

MEASUREMENTS OF VELVET HAND ILLUSION BY MAGNITUDE ESTIMATION AND PAIRED COMPARISON

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Abstract

The purpose of this study was to measure the level of the Velvet Hand Illusion (VHI) and to propose mechanisms that produce the VHI. The experimental stimuli were instruments with two straight rods positioned parallel to each other. The participant held the two rods between his/her hands and moved both hands simultaneously in the direction orthogonal to the rods. The participants judged the level of the VHI by the methods of magnitude estimation and paired comparison. Both methods gave the highest level of the VHI when the distance between the rods was 100 mm, and the lower level of the VHI when the distance was larger or smaller than 100 mm. In this paper, we described the experiments and presented a simulation model to explain the VHI levels, and we suggested the mechanisms that produce the VHI.

One can easily feel the Velvet Hand Illusion (VHI) by holding a coarse-wire net between both hands and moving them simultaneously on the net. The surface of the contralateral hand feels very soft and smooth, as if one is touching the surface of velvet. But, wire is not needed for experiencing the VHI: two rods positioned parallel to each other (shown in Fig. 1) will also suffice. If one holds the two rods between his/her hands and moves both hands simultaneously in the direction orthogonal to the rods, the same perception as that by the coarse-wire net can be experienced.

The VHI is one of the clearest illusions in tactile sensation. But only a few studies have been conducted and the mechanisms to produce the VHI have not been found (Ohka et al., 2010; Rajaei et al., 2012). The purpose of the current study was to measure the level of the VHI by two methods, magnitude estimation and paired comparison. We produced a mathematical model to explain the level of the VHI, and we proposed the brain mechanisms that make the VHI possible.

Experiment 1

The purpose of Experiment 1 was to determine the level of the VHI. In this experiment, we adopted the magnitude-estimation method, which uses a modulus.

Method

Participants: Eight males and one female in their twenties participated in Experiment 1. None of the participants had prior experience of this type of experiment.

Stimuli: Two straight rods were used as stimuli. As shown in Figure 1, the rods were set in a U-shaped frame. The two rods were positioned parallel to each other. The diameters of the rods and the frame were 3 mm and 8 mm, respectively. The rods and the frame were made of

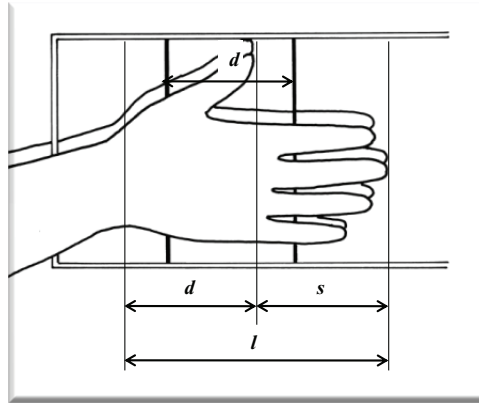


Figure 1. An example of the stimuli used in Experiments 1 and 2. The participant held two rods between both hands and moved the hands simultaneously in the orthogonal direction to the rods. The distance between the two rods is d . The length of the hand movement is s . The length of the palm region is l .

iron covered by plastic. Seven distances between the rods (d in Figure 1) were used in Experiment 1: 20, 40, 60, 80, 100, 120, and 140 mm.

Procedure: The participant was seated in a chair and wore an eye mask to prevent visual inspection of the stimuli. Two stimuli, one that was a standard stimulus and the other one that was a comparison stimulus, were set on a desk in front of the participant. The two stimuli were set on the right and left sides from the participant's viewpoint and 25 cm apart from each other. In the magnitude-estimation procedure, a modulus was used. The stimulus with the 80 mm distance between rods was chosen as the "standard" stimulus and given the modulus number "100". The participant was asked to assign a number as the illusion level of the comparison stimulus when it was compared with the illusion level of the standard stimulus. The experimenter informed the participant which was the standard stimulus in the two stimuli set on the right and left sides.

The maximum presentation time of one set of stimuli was 15 seconds and inter-stimulus interval was 20 seconds. Each participant responded 20 times for each stimulus set. Therefore, the total number of experimental trials for each participant was 140. The presentation order of each set was random.

The temperature in the laboratory was maintained at higher than 25°C in the experimental period to avoid the decrease of tactile sensation.

Results and discussion

The geometric mean values of the magnitude estimation were calculated based on the experimental data of the nine participants. The results are shown in Figure 2. The diamonds in the figure are the means of the magnitude estimations.

This figure shows that the mean values of the magnitude estimations increased when the distances between the two rods increased from 20 mm to 80 mm, and reached a maximum at 80 mm (mean: 102) and at 100 mm (mean: 103). The magnitude-estimation values decreased when the distances increased to more than 100 mm. For example, the magnitude-estimation values were 66.1 at 140 mm.

The participants reported that the tactile impression of the two rods was strong in the

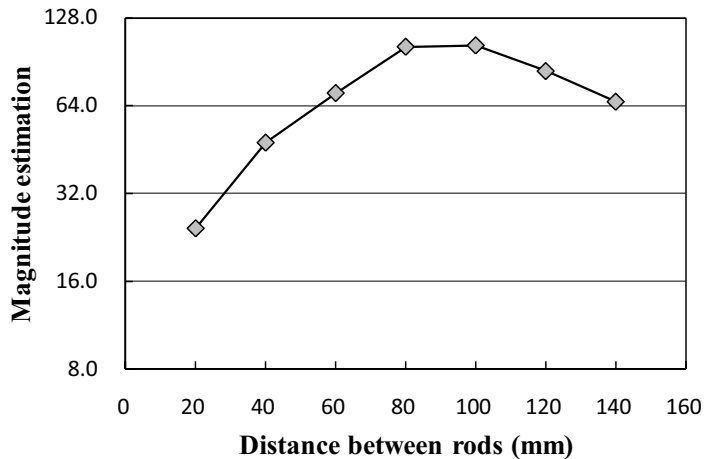


Figure 2. Levels of the VHI measured by the magnitude-estimation method. The vertical axis shows the magnitude-estimation value and the horizontal axis shows the distance between the rods. Each diamond symbol in the figure shows the geometric mean of the magnitude-estimation value.

20 mm distance condition. The shorter distance masked the illusion and the VHI became weak. In contrast, the participants reported that the 140 mm distance was too large to allow enough hand movement (s in Figure 1) and the illusion became weaker.

The results of the magnitude-estimation experiment showed that the levels of the VHI were determined by the distances between the rods. The curve of the illusion level was convex upward and the VHI were at the highest level when the distances of the rods were between 80 and 100 mm. The illusion level decreased below 80 mm and above 100 mm, but the causes for making the illusion decrease might be different between the short and long distances of the rods.

Experiment 2

The purpose of Experiment 2 was to determine the levels of the VHI by the method of paired comparison. The relative magnitudes of VHI were calculated using Thurstone's Case V method.

Method

Participants: Ten males and one female in their twenties participated in Experiment 2. None had prior experience of a paired-comparison experiment.

Stimuli: The same types of stimuli as in Experiment 1 (shown in Figure 1) were adopted in Experiment 2. Seven stimuli were given with the following distances between rods (d in Figure 1): 80, 85, 90, 95, 100, 105, and 110 mm.

Procedure: The participant was seated in a chair and wore an eye mask. Two stimuli were set on the desk. The method for the stimulus setting was the same as that for Experiment 1. The participant touched the two stimuli successively and compared the levels of the VHI of the two stimuli. The participant determined which stimulus produced a larger illusion and responded by the two-alternative forced-choice technique.

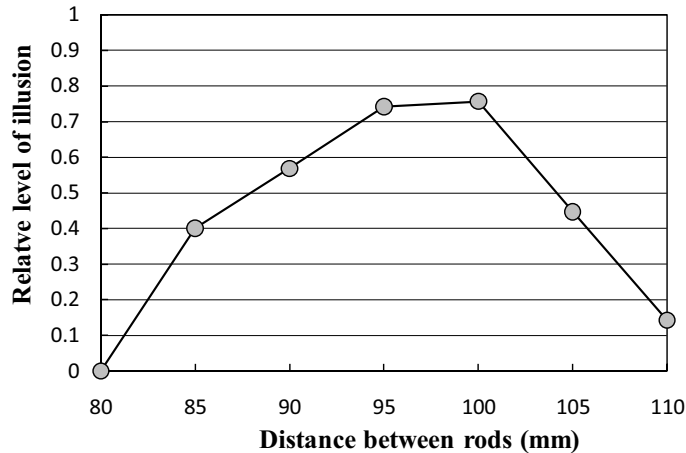


Figure 3. The VHI measured by the method of paired comparison. The vertical axis shows the relative level of illusion. The horizontal axis shows the distance between the rods. Each symbol in the figure shows the relative level of the VHI.

The number of combinations for choosing two stimuli from the seven distinct stimuli was 21. Since it was necessary to counterbalance the right and left side positions of the stimuli, the total number of combinations was 42. The maximum presenting time of a stimulus set was 15 seconds and the inter-stimulus interval was 20 seconds. Each participant performed 10 trials for each combination. Therefore, the total number of experimental trials was 420 for each participant.

Other experimental conditions were the same as those in Experiment 1.

Results and discussion

The relative VHI levels were calculated by Thurstone's Case V method, based on the paired-comparison data of the eleven participants. The results are shown in Figure 3. The circles in the figure show the relative levels of the VHI. The illusion level was set to zero when the distance between the two rods was 80 mm. The illusion levels increased from 80 mm, reached the maximum at 100 mm (relative level of illusion = 0.757), and decreased above 100 mm.

The patterns of the curves of the magnitude estimation (Experiment 1) and of the paired comparison were generally similar to each other. However, their details were different. The illusion levels in the magnitude-estimation experiment did not change much between 80 mm and 120 mm (80 mm: mean 102, 100 mm: mean 103, and 120 mm: mean 84.2). However the illusion levels in the paired-comparison method greatly changed; the illusion levels in the paired-comparison method were a relative one and, generally speaking, the paired-comparison method is more accurate than the magnitude-estimation method.

From the results of both experiments, we induced the following hypothesis:

- (1) When the distance between two rods is short, the impression of the rods is strong and masks the VHI. By increasing the distance, the levels of the VHI become high.
- (2) The VHI level is high when the distance between the two rods is not too long and the participant can move his/her hands enough to touch both rods. The illusion levels decrease if the participant cannot touch both rods simultaneously when he/she moves both hands.

General discussion

We explain the simulation model of the VHI first and then propose the mechanisms that make the VHI possible.

Simulation model of the VHI

Suppose that the level of the VHI is determined by the length of the palm region (l in Figure 1), the distance between the two rods (d in Figure 1), and the length of the hand movement (s in Figure 1). The participant holds the rods between his/her hands and sets the wrist joint at the same position of the proximal side of the rod and moves both hands in the proximal direction.

The VHI occurs at a maximum level when $0 < d \leq l - sc$, where sc is a constant to determine the beginning point of the VHI decrease. The VHI decreases when $l - sc < d \leq l$. The VHI does not occur when $d > l$, because the participant touches only one rod. These conditions are modeled as

$$\begin{cases} f_1(d) = 1 & (0 < d \leq l - sc) \\ f_1(d) = -\frac{1}{sc^2} \{d - (l - sc)\}^2 + 1 & (l - sc < d \leq l) \end{cases} \quad (1)$$

Equation (1) is shown by the diamonds and the dotted line in Figure 4, where $l = 170$ mm and $sc = 90$ mm.

The level of the VHI also changes depending on the distance between the two rods. When the distance is short, the impression of the rods is strong and masks the illusion. When the distance becomes longer, the VHI becomes larger. These relations are modeled as

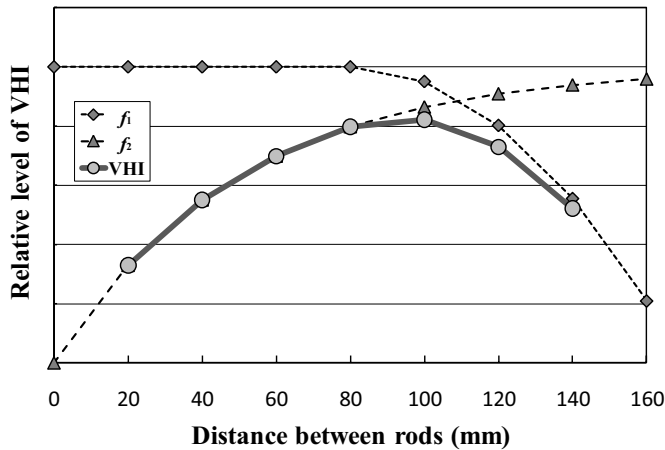


Figure 4. The simulation model of the VHI. The terms f_1 and the f_2 in the legend mean $f_1(d)$ and $f_2(d)$, respectively. The levels of the VHI are determined by multiplication of $f_1(d)$ and $f_2(d)$ and are shown by the thick line.

$$f_2(d) = \frac{e^{ad} - 1}{e^{ad}} \quad (2)$$

where a is a time-constant parameter. Equation (2) is shown by the triangles and the dashed line, where $a = 0.02$.

The total levels of the VHI are presented as the multiplication of $f_1(d)$ and $f_2(d)$ and are shown by the circles and the thick line in Figure 4. The simulation model explains, in particular, the convex curve of Experiment 1 well.

Inference of mechanisms that make the VHI possible

We proposed the emergence mechanisms of the VHI as follows.

The participant holds a coarse-wire net between his/her hands and moves both hands simultaneously. He/she touches the wire net and the surface of his/her hands. The wire net moves against the hands, but the hands do not move against each other because the participant moves both hands simultaneously. The contralateral surface of the hand gives no friction. The brain of the participant infers that the hands are moving on the surface of some objects. But the contralateral surface of the other hand gives no friction. Therefore, the brain concludes that the contralateral surface of the hand is very smooth and soft.

Conclusion

In this study, we performed magnitude-estimation and paired-comparison experiments, and showed that the level of the Velvet Hand Illusion was the highest when the distance of the rods was 100 mm. We presented a simulation model to explain the level of the VHI, and proposed mechanisms that produce the VHI. Further studies are needed to reveal the neural mechanisms that produce the VHI.

References

- Ohka, M., Kawabe, Y., Abdullah, C., Rajaei, N., Yussof, H. B., and Miyaoka, T. (2010). Investigation on Velvet Hand Illusion using psychophysics and FEM Analysis. *International Journal of Smart Sensing and Intelligent Systems*, 3, 488-503.
- Rajaei, N., Kawabe, Y., Ohka, M., Miyaoka, T., Chami, A., and Yussof, H. B. (2012). Psychophysical experiments on Velvet Hand Illusion toward presenting virtual feeling of material. *International Journal of Social Robotics*, (online).