Tactual Motion Adaptation Phenomenon

Junji Watanabe[1] PRESTO JST /NTT CS lab
Seiichiro Hayashi[2] The University of Tokyo
Hiroyuki Kajimoto[3] The University of Tokyo
Susumu Tachi[4] The University of Tokyo

ABSTRACT

Tactual motion perception is one of the most important functions for realizing a delicate appreciation of the tactile world. To study the mechanism of information processing in the brain, the adaptation phenomenon has been a useful probe. Tactual motion aftereffects have not been reported in a reproducible fashion, however here, we demonstrate a clear and robust adaptation phenomenon using appropriate combinations of adaptation and test stimuli. Our results indicate that the adaptation paradigm can be used for investigating not only visual but also tactual motion processing.

Keywords: Tactile motion perception, Motion aftereffect, Adaptation paradigm

1 INTRODUCTION

One way we explore the external world is through our sense of touch. Tactual motion perception is one of the most important functions for realizing a delicate appreciation of the tactile world. When we touch an object in space, we actively move our fingers across its surface. From this movement, we can perceive various kinds of features of the object, such as shape, roughness, and compliance. The information of motion between the fingertip and the object should play a significant role in perceiving the tactual features. Therefore, to gain further insight into the mechanism of tactual perception, we investigated the functional mechanism of tactual motion perception using an adaptation paradigm.

The adaptation phenomenon has been useful to investigate mechanism of information processing in the brain without imaging or neurophysiology. Especially, human visual perception of motion has been studied by the visual motion adaptation phenomenon. After prolonged observation of a waterfall, an illusory upward motion can be seen in a static environment. This phenomenon is referred to as Motion AfterEffect (MAE) [1] [2]. Although MAE in vision is a robust and rigid phenomenon, tactile MAE has not been reported in a reproducible fashion [3] [4] [5].

Thalman, in 1922, reported a number of conditions that might be expected to generate MAEs. Since then, little research has been performed on this issue, and the conditions that produce reliable reports of tactile MAE are presently under discussion. Hollins and Favorov (1994) reported robust phenomena of tactile MAEs with the use of a rotating drum. The palm and all fingers were placed down on a 90 mm diameter drum, which then rotates at 60 rpm, as illustrated in Figure 1(a). After 120 sec of stimulation, subjects were instructed to lift their hands up, and the hand was then placed back on a stationary drum for a 60 sec period, and subjects answered questions about their feelings. Five subjects participated in this experiment, and tactile MAEs were reported in the most parts of the trials. However, in a replicated experiment by Lerner & Craig (2002), no MAE was reported in about half of the trials, though fifty subjects

performed the experiment. In addition, negative MAE was only about 10% of perceived MAE, though one would expect the aftereffects to be in the negative direction, that is, opposite to the direction of adaptation as in Figure 2. Lerner & Craig also performed experiments using OPTACON, a reading aid for the blind illustrated in Figure 1(b). Each row of OPTACON was activated sequentially. After adaptation for 120 sec, subjects held their fingers in the air for 60 sec, and answered questions about their feelings. In this method, clear negative MAEs were not observed again.

These previous results show that tactile MAE is not vivid or a robust phenomenon. Therefore, it is suggested that tactual MAE cannot be used for investigation into the tactual mechanism of motion perception. However, in this paper, we demonstrate clear and robust adaptation phenomenon using appropriate combinations of adaptation and test stimuli. Our results indicate that the adaptation paradigm can be a useful method for investigating not only visual but also tactual motion processing.

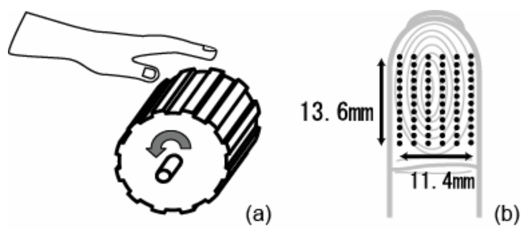

Figure 1 : (a) Hollins' and (b) Lerner's experiments

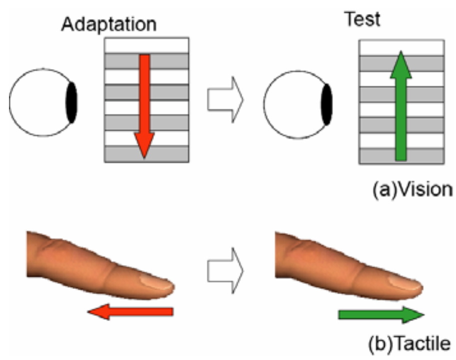

Figure 2 : (a) Visual and (b) tactile motion aftereffect

2 MAE IN TACTILE SENSATION

2.1 Apparatus & Subjects

Subject's right index finger was mounted on a metal board, as illustrated in Figure 3. Three pins were arranged with 5 mm spatial intervals as shown in Figure 4, and then vertically vibrated through a hole in the board. The pins were driven by

1 e-mail: watanabe@avg.brl.ntt.co.jp
2 e-mail: Seiichiro_Hayashi@ipc.i.u-tokyo.ac.jp
3 e-mail: kaji@star.t.u-tokyo.ac.jp
4 e-mail: tachi@star.t.u-tokyo.ac.jp

a vibration generator (EMIC Inc. 511-A) with the frequency of vibration 30 Hz, amplitude 0.06 mm, and duration 200 ms. The pin material was piano wire of 1.0 mm diameter. When the pins were sequentially driven, the subjects perceived apparent motion on the finger cushion. For example, pin “C” sticks out first, then “B” and finally “A”, as in Figure 4; subjects thus perceive tactual motion to the fingertip. The magnitude of the perceived motion was controlled in the experiments by varying the Inter Stimulus Onset Interval (ISOI)

Four subjects (one author and three naive males), aged from 22 to 24 years, participated in all experiments. Subjects, who could not hear the sound of vibrations, performed experiments with eyes open to maintain their arousal level.

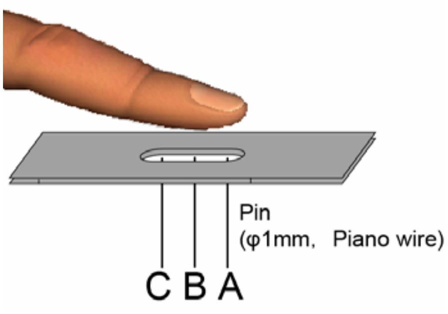

Figure 3 : Experimental apparatus

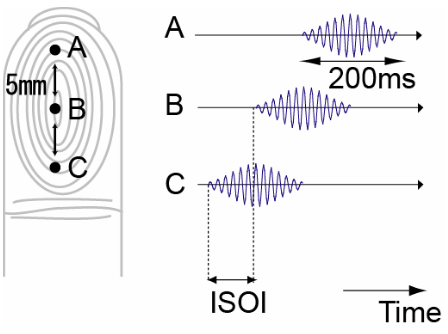

Figure 4 : Stimulus arrangement and time chart

2.2 Procedures

The experimental procedures are described in Figure 5. In the adaptation phase, tactual motion was presented at 100 ms ISOI (that is, the duration of the motion was 400ms). The tactual motion was presented 10 times at 600 ms intervals. After a 10 sec adaptation phase, a 2 sec interval was given, and test stimulus was then presented once with one of nine ISOIs (-120, -60, -30, -15, 0, 15, 30, 60, 120 ms). A positive ISOI value means motion to the fingertip (described as “Upward”), and a negative value means motion to the base of the finger (described as “Downward”). Subjects answered “Upward” or “Downward” with two alternative forced choices.

This experiment was performed under three experimental conditions (Upward adaptation, Downward adaptation, and No adaptation). One session of the experiments consisted of 18 trials (each ISOI included 2 trials). 10 sessions were performed for each condition. The order of sessions were sequential decided (No adaptation -> Upward adaptation, -> Downward adaptation -> No adaptation). Subjects took a enough rest more than 5 minutes between sessions. A total of 600 trials were performed for each subject (20 trials x 10 sessions x 3 conditions).

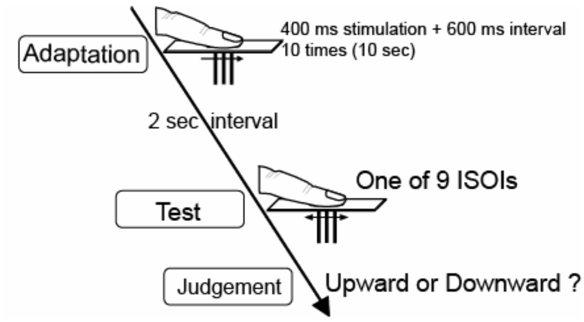

Figure 5 : Experimental procedures

2.3 Results in a Vertical Motion Condition

Figure 6 shows the rates of “Upward” responses obtained. The horizontal and vertical axes represent ISOI of the pins in a log scale, and the rate of a subject’s response of “Upward”. The blue triangles, green crosses and red circles represent the averages of each of 20 trials in No, Upward and Downward adaptation conditions, respectively. A thin blue line, a dotted green line and a broken red line indicate the fitted line with cumulative normal distribution. In the data of No adaptation (blue triangles), when ISOI was 0, the rate of an “Upward” answer was about 0.5. When an ISOI of 120 ms was presented, all subjects in all trials answered “Upward”. On the other hand, when an ISOI of −120 ms was presented, the rate declined to zero. If upward motion was presented in an adaptation phase (green crosses), less “Upward” responses were obtained in the wide range of ISOIs. On the other hand, in the downward condition (red circles), the rate of “Upward” responses increased. These tendencies were observed for all subjects, except in the downward adaptation condition of subject AK.

The Point of Subjective Equality was calculated for all adaptation conditions. The shifts of PSEs in a downward (upward) condition from a no adaptation condition are shown in Figure 7. The error bars represent standard errors. The averaged PSEs are -13.9 ms in the downward condition, and +14.9 ms in the upward condition. Considering standard errors, we can conclude that the tactual motion adaptation affects the perceived direction of motion presented in the test phase, and that the number of responses in the opposite direction to the adapted motion direction systematically increased.

2.4 Results in Horizontal Motion, Rotation Motion and Long Distance Motion Conditions

Our next investigation looked various ways for motion aftereffects. We tested adaptation phenomenon in horizontal, rotating, and long distance motions. In the case of horizontal motion, the pins were horizontally arranged with 5 mm spatial intervals, as illustrated on the left in Figure 8(a). The same experimental procedures as in the case of the vertical motion without ISOI variation were used. The ISOI presented in the horizontal motion condition were -30, 0, and +30 ms. A positive value means that leftward motion was presented, and vice versa. The averages and standard errors of four subjects are shown on the right in Figure 8(a). The vertical and horizontal axes represent the rate of the response “Leftward” and ISOIs, respectively (The vertical and horizontal axes of all the following graphs represent the rate of the responses and ISOIs respectively. Both averages and standard errors of the four subjects are shown.). Leftward and rightward adaptation conditions were performed. In general, when ISOI increased, more “Leftward” responses were obtained. For the Rightward adaptation condition (red circle), more “Leftward” responses were obtained than in the leftward adaptation condition (green cross). This trend suggests that the tactile motion aftereffect can also be observed in horizontal motion.

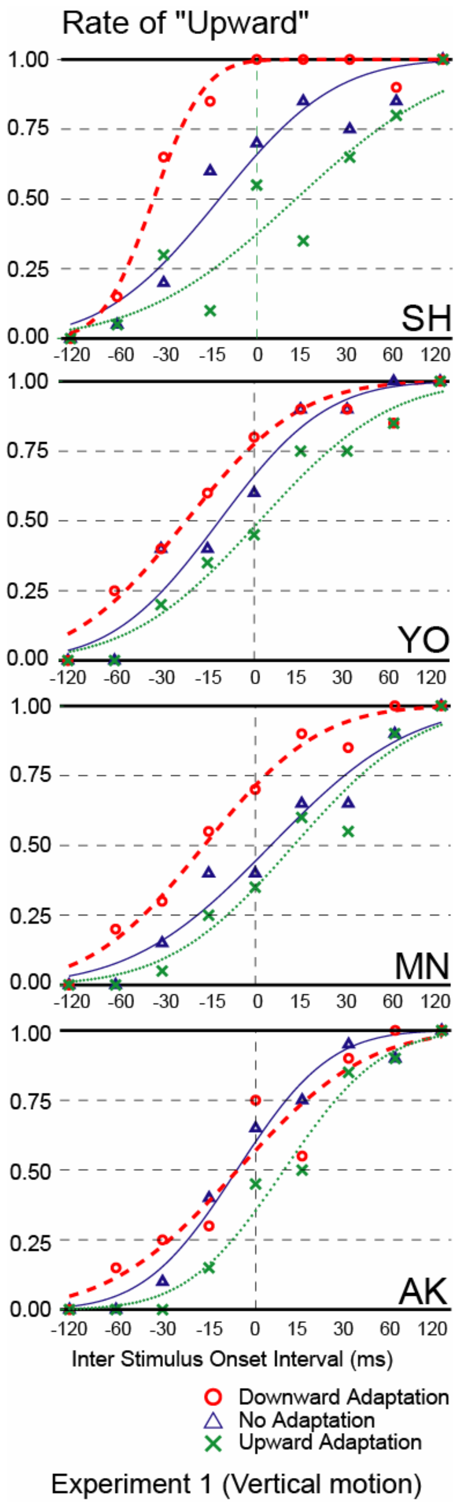

Figure 6 : Results of the experiment for vertical tactual motion. Horizontal and vertical axes represent ISOI (ms) in log scale and the rate of subjects’ “Upward” responses

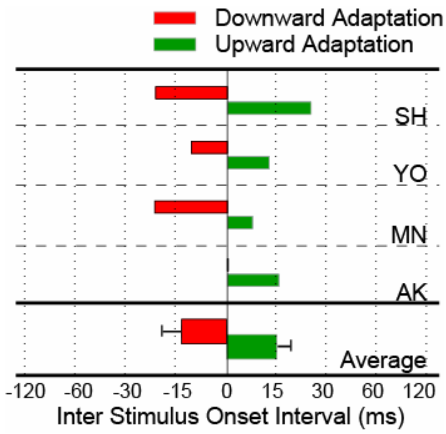

Figure 7 : Shift of PSE caused by adaptation (error bars correspond to standard errors)

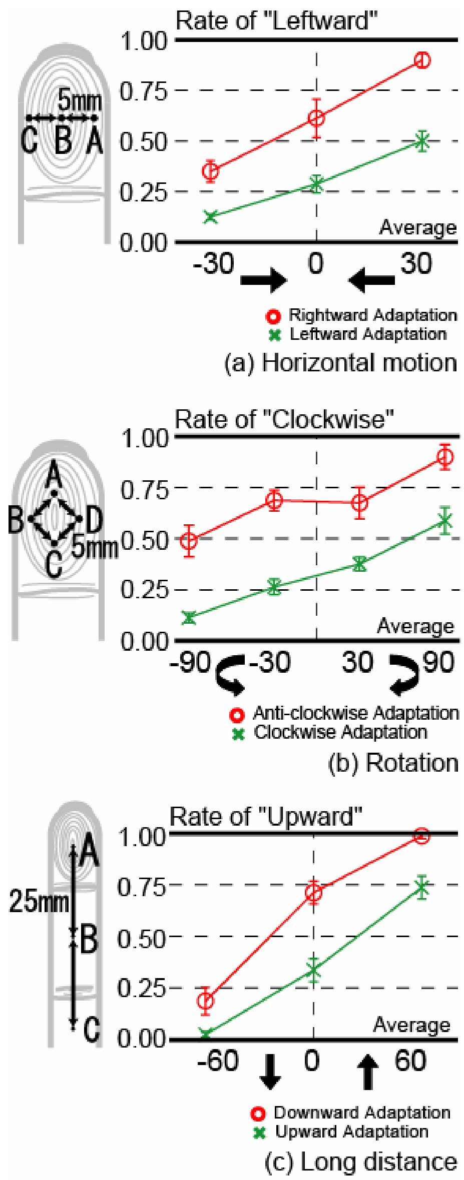

Figure 8 : Stimulus arrangements and results under (a) horizontal motion, (b) rotation, and (c) long distance conditions

In the case of rotating motion, the pins were arranged in a square with 5 mm spatial intervals as illustrated in Figure 8(b) left. Pins were vibrated clockwise or anti-clockwise, that is A-D-C-B-A or A-B-C-D-A, respectively. Smooth circular motion was perceived not discrete square motion. The presented ISOI was varied in −90, -30, +30, and +90. The results are shown on the right in Figure 8(b). Positive values in the horizontal axis mean that clockwise motion was presented, and vice versa. When ISOI increased, more "Clockwise" responses were obtained. For the anti-clockwise adaptation condition (red circle), more "Clockwise" responses were obtained than in the clockwise adaptation condition (green cross); suggesting that the tactual motion aftereffect can also be observed also in rotating motion.

In the case of long distance motion, the pins were vertically arranged with 25 mm spatial intervals, as illustrated on the left in Figure 8(c). Although the motion sensations were weaker than those in the first experiment, the subjects rather perceived the sequential stimuli as motion, than as separate three stimuli. The presented ISOI was varied in −60, 0, and +60. The results are shown on the right in Figure 8(c). Subjects gave more "Upward" answers in the downward adaptation. Divergence between adaptation conditions was also observed, which indicates the occurrence of tactual MAE in long distance motion.

3 DISCUSSION

3.1 Differences between this and earlier reports

We demonstrated that tactual motion aftereffect can be observed when appropriate combinations of adaptation and test stimuli are employed. There are differences between earlier studies that did not report robust tactual motion aftereffects, and our experiments. Tactual mechanoreceptors, which would be stimulated in the rotating drum (Hollins & Favorov, 1994), the Optacon (Lerner & Craig, 2002), and the pin stimuli (our) experiments, are shown in Table 1. The upper rows represent the statuses in the adaptation phase and the lower rows represent those in the test phase. When a fast rotating drum is presented to the palm, as in the Hollins' experiments, mainly the mechanoreceptor RAI would be stimulated. A static drum, however, which was used as the test stimuli, would activate only SAI. As a result, the adapted mechanoreceptor (RAI) was not stimulated in the test phase. The results in Lerner's studies can be ascribed to this misallocation of adapting and testing stimuli. When the Optacon was used as the stimulating device, the perceived motion was generated by successive stimulation with rows of pins. This method produces a motion sensation in a way that is different from the way produced by the rotating drum. It was actually reported that the Optacon array will not activate SAI in a barbiturate-anesthetized monkey study [6]. In Lerner's experiments, however, the subjects held their finger in midair; thus mechanoreceptors were not activated after the adaptation phase (if mechanoreceptors were activated without any tactual stimulation, humans would always have some kind of tactual feeling, even when not touching anything). Appropriate tactual stimuli are necessary in the test phases to generate feelings of MAEs. On the other hand, the same mechanoreceptor (RAI) was stimulated in the adaptation and test phases in our experiment. Therefore, tactile MAEs could be observed.

	Drum (Hollins)	Optacon (Lerner)	Pins (This paper)
Adapt			
SAI	X		
RAI	XXX	XXX	XXX
Test			
SAI	XXX		
RAI			XXX

Table 1: Tactual mechanoreceptors that would be stimulated in rotating drum, Optacon, and our experiments.

3.2 Tactual Motion Perception and Somatosensory information

Our clear observation of tactile MAE indicates that the MAE can be used for investigating the tactual motion processing mechanism. Tactual motion can be perceived in both the local skin and environmental coordinates. In the former, motion is perceived based on the relative configuration on the finger cushion. In the latter, the direction of the motion on the skin can be translated using the information of the hand position into motion in the environmental coordinate. Here we clarify which coordinate is employed for tactual motion perception using the motion adaptation phenomenon.

The experimental apparatus, procedure and the subjects were the same as in the experiment for the horizontal motion condition, without finger direction during the adaptation phase. The subjects rotated their wrists by 180 degrees, and placed their index fingers in the opposite direction to the previous experiment as illustrated in Figure 9. After an adaptation phase, they turned their hands and then, placed their finger in the normal way. When the subject adapts to the motion toward the middle finger (leftward motion in the environmental coordinate), if tactile motion was perceived based on the local skin coordinate, the subject would report MAE to the thumb (the same direction as in the adaptation phase in the environmental coordinate) irrelevant of the hand direction. On the other hand, if it were perceived based on the environmental coordinate, the subject would report MAE toward the middle finger (rightward motion).

The ISOI presented varied in −45, -15, +15, and +45. The results are shown in Figure 9. The vertical and horizontal axes represent the rate of the "Leftward" response in the environmental coordinate and ISOIs, respectively. When leftward motion was presented in the adaptation phase (motion toward the middle finger), more "Leftward" (motion toward the thumb) responses were reported in the test phase than when rightward motion was presented in the adaptation phase. This trend was observed in a wide range of ISOIs, though the amount of adaptation effect was reduced, and this suggests that the tactual MAE occurs in the local skin coordinates.

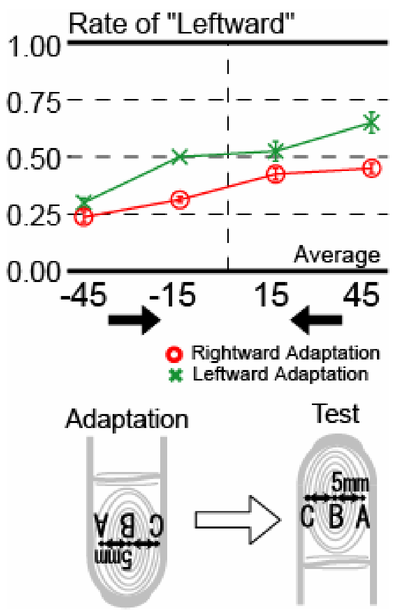

Figure 9 : Stimuli and results of the hand-reversal experiment

4 TACTUAL MAE FOR INTER-FINGER MOTION

We have demonstrated that tactile MAE occurs when the motion is presented within one finger cushion. Tactual apparent motion can also be observed for inter-finger motion produced by two pins that sequentially stimulate the index and middle fingers. We performed three experiments that investigated the mechanism involved in inter-finger motion processing.

In the first experiment, fingers were arranged in the normal way. The index and middle fingers of the right hand were placed at the normal position, as illustrated on the left in Figure 10(a), in both adaptation and test phases. In the second experiment, subjects rotated their wrists by 180 degrees in the adaptation phase, and then placed their fingers normally in the test phase, as shown on the left in Figure 10(b). In the third experiment, the subject's fingers were crossed during the adaptation phase, and the fingers placed normally in the test phase, as in Figure 10(c). The same four subjects performed these experiments.

The results of these three experiments are shown in Figure 10. The ISOI was varied in −45, -15, +15, and +45. The vertical axis represents the rate of the "Leftward" response in the environmental coordinate. In the data from the first experiment, more leftward motion responses were obtained, when subjects adapted to the rightward motion, and similarly vice versa. This indicates that tactual MEA can be observed also when inter-finger motion was presented. In the data from the second experiment, when rightward motion (that is, motion from the middle to the index finger) was presented in the adaptation phase, more rightward motions (motion from the index to the middle finger) were perceived in the test phase. This suggests that tactual MAE also occurs irrelevant of the hand direction for inter-finger motion. On the other hand, in the data from the third experiment, when rightward motion was presented with fingers crossed (from the middle to the index finger) in the adaptation phase, more leftward motion (from the middle to the index finger) responses were observed. Although the order of the finger stimulated in the adaptation phase is from the middle to the index finger (or vice versa), tactile MAE in the same order as the finger was observed. This result suggests that inter-finger motion can be processed using the configuration of the finger positions.

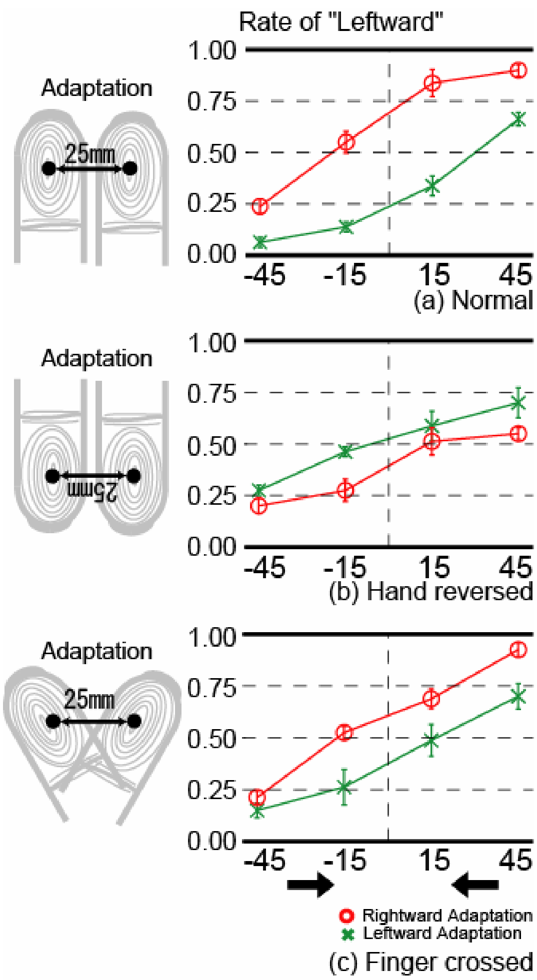

Figure 10 : Adaptation stimuli and results of the inter-finger motion experiments

5 CONCLUSION

In this paper, we demonstrated that the tactual motion adaptation phenomenon robustly occurs for motion presented both within a finger cushion and inter-finger. For this we used appropriate combinations of adaptation and test stimuli. Additionally, we utilized the phenomenon to investigate the functional mechanisms involved in tactual motion processing. Our results indicate that an adaptation paradigm can be used to investigate not only visual but also tactual motion processing.

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