. Then, the participants were asked to repeat the task until they understood the procedure, and considered themselves to be familialized with the slippage-perception using the NDP&DR hand-assignment.

Next, in each of the training days, three training sessions were consecutively iterated, accompanied by a pre-test and post-test session. The sessions are constituted of 16 trials, and each trial is given by Steps 1 to 4 in training, while that is given by Steps 1 and 2 in testing, as shown in Figure 7.

[Step 1] Aiming at a target hand-stroke, an AWFT-interface presents a slippage, called a first slippage. Since the subject does not know of the true value of the first slippage, the learning for the slippage sensitivity can be regarded as an unsupervised learning. While perceiving the initial slippage, a subject memorizes it as a translational motion, called a first mental motion where a slippage perceptual error is involved. The slippage perceptual error is to be reduced after perceptual learning.

[Step 2] While recollecting the first mental motion, the subject reproduces the mental motion as a hand-stroke on a TPD with a stylus. In this process, proprioceptive error is involved, which would be much smaller than the slippage-perceptual error, and is not considered.

[Step 3] The AWFT-interface presents a second slippage corresponding to the subject-reproduced hand-stroke. The subject perceives the second slippage and recognizes as a second mental motion, where another slippage perceptual error is involved. Next, comparing the second mental motion to the first one, the subject modifies their slippage perceptual sensitivity so as to match them. Since the second slippage corresponds to the hand-stroke reproduced by the subjects themselves, the sensitivity learning can be regarded as a supervised.

[Step 4] The AWFT interface again presents the first slippage. Based on the modified sensitivity, the subject again perceives the first slippage, and recognizes it as a third mental motion. Next, comparing the third mental motion to the second one, the subject furthermore modifies their slippage perceptual sensitivity so as to match the second to the third mental motion. Since the subject can compare the third with second mental motion, the sensitivity learning can be regarded as another supervised learning.

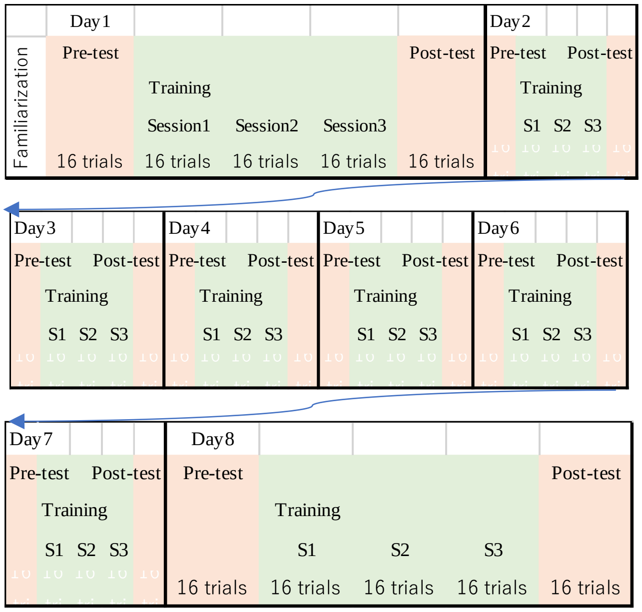
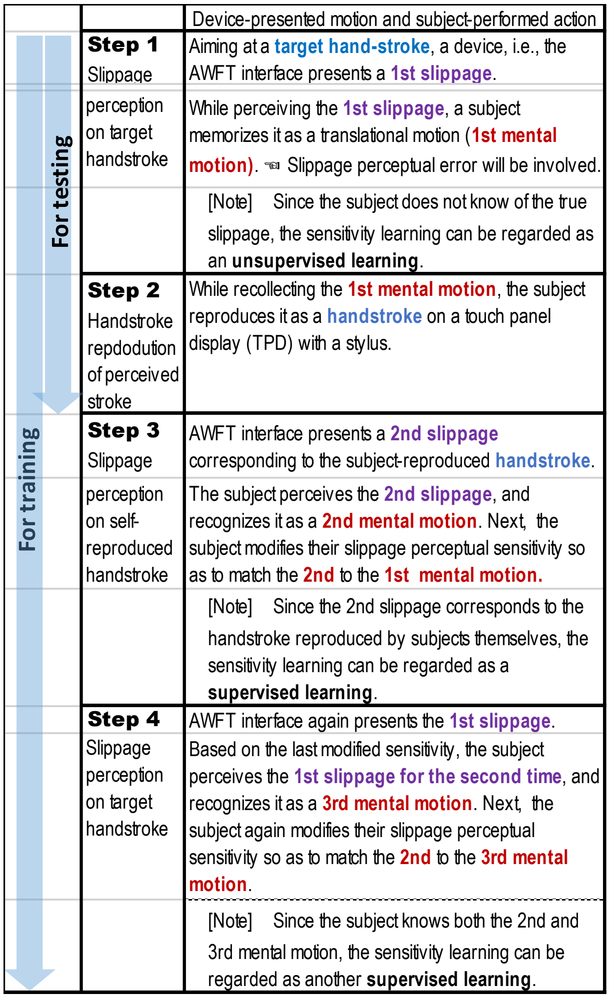


Figure 6. Protocol of an eight-day sensitivity training of slippage perception and stroke reproduction for a single straight line-drawing-stroke.



	Device-presented motion and subject-performed action
Step 1 Slippage perception on target handstroke	Aiming at a **target hand-stroke**, a device, i.e., the AWFT interface presents a **1st slippage**.
	While perceiving the **1st slippage**, a subject memorizes it as a translational motion (**1st mental motion**). ☜ Slippage perceptual error will be involved.
	[Note] Since the subject does not know of the true slippage, the sensitivity learning can be regarded as an **unsupervised learning**.
Step 2 Handstroke repdodution of perceived stroke	While recollecting the **1st mental motion**, the subject reproduces it as a **handstroke** on a touch panel display (TPD) with a stylus.
Step 3 Slippage perception on self-reproduced handstroke	AWFT interface presents a **2nd slippage** corresponding to the subject-reproduced **handstroke**.
	The subject perceives the **2nd slippage**, and recognizes it as a **2nd mental motion**. Next, the subject modifies their slippage perceptual sensitivity so as to match the **2nd** to the **1st mental motion.**
	[Note] Since the 2nd slippage corresponds to the handstroke reproduced by subjects themselves, the sensitivity learning can be regarded as a **supervised learning**.
Step 4 Slippage perception on target handstroke	AWFT interface again presents the **1st slippage**.
	Based on the last modified sensitivity, the subject perceives the **1st slippage for the second time**, and recognizes it as a **3rd mental motion**. Next, the subject again modifies their slippage perceptual sensitivity so as to match the **2nd** to the **3rd mental motion**.
	[Note] Since the subject knows both the 2nd and 3rd mental motion, the sensitivity learning can be regarded as another **supervised learning**.

Figure 7. Protocol of a sensitivity-training trial constituted of Steps1 to 4 and that of the pre/post test trial constituted of Steps 1 and 2.

IV. EXPERIMENT

In this section, an experimental method to confirm an effectiveness of the sensitivity training is first explained, and, then, experimental results of the sensitivity training are described.

A. Experimental Method

1) Experimental conditions

Eight healthy right handed males in their 20s (20~25, mean=21.8, standard deviation (SD) =1.5) participated in the experiment. All the participants gave signed consent and received monetary compensation. All procedures were approved by Research Ethics Committee of Graduate School of Engineering, the Mie University.

The three training sessions and the pre- and post-test session consist of 16 trials. In the 16 trials, 16 different slippages that represent different single straight-strokes were presented with the AWFT interface: the levels of the speed, time-duration and angle factor were given by an orthogonal array of n = 128 (4 factors of 5 levels and 1 factor of 8 levels) where the subject was also assigned to the eight-level factor in the orthogonal array. The 16 slippage patterns were different between testing and training, and between the subjects, while, for each subject, the 16 slippage pattern was identical throughput the training sessions, i.e., from the 1st training session in the 1st day to the final 3rd training session in the 8-th day. Similarly, the 16 slippage pattern was identical from the pre/post-test session in the 1st day to the post/post-test session in the 8-th day.

The elapsed time for one day training was approximately 60 min, and no subjects reported that they did not feel to be tired to an extent that they suffered any ill effects in their performance. Practically, considering the subjects' response, the one-day training schedule composed of three-training and two-testing sessions was designed.

TABLE I. FACTORS AND FACTOR LEVELS EMPLOYED IN EXPERIMENT.

Factor	Factor level
Presentation strategy	After-recognition go strategy
Hand assignment	Slippage-perception with a non-dominant hand and stroke reproduction with a dominant hand (NDP&DR hand-assignment)
Presented line drawing stroke	Single stroke by uniform motion
Time duration [s]	4 levels: 1.0, 1.7, 2.9, 5.0
Speed [mm/s]	4 levels: 10, 17, 29, 50
Direction [deg]	16 levels: 0, 22.5, 45,, 315, 337.5

2) Evaluation values

The presented stroke length, $l_{presented}$, and time-duration, $\tau_{presented}$, are related to the presented speed $v_{presented}$ by

$$v_{presented} = l_{presented} / \tau_{presented} \tag{1}$$

On the other hand, we obtained a secant from a subject-reproduced stroke—the word "secant" represents the line segment connected from a start to an end. Next, for the secant of the reproduced stroke, we measured the length $l_{reproduced}$ and angle $\theta_{reproduced}$. In addition, a time-duration $\tau_{reproduced}$ of the reproduced stroke was obtained from a time record. Then, using $l_{reproduced}$ and $\tau_{reproduced}$, the speed of the reproduced stroke $v_{reproduced}$ is given by

$$v_{reproduced} = l_{reproduced} / \tau_{reproduced} \tag{2}$$

Then, taking an example of velocity, a procedure of modelling is explained with respect to the reproduced strokes. That is, by applying a linear least-squares method to the pairs of $v_{reproduced}$ and $v_{presented}$, a linearly modelled value of the reproduced stroke speed, $v_{modelled}$, is given by

$$v_{modelled} = s_v \, v_{presented} + i_v \tag{3}$$

where s_v and i_v are a slope and an intercept of the modelled speed, respectively. The slope, s_v, together with the standard error, σ_{sv}, is estimated by the least squares method from sample data for each of the eight pre/post tests, which comprise of pairs of $v_{reproduced}$ and $v_{presented}$. Similarly to the speed, the time-duration is modelled by

$$\tau_{modelled} = s_\tau \, \tau_{presented} + i_\tau \tag{4}$$

The slope, s_τ together with the standard error, $\sigma_{s\tau}$, are also estimated by the least squares method from sample data, which comprise of pairs of $\tau_{reproduced}$ and $\tau_{presented}$.

A slope is a representative measure of sensitivity from the viewpoint of systematic error: the larger the slope is, the higher the sensitivity is. The difference of the slope from the ideal value of 1 can be regarded as a systematic-error measure. On the other hand, a random error measure can be defined by the standard error of the estimated slope, σ_{sv} and $\sigma_{s\tau}$. In order to comprehensively combine both the systematic and random error, a secondary evaluation measure is, then, introduced, that is, a ratio of the estimated slope to the standard error, s_v/σ_{sv} and $s_\tau/\sigma_{s\tau}$: they are a kind of signal-to-noise ratios (SN ratios) and follow a t-distribution.

As for the angles, there is no significantly large systematic error in the reproduced angles although a little periodical error may be involved. Consequently, we did not examine the systematic error of the angular perception. While, for the random error, the difference between reproduced and the presented angle, $\theta_{presented}$, were evaluated as shown in Figure 8. That is,

$$\Delta\theta = \theta_{secant} - \theta_{presented} \tag{5}$$

Then, the standard deviation of $\Delta\theta$, $\sigma_{\Delta\theta}$, is employed as a random-error measure on angular perceptual sensitivity. These values s_v/σ_{sv}, $s_\tau/\sigma_{s\tau}$, and$\sigma_{\Delta\theta}$ were evaluated for all the pre-training sessions and the post-training sessions for each of the 1st to 8th training days.

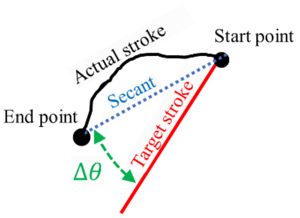


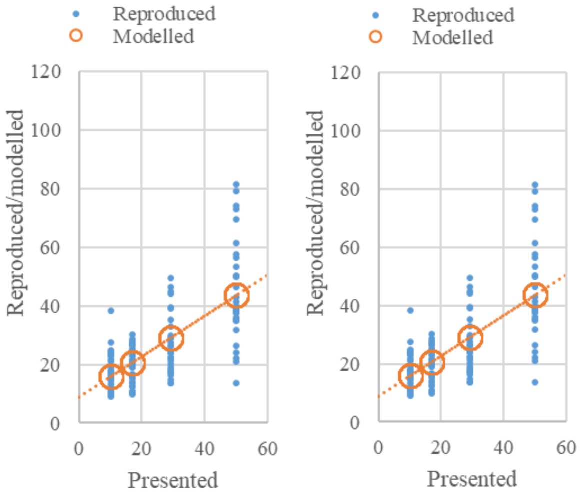
Figure 8. The secant of actual trajectory and the presented target trajectory were evaluated.

B. *Experimental Results*

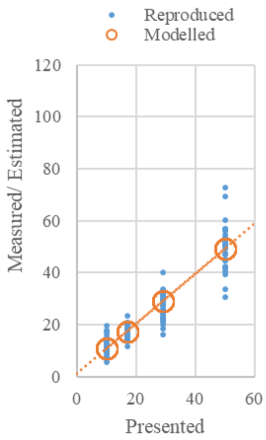
1) Relationships between reproduced and presented speeds, time-durations, and angles

Some relationship of the measured and estimated values of the speeds, time-durations, and angles of the reproduced stroke to the presented values are shown in Figures 9, 10, and 11, respectively. In each of these figures, detailed results are shown in (a) the 1st-day pre-training session (b) the 1st-day post- training session (c) the 8th-day post- training session. From these figures, we can see the followings.

i. The reproduced speed, time-duration, and angle, were, as expected, almost proportional to the presented ones.
ii. The slopes of the speed and the time-duration, and the means in the angles represents systematic errors, and the dispersions represents the random errors. The slopes and the dispersion show much improvement after the 1st day training, and, also, another improvement throughout the eight-day training. That is, as for the reproduced speed and time-duration, the intercepts go to approach zero and the slopes become larger. As for the reproduced angles, mean errors for each of the presented angles 0 to 337.5 also go to approach zero. The dispersions for all the physical values, i.e., the speeds, the time-durations, and the angles, become narrow.

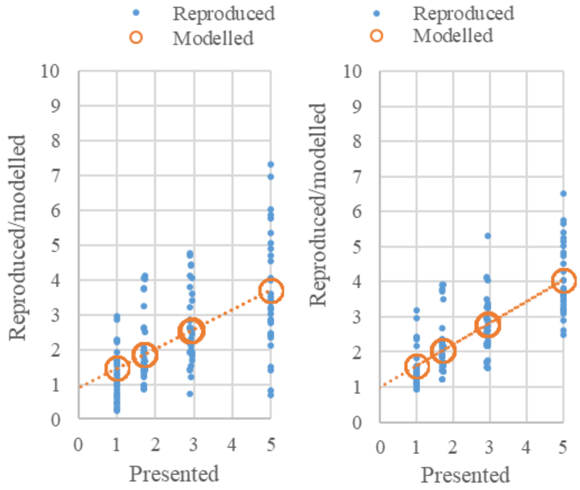


(a) 1st-day pre-training (b) 1st-day post- training

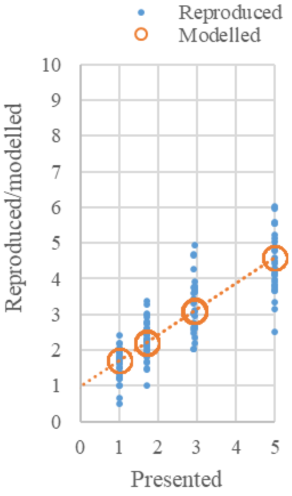


(c) 8th-day post- training

Figure 9. Some of the reproduced and modelled speeds.

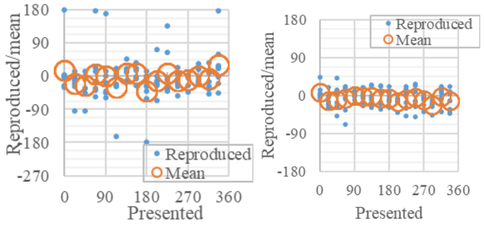


(a) 1st-day pre-training (b) 1st-day post- training

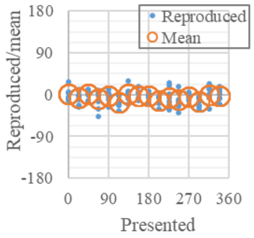


(c) 8th-day post- training

Figure 10. Some the reproduced and modelled time-durations.



(a) 1st-day pre-training (b) 1st-day post- training

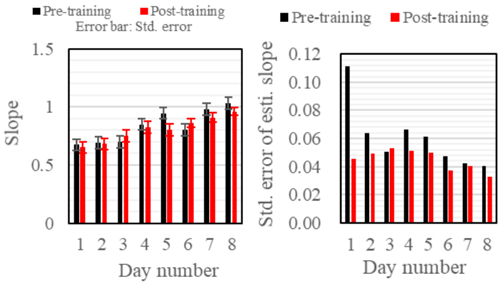


(c) 8th-day post- training

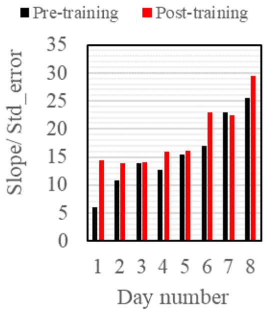
Figure 11. Some of the reproduced angle errors and their means.

2) Speed slope, time-duration slope, and angular error mean

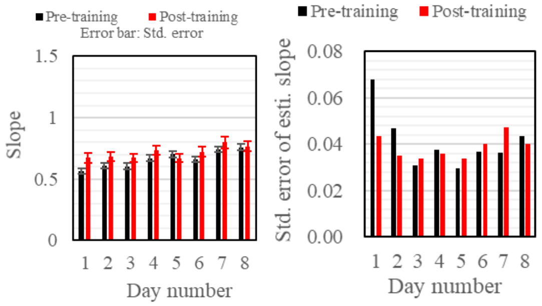
The results of the slopes, s_v and s_τ, and the angular error mean, $\Delta\theta$, are shown in Figures 12, 13, and 14, respectively. In these figures, the estimated slopes, s_v and s_τ, are shown in Figures 12 (a) and 13 (a), and their standard errors, σ_{sv} and $\sigma_{s\tau}$. are shown in Figures 12 (b) and 13 (b). Furthermore, the ratio of the estimated slope to the standard error, s_v/σ_{sv} and $s_\tau/\sigma_{s\tau}$ are shown in Figures 12(c) and 13 (c). While, the means of $\Delta\theta$ are shown in Figure 14 (a), and their standard deviations are shown in Figure 14 (b).



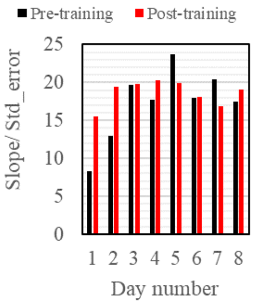
(a) Modelled slope (b) Standard error of the modelled slope



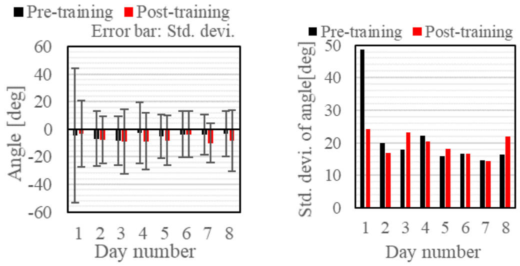
(c) Ratio of the modelled slope to its standard error
Figure 12. Evaluation values for the reproduced speeds.



(a) Modelled slope (b) Standard error of the modelled slope



(c) Ratio of the modelled slope to its standard error
Figure 13. Evaluation values for the reproduced time-durations.



(a) Mean and standard deviation (b) Standard deviation
Figure 14. Evaluation values for the reproduced angles.

The three physical properties, i.e., s_v, s_τ, and $\Delta\theta$, were evaluated from the following two viewpoints.

i. Initial learning effect: the post-training test at the 1st training day (Post-1st) was compared to the pre-training test at the same 1st training day (Pre-1st). The comprehensive evaluation values were markedly improved for all the three physical properties. That is, s_v/σ_{sv} was improved from 6.04 (Pre-1st) to 14.4 (Post-1st), $s_\tau/\sigma_{s\tau}$ was 8.29 (Pre-1st) to 15.5 (Post-1st). Although each of s_v/σ_{sv} and s_v/σ_{sv} follows the *t*-distribution, the degree of freedom (DOF) for both, 79, are large enough to approximate the *t*-distribution by the standardized normal distribution. Then, we can approximate the distributions of the difference between s_v/σ_{sv} and s_v/σ_{sv} by the normal distribution (mean=0, variance=2). As a result, the differences of s_v/σ_{sv} and $s_\tau/\sigma_{s\tau}$ between Post-1st and Pre-1st were concluded significantly large with practically null significant probability. In addition, the standard deviation of $\Delta\theta$ was also improved from 48.6 to 24.1. Since the ratio of two variances follows the F-distribution (DOF: 79, 79), the value of $4.07 = (48.6/ 24.1)^2$ concludes that the two variances were not equivalent at all. In short, the sensitivity of speed, time-duration, and angle after an initial learning were approximately two-times better than before.

ii. Overall learning effect: the post-training test at the final 8th training day (Post 8th) was compared to initial post-training test at the 1st training day (Post-1st). The comprehensive evaluation values were also markedly improved for all the three physical properties. That is, s_v/σ_{sv} was improved from 14.4 (Pre-1st) to 29.4 (Post-8th), $s_\tau/\sigma_{s\tau}$ was 15.5 (Post-1st) to 19 (Post-8th). Similarly to the initial learning effect, the differences of s_v/σ_{sv} and $s_\tau/\sigma_{s\tau}$ between Post-1st and Post-8th were concluded significantly large with practically null significant probability. In addition, the standard deviation of $\Delta\theta$ was also improved from 24.1 to 22.0. It confirms that the two variances were not equivalent. As a result, from the viewpoint of post-training test, it is confirmed that the sensitivity of speed, time-duration, and angle by Post-8th were also much better than those by Post-1st.

V. PRACTICAL EXPERIMENT

In this section, another perception-and-reproduction experiment on sime line-drawings composed of multiple strokes is described in order to show an effect in a practical application by exemplifying an improvement between before/after learning.

A. *Experimental Method: Conditions and Procedures*

As a practical experiment, the number of strokes was increased to seven or eight strokes including motions in the air: speeds and time-durations were selected from the experimental conditions are shown in Table II. The five subjects were the ones included in the eight subjects who had gone through the training.

The procedure was the same as that for testing described in Section III: Steps 1 and 2 were only once conducted for each stroke in a multi-stroke pattern, and no repetition was allowed.

TABLE II. FACTORS AND LEVELS IN PRACTICAL EXPERIMENT.

Factor	Level
Presentation strategy	After-recognition go strategy
Hand assignment	Slippage-perception with a non-dominant hand and stroke reproduction with a dominant hand (NDP&DR hand-assignment)
Presented line drawing stroke	Seven or eight strokes by uniform motion. The stroke patterns are not failliar to the subjects.
Speed [mm/s] × Time duration [s]	Pattern i and ii 4 levels: 10, 17, 29, 50 mm/s ×2.9 sec
	Pattern iii 4 levels: 29 mm/s ×2.1, 2.4, 2.9, 4.3, 4.8 sec

B. *Experimental Results*

Experimental results are shown in Figure 15. Although it leaves a little to be improved, the reproduced patterns after learning did much better than those before learning. Yet this is just an example, it clearly suggests a potential of the proposed learning protocol.

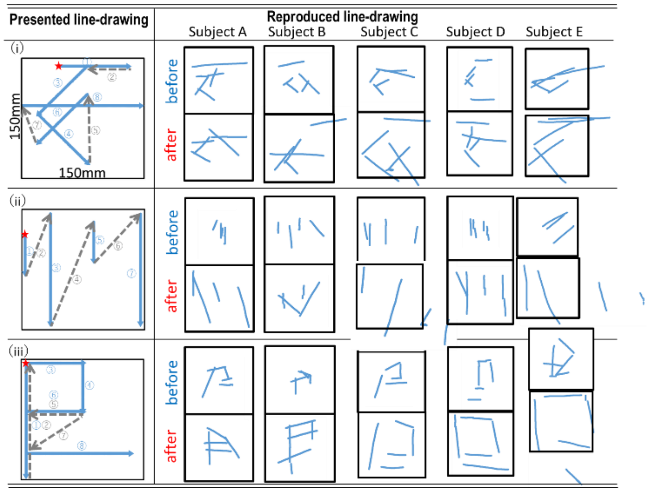


Figure 15. Experimental results of multi-stroke line drawing perception/reproduction before/after 8-day learning.

VI. CONCLUSION AND FUTURE WORK

A learning protocol for a finger tactile interface, i.e., an active-wheel-based finger-tactile (AWFT) interface was proposed. That is,

[Step 1] Aiming at a target hand-stroke, an AWFT-interface presents an initial slippage. While perceiving the initial slippage, a subject memorizes it as a translational motion, called an initial mental motion.

[Step 2] Recollecting the initial mental motion, the subject reproduces it as a hand-stroke.

[Step 3] The AWFT-interface presents a 2nd slippage corresponding to the subject-reproduced hand-stroke. Since the slippage is given by the motion made by subject's own self, the subject can improve their slippage sensitivity.

[Step 4] The AWFT interface again presents the initial slippage. Making sure of their initial mental motion, the subject can furthermore improve their slippage sensitivity.

As a result of a psychophysical experiment involving an intensive eight-day training on perceptual learning, users significantly improved their stroke perception-and-reproduction ability. The 1st day training doubled the perceptual sensitivities: the sensitivities with respect to the stroke speeds and time-durations were defined by the ratio of the estimated slope to its standard error—the slopes represent the proportional coefficient between the reproduced and presented speed and time-duration. While, the sensitivity with respect to the stroke angles was defined by the standard deviations of the angular errors.

Furthermore, the intensive eight-day training made the perceptual sensitivities significantly better than those after the 1st day training. In particular, the speed sensitivity was improved by two-times.

Thus, significant learning effects were confirmed from the viewpoint of the 1st day training and eight-day intensive training.

In the future, applicable area is expected to be extended for such strokes as curved and variable velocity strokes.

ACKNOWLEDGMENTS

This work was partly supported by KAKENHI (Grant-in-Aid for Scientific Research (B) 15H02929 from Japan Society for the Promotion of Science (JSPS). The authors wish to thank K. Katsuta (Ms. Eng.) for his contribution to the experiment.

REFERENCES

[1] Y. Nomura, Y. Kashino, K. Katsuta, and T. Sugiura, "Line drawing perceptual characteristics for the number of strokes using an active-wheel mouse," Proceedings of the 12th International Conference on Advances in Computer-Human Interactions, pp. 199-203, Greece, March 2018. ISSN: 2308-4138, ISBN: 978-1-61208-616-3.

[2] Y. Nomura, Y. Kashino, and T. Sugiura, "Line-drawing presentation strategies with an active-wheel mouse," Proceedings of the 11th International Conference on Advances in Computer-Human Interactions, pp. 199-203, Rome, March 2018. ISSN: 2308-4138, ISBN: 978-1-61208-616-3.

[3] Y. Nomura, Y. Kashino, and T. Sugiura, "Line-drawing presentation strategies with an active-wheel mouse," The International Journal on Advances in Intelligent Systems is Published by IARIA. vol. 11, no. 311. pp. 290-298, 2018. ISSN: 1942-2679.

[4] Y. Nomura and S. Oike, "Active-wheel mouse for human-computer interface: slippage-perception characteristics on fingerpad," Proceedings of the 10th International Conference, UAHCI 2016, Part of HCI International 2016, part II, pp. 54-61, 2016.

[5] Y. Nomura, Y. Kashino, and S. Oike, "Proposal of active-wheel-based finger-tactile interface and its slippage-presenting functions," Transactions of the JSME, vol. 83, no. 852, pp. 1-17, 2017 (in Japanese).

[6] K. Katsuta, Y. Nomura, N. Kato, and S. Inagaki, "Comparison between Four Assignments of slip-perception and stroke-reproduction task to dominant/nondominant hand," Transactions of the JSME, vol. 85, no. 876, pp. 1-14, 2018 (in Japanese).

[7] N. Tsuda, N. Kato, and Y. Nomura, "Instruction of arm motion for calligraphy using vibrotactile stimulations," Proceedings of the 2011 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 677-682, 2011.

[8] A. Causo, S. H. Yeo, and I. M. Chen, "Vibrotactile motors on stationary arm as directional feedback to correct arm posture," Proceedings of the 2012 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 202-207, 2012.

[9] S. L. Norman, A. J. Doxon, B. T. Gleeson, and W. R. Provancher, "Planar hand motion guidance using fingertip skin-stretch feedback," IEEE Transactions on Haptics, vol. 7, no. 2, pp. 121-130, 2014.

[10] B. T. Gleeson, S. K. Horschel, and W. R. Provancher, "Perception of direction for applied tangential skin displacement: effects of speed, displacement, and repetition," IEEE Transactions on Haptics, vol. 3, no. 3, pp. 177-188, 2010.

[11] R. L. Koslover, B. T. Gleeson, J. T. De Bever, and W. R. Provancher, "Mobile navigation using haptic, audio, and visual direction cues with a handheld test platform," IEEE Transactions on Haptics, vol. 5, no. 1, pp. 33-38, 2012.

[12] A. Ion, E. J. Wang, and P. Baudisch, "Skin drag displays: dragging a physical tactor across the user's skin produces a stronger tactile stimulus than vibrotactile," Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, pp. 2501-2504, 2015.

[13] N. G. Tsagarakis, T. Horne, and D. G. Caldwell, "Slip aestheasis: A portable 2d slip/skin stretch display for the fingertip," Eurohaptics Conference, 2005 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp. 214-219, 2005.

[14] A. Moscatelli, A. Naceri, and M. Ernst, "Navigation in the fingertip," Proceedings of the IEEE World Haptics Conference, pp. 519-523, 2013.

[15] M. Wong, V. Gnanakumaran and D.Goldreich, "Tactile spatial acuity enhancement in blindness: evidence for experience-dependent mechanisms," Journal of Neuroscience, vol.31, no.19, pp.7028-7037, 2011.

[16] M. Wong, R.M. Peters and D. Goldreich, "A physical constraint on perceptual learning: tactile spatial acuity improves with training to a limit set by finger size," Journal of Neuroscience, vol.33, no.22, pp.9345-9352. 2013.

[17] V. Harrar, C. Spence, and T.R. Makin, "Topographic generalization of tactile perceptual learning," Journal of Experimental Psychology: Human Perception and Performance, vol.40, no.1, p.15-23. 2014.

[18] Y. Nomura and K. Iwabu, "Length perceptual characteristics on raised-dot slippages," Human-Computer Interfaces and Interactivity: Emergent Research and Applications, IGI Global, pp. 286-308, 2014.

[19] Y. Nomura and H. Kato, "Raised-dot slippage perception on fingerpad using active wheel device," Recent Advances on Using Virtual Reality Technologies for Rehabilitation, Nova Science Publishers, Inc., New York, pp. 165-172, 2015.