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# A study on line length and direction perception via cutaneous sensation

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**Abstract:** In this paper, we studied the contribution of the cutaneous sensation in the perception of the line segment's length and direction through psychophysical experiments where a mechatronic stage was utilized to express virtual line segments. The perceived lengths and directions were compared to the true values, and the mean errors, the standard deviations, and RMSE (Root Mean Square Error) were examined. As the results of the examinations, it was found as for the mean error of the perceived length that the more the length is increased from 10 to 90 mm, the more the subjects perceived decreased length from about 0 to 30%. As for the mean error of the perceived direction, another finding was that the subjects can recognize the direction with less than errors of about 10 degrees in the counter-clock wise direction.

**Keywords:** haptic display, length perception, direction perception, cutaneous sensation.

## 1 INTRODUCTION

Support systems have been developed to improve communication and quality of life for the people in need. Human can accept objects' geometrical information such as the lengths and directions of the line segments as the results of physical contacts [1]. Therefore, as an alternative for visually impaired persons, to create mental images of the objects, researchers have been studying human haptic sensational characteristics in the object perception. As for the objects, the representative ones are line segments, and they were provided as the raised dots and edges, rods, and ditches [2, 3, 4, 5], and, nowadays, by virtue of the development of robotic technologies [6, 7], the objects can be virtually represented by a feedback force as in this paper.

Here, the perceptual processes with the contacts can be categorized from the two viewpoints. The first is the sense organs; (1) the cutaneous sense on a fingertip abdomen (where the index finger is often used) (2) the proprioceptive sense such as the joint rotation and the kinematic/force sense relating to muscle expansions and contractions, and (3) the combination of both the cutaneous and the proprioceptive.

The second sense, i.e., the proprioceptive sense is with the movements of his/her hand, and it works only when his/her hand moves. Here, the person can take initiative against the outside world in the perceptual process, and the person moves his/her hand voluntarily: the mode of movement is called "active" in this paper [19, 20]. On the other hand, the outside world, vice versa, can take initiative against the person in the perceptual process, and his/her hand is forcibly moved by external actuators: the mode of movement is called passive movement [19, 20]. That is, as for the proprioceptive sense, we should consider the two modes: (1) the passive movement when the person has his/her hand motion activated by actuators, and (2) the active movement when the person voluntarily activates his/her hand to gain some haptic information about the outside world. Therefore, relating to the proprioceptive sense, both active and passive movements should be considered, which results in the following four modes: (1) PrPa mode (proprioceptive passive), (2) CoPa mode (combined passive), (3) PrAc mode (proprioceptive active), and (4) CoAc mode (combined active) [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21]. As a result, five modes would be considered in the haptic perception, and these five modes is considered to be important in practical situations.

As for the sense, i.e., the cutaneous sense itself, even though his/her hand is stationary or not, the cutaneous sense works if the touched object moves relatively to his/her fingertip, and causes slip to the fingertip abdomens. Thus, we can consider a mode, i.e., (5) CuPa mode (cutaneous passive): the person keeps his/her hand stationary while the outside object moves, and he/she passively gets information through the physical interactions between the fingertips and the outside object.

The cutaneous sense is considered to enhance the performance of the proprioceptive sense in the combination, and, therefore, the CuPa mode must be a key issue in considering the performances of the above mentioned five modes since the CoPa mode is an integration of CuPa and PrPa, and the CoAc mode is an integration of CuPa and PrAc.

In this paper, we studied the contribution of the cutaneous sensation in the perception of the line segment's length and direction through psychophysical experiments where a mechatronic stage was utilized to express virtual line segments.

## 2 EXPERIMENTAL METHOD

### 2.1 Apparatus

**Fig.1.** shows the experimental apparatus. The length, width and height of table base are 510 × 500 × 610 mm, respectively. It consisted of a power supply, a controller, an acrylic plate with a hole, a flat plate, a linear actuator and a rotation board. The acrylic plate was mounted on top of the flat plate. The hole was at the center of the acrylic plate. The gap between the two plates was set at 6 mm. The flat plate was attached on the top of the linear actuator (IAI-ICSA series) and it could be moved in the left and right direction in 300 mm range. The linear actuator was mounted to the top of the rotation board so that it could be rotated 360 degrees.

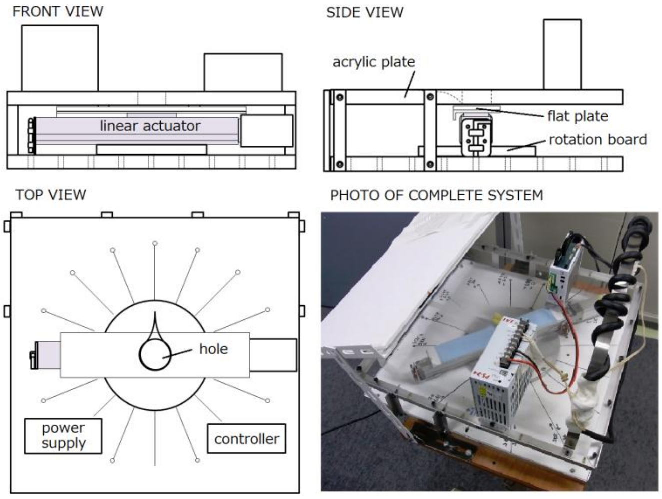



**Fig.1.** Experimental apparatus

### 2.2 Subjects

Eight right-handed subjects (male students, aged 22 to 35 years) volunteered for their participation. None of the subjects had a neurological disorder affecting the hands and fingers. None of subjects had any previous experience with the stimuli or tasks used in this study.

### 2.3 Task

The line lengths presented were 10, 30, 50, 70, 90 mm and the directions were 0 to 360 degrees with the interval of 22.5 degrees: the number of pieces of the presented lengths is five and that of the directions is 16. Subjects were asked to choose which line segment corresponded to the tested one among the multiple solutions presented on the answer board. This answer board consisted of a reference pattern as shown in **Fig.2.,** that was composed of concentric circles of which radiuses were 5 to 125 mm with the interval of 5 mm. All the patterns of 80 line segments with 5 lengths by 16 directions were presented in pseudo random order. All the experiments were carried out with a speed of 50, 100,141 and 200 mm/s.

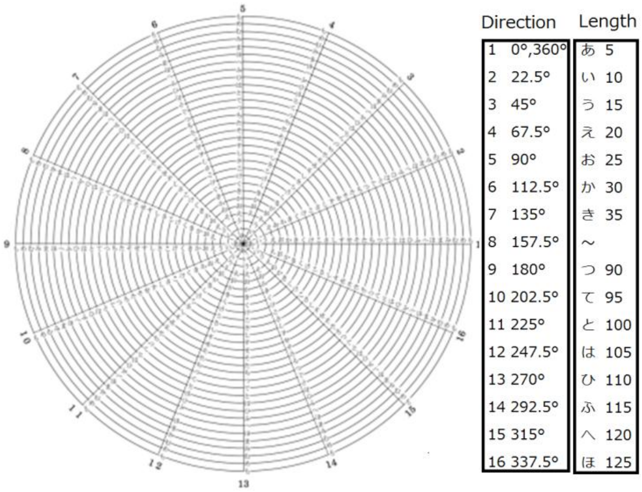



**Fig.2.** Answer board

### 2.4 Procedure

**Fig.3.** shows the experimental views. The subjects were comfortably seated in a chair (**Fig.3.(b)**) with their right hand on the acrylic plate (**Fig.3.(a)**). During experiment, subjects were instructed to relax, close their eyes, and focus on the perception of the length and direction of the presented line segment through the cutaneous sensation of his/her index finger. The subjects put their index fingertip abdomen on the surface of the flat plate (**Fig.3.(a)**), at that same time the subjects arm angle was positioned at 90 degrees or horizontal to table base (**Fig.3.(c)**). The subject shoulder was on the mid-sagittal axis, aligned with the hole in the acrylic plate (**Fig.3.(d)**). Headphones with white noise were provided to the subject to prevent hearing the sound generated by linear actuator. The white noise was played at a volume just below the irritation threshold to mask any remaining sound cues and avoid any side effects on the spatial perception. Stimulation starts when fingertip is at an end of the line stimulus and stops when it reaches the other end. The velocity is generated by the linear actuator controlled with a computer and the software X-SEL. It should be noted that the speed of movement is driven with a rectangular velocity pattern. The direction of the linear actuator was set by manual operation each time. The velocity and angle were pseudo-randomly assigned for each subject. After the experiment, subjects open their eyes

and, by looking at the answer board, they give their perceived direction and length by stating a number between 1 and 16 and a letter between A and HO (**Fig.3.(b)**). The whole experiment took 25-35 minutes per subject.

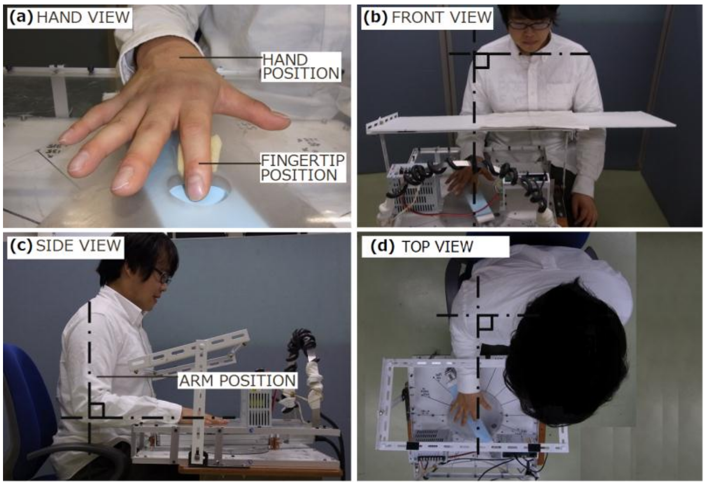



**Fig.3.** Experimental view

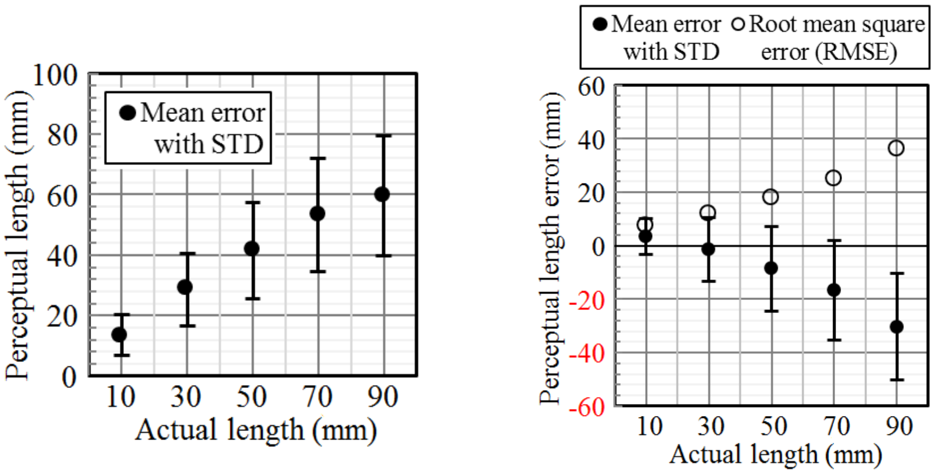
## 3 RESULTS AND DISCUSSION

### 3.1 Analysis of length

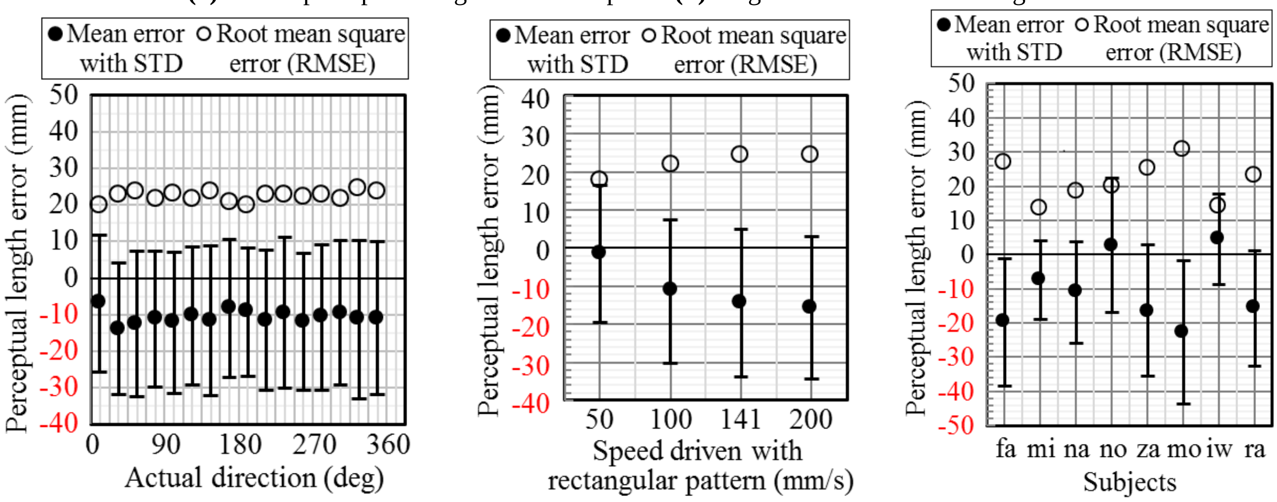
**Fig.4.** shows the experimental results with the length perceptual error characteristics.

(1) **Fig.4.(a)** shows the actual-perceptual length relationship. Form this data, the errors were obtained and plotted in **Fig.4.(b)**.

(2) **Fig.4.(b)** shows the length-caused foreshortening effect with the length perceptual error.
The systematic errors: in the case of the actual length of 10 mm, the perceptual length mean error was positive with less than 5 %. On the other hand, the longer the actual length was than 30 mm, the more the magnitude of the perceptual length mean error increased in the negative value up to 30 % at 90 mm of actual length.
The random errors: for all the variations of the actual lengths, the longer the actual length was, the more the




**(a)** Actual-perceptual length relationship **(b)**Length-caused foreshortening effect




**(c)** Directionally isotropic characteristic **(d)** Speed-caused foreshortening effect **(e)** Individual variation with subjects

**Fig.4.** Experimental results with the length perceptual error characteristics

STD of the perceptual length deviations increased, Therefore, RMSE (Root Mean Square Error) was raised up.

(3) **Fig.4.(c)** shows the directionally isotropic characteristic with the length perceptual error. The direction of subjects shows RMSE stayed constant at approximately 20 degree.

(4) **Fig.4.(d)** shows the speed-caused foreshortening effect with the length perceptual error. Perceptual the length was perceived shorter as velocity increased more than 100 mm/s and this became significant as the length became longer.

(5) **Fig.4.(e)** shows the subjects with the length perceptual error. Individual variation with the eight subjects was observed, and its STD was given by 10 mm.
For six out of the eight subjects, a more or less beneficial effect was found of having perceptual length.

### 3.2. Analysis of direction

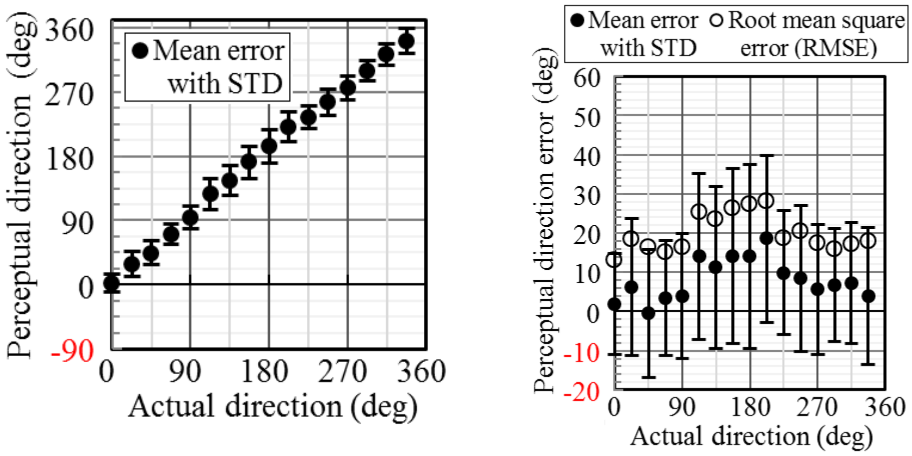
**Fig.5.** shows the experimental results with direction perceptual error characteristics.

(1) **Fig.5.(a)** shows the actual-perceptual direction relationship. Form this data, the errors were obtained and plotted in **Fig.5.(b)**.

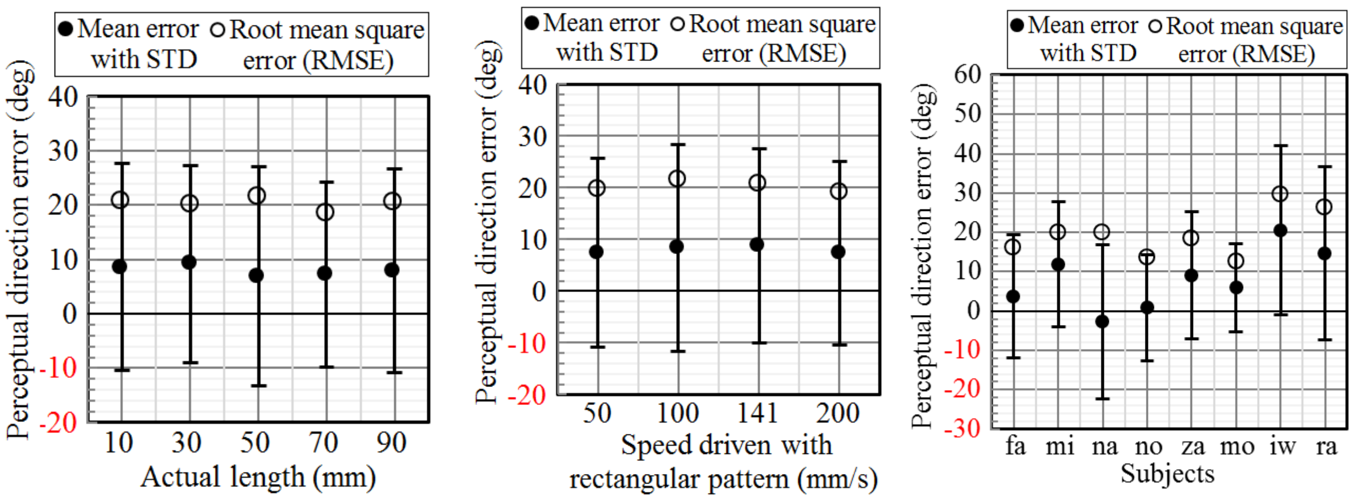
(2) **Fig.5.(b)** shows direction-related rotating effect: the subjects perceived the direction with the additional value of about 0 to 15 degrees in the counter-clock wise direction. The rotating effect of the mean error shows greater by about 15 degrees in the upper-left direction (in the region of actual direction between 112.5 and 202.5 degrees where the rightward direction is defined as zero degree), meanwhile, it shows less by about 0 to 5 degrees in the remaining direction. As for the STD, they are almost identical over the whole direction.

(3) **Fig.5.(c)** shows the length invariant characteristics with the directional perceptual error. The mean errors and RMSE shows no significant change against the actual length variation.

(4) **Fig.5.(d)** shows the speed invariant characteristics with the directional perceptual error. The mean errors and




**(a)** Actual-perceptual direction relationship **(b)** Direction-related rotating effect




**(c)** Length invariant characteristic **(d)** Speed invariant characteristics **(e)** Individual variation with subjects

**Fig.5.** Experimental results with the directional perceptual error characteristics

RMSE shows that no significant change was found when changing the speed.

(5) **Fig.5.(e)** shows the between-subjects individual variation with the directional perceptual error. The mean error with the directional perception shows that all the subjects have different sensitivity between 0 and 20 degrees in the counter-clock wise direction.

## 4 CONCLUSIONS

The perceived lengths and directions were compared to the true values, and the mean errors, the standard deviations, and RMSE were examined. The results are

(1) As for length perception, the more the length is increased from 10 to 90 mm, the more the subjects perceived decreased length from about 0 to 30% .

(2) As for the direction perception, another finding was that the subjects can recognize the direction with the mean errors of about 10 degrees in the counter-clock wise direction.

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