Sliding Raised-Dots Perceptual Characteristics

Speed Perception or Dot Count

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Abstract— **The authors have studied new mode of cutaneous sensation characteristics on finger pads toward an accurate physical-line presenting computer-human interface. A series of psychophysical experiments were carried out on motion perception characteristics with the raised dots sliding on finger pads. As a result, it was found that there were two kinds of modes with the perception: (1) dot-counting mode, (2) raised-dots sliding-speed perceptual mode. The first mode worked in the long period of dot spacing and in the low sliding speed conditions, and showed such a high accuracy as a proprioceptive-sensation-based fingertip motion perception. The second mode worked in the short period or in the high speed conditions, and suffered ill performance similar to sliding flat surface.**

Keywords; cutaneous sensation; fingerpad; sliding; raised dots; counting; speed

I. INTRODUCTION

We can accept such geometrical information of objects as the lengths and directions of line-segments via our haptic sensations. Therefore, the haptic sensations have been expected as an alternative for visually impaired persons to create geometrical mental images. In the haptic sensations, there are two important factors: the sensation factor and initiative factor. As for the sensation factor, not only the cutaneous sensation but also the proprioceptive one was employed in perceptual processes. On the other hand, as for the initiative factor in the hand motion activation, there are such two schemes as the passive and active schemes.

The cutaneous sensation is a principal cue in hand-stationary passive touches, and is also used as a supplementary cue to proprioceptive one in hand-moving passive/active touches. Therefore, we can say an importance of investigating human cutaneous sensations for understanding the haptic perceptual mechanism.

Thus, there have been studied many cutaneous-sensation-based perceptual characteristics. For example, slip length perceptual characteristics of moving flat surface were studied in [1]~[4]. Under the active touch condition, Hollins et al. reported a perceived-length formula as a function of velocity and duration [1]. Armstrong et al., focusing on the duration time, suggested that the radial–tangential anisotropy in the length perception can be explained by temporal differences in exploratory movements [2]. In these years, the passive length perception scheme has been studied in detail. For example, Terada et al. found a complimentary characteristic between the cutaneous and proprioceptive sensations and proposed some formula representing the perceived length as the function of velocity dependence and actual-length [3]. Wouter et al. reported that the cutaneous condition (Cu) was much inferior to a proprioceptive condition (Pr) and a cutaneous-combined proprioceptive condition (CuPr). In the CuPr-condition, the cutaneous sensation contributes a little to the Pr-condition [4]. Introducing another important aspect of movement direction, Yusoh et al. have also presented other formulas representing the perceived length as the function of velocity dependence and actual-length [5].

As for the dots-counting sensation that was an important factor in this work, there were few researches except for those on vibrotactile sensations. For examples, papers of [6~9] took up the perception of single site vibration. However, we can't find such similar studies on moving-raised-dots produced stimuli as in this work, and papers of [10~12] took up the perception of pattern-like vibration..

Raised dots have been used for Braille, i.e., dotted letters and for tactile-graphics since they have been considered to be distinctive and informative stimuli for representing geometrical information. Therefore, the raised dots were expected to contribute for new physical-line presenting interfaces: for example, forming raised dots on actively rotating wheel surface, by embedding the wheel, we could make up novel active mouse interface.

Thus, the raised dot was expected to be a promising tactile presentation framework. In this study, paying notice to the sliding-raised dot pathway perception, the authors have studied cutaneous sensation characteristics on finger pads in the passive touch scheme.

In this paper, Section 2 introduced such methodology of experiments as the apparatus and procedures. Next,

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comparing some related existing works, Section 3 presented experimental results with the sliding length perceptual characteristics for the short/long period dot specimens. Here, it was referred that a transition of the sliding dot perceptual mode from dot counting to sliding speed perception occurred even in the long period dot specimen. Finally, Section 4 closed this paper by summarizing important findings.

II. Experimental Method

A. Apparatus

Figure 1 shows the experimental apparatus. The length, width, and height of table base are 510×500×610mm, respectively. It consisted of a power supply, a controller, an acrylic plate with a hole, a specimen plate, a linear actuator (IAI-ICSA series) and a rotation board. The acrylic plate was mounted on the top of the flat plate. A hole was opened at the center of the acrylic plate. The specimen plate, to the top surface of which paper specimen adhered, was attached on the top surface of the linear actuator and it could be moved in both the directions within the 300mm range. The gap between the acrylic and specimen plates was set at 6mm. The linear actuator was, furthermore, mounted to the top of the rotation board so that the linear actuator could be rotated and be fixed at a direction within 360° with an interval of 22.5°.

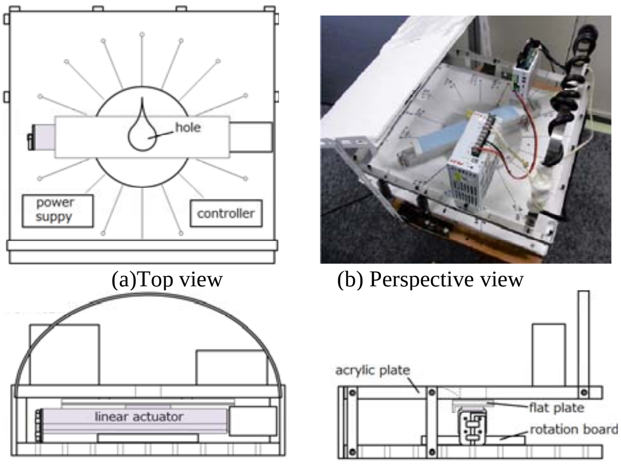


Figure 1. Experimental apparatus: a specimen was moved by a linear actuator on a rotation board.

We introduced two kinds of specimens, on the surfaces of which a raised dot pathway was formed so as to be aligned in straight: one specimen had a 20.1mm-period of raised dots and the other did a 2.5mm-period. The raised dots were 1.5mm in diameter and 0.4mm in height (see Figure 2). In the case of 20.1mm period dot, the dot appeared one-by-one on the contacting fingerpad. On the other hand, in the other case of 2.5 mm period, multiple dots contacted with the fingerpad. This gave birth to an important difference in perceptual mode between the two periods. In the case of 20.1mm period, we could perceive each of the sliding raised dots one-by-one with the finger pad cutaneous sensation and could count the number. Meanwhile, in the other case of 2.5mm period, we no longer could not count them but, as an alternative, perceived sliding speed of the raised dot. The characteristics for both of the perceptual modes were discussed in the experiments.

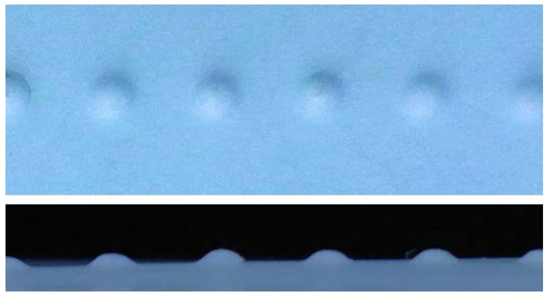


Figure 2. Specimen (upper: top view. lower: front view).

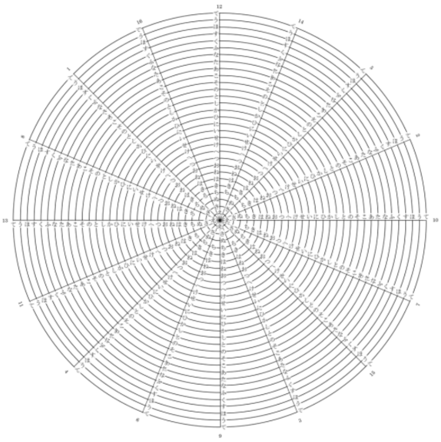
B. Procedures

1) Conditions

The line lengths being presented were 50, 75, 100, 125, 150mm, and the directions were set at 0 to 360° with an interval of 22.5°. Therefore, the number of presented lengths was five and that of the directions was 16. In the case of 20.1mm period, the lengths, 50, 75, 100, 125, 150mm, corresponded to 2, 3, 4, 6, and 7 dots, respectively. The 80 line segment patterns by 5 lengths and 16 directions were presented in pseudo random orders. All the experiments were carried out with the speeds of 25, 50, 75, 100, 125, 150, 175 and 200mm/s. Five subjects aged 22 to 57 years old participated in the experiments.

2) Task

In the case of 2.5mm period dots, the subjects were informed to perceive both the sliding length and direction during the dotted paper specimen sliding on his fingerpad. They were also asked to make oral reports of the perceived length and direction with the character-represented codes: the codes were written on an answer board being showing concentric circles, of which radii were 5 to 200mm with a 5mm interval (see Figure 3). In the other case of the 20.1mm-period-dot, the subjects were informed to count the number of the dots, and also to perceive the sliding direction as one of the 16 candidate directions during the dotted specimen sliding on their finger pad. Just after the slide having been finished, the subjects made oral reports of the frequency of counted dots, and the perceived direction.



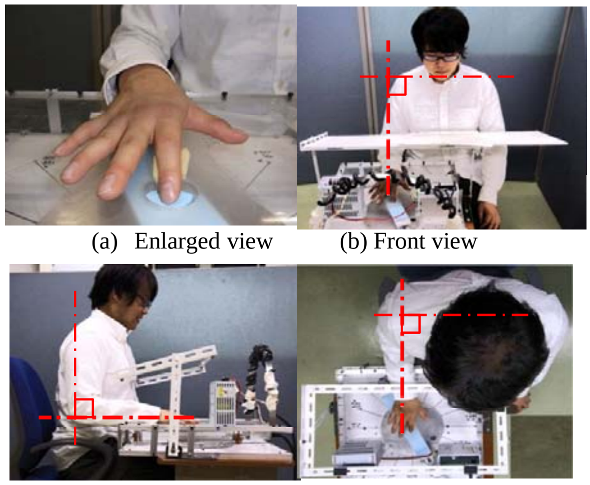
Direction		Length			
10	0°,360°	え	5	か	80
2	22.5°	さ	10	し	85
5	45°	ぬ	15	と	90
14	67.5°	ち	20	の	95
12	90°	き	25	そ	100
16	112.5°	は	30	こ	105
1	135°	ね	35	あ	110
8	157.5°	お	40	た	115
13	180°	つ	45	な	120
11	202.5°	へ	50	ふ	125
4	225°	け	55	く	130
6	247.5°	せ	60	す	135
9	270°	い	65	ほ	140
3	292.5°	に	70	う	145
15	315°	ひ	75	て	150
7	337.5°				

Figure 3. Answer board: subjects chose a pair of words to answer the perceived direction and length from a word set shown in the answer board

3) Procedures

Figure 4 shows some experimental views. Subjects were seated in a chair, setting their right forearm on the acrylic plate. During experiments, subjects were instructed to relax, and to focus on to perceive the presented linear slide motions. The subjects put their index fingerpad on the surface of a flat specimen (Figure 4(a)) where the subject arm angle was set at 90° (Figure 4(b)-(d)), and the arm direction was set to horizontal to table base (Figure 3(c)). The subject aligning his shoulder in the frontal plane and holding his upper body not twisted at the waist was placed at the position so that his right arm was parallel to the sagittal plane direction and so that his index fingertip was located at the hole in the acrylic plate (Figure 4(d)). A white noise sound was applied to the subjects via headphones for masking any sound cues on the spatial perception. In an arbitrary waiting time, after the subject put his fingerpad on a specimen, the specimen started to move, and stopped at a given point with approximate rectangular velocity pattern: by using the linear actuator, the specimen was accelerated with 3 m/s^2, then, it was moved with constant speed after reaching at the predetermined speed, and it was finally decelerated by 3 m/s^2.

The direction of the linear actuator movement was set by manual operation each time. The velocity and direction were pseudo-randomly presented for each of the subjects. It took about 30 minutes for the whole experiment per a subject.



(a) Enlarged view (b) Front view

(c)Side view (d) Top view

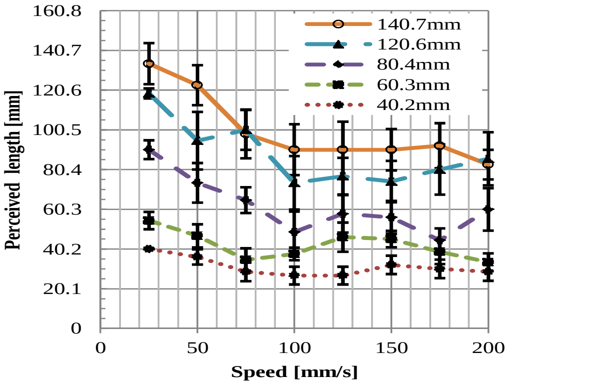
Figure 4. Experimental view showing the posture of a subject

III. Experimental Results

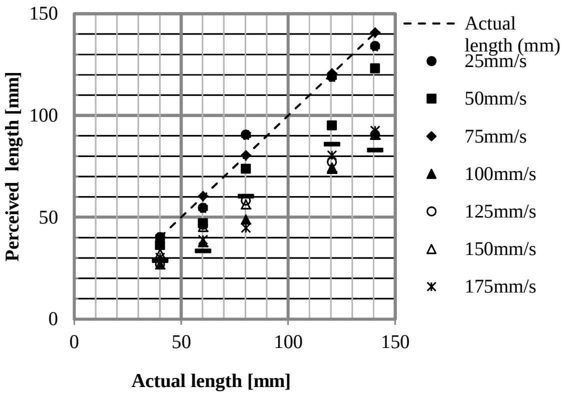
A. From Dot Counting to Sliding Speed Perception

Figure 5(a) shows an experimental result for the 20.1 mm period raised dot specimen. In this figure, counted dot numbers were inverted into length dimension by multiplying 20.1. In this case, a speed-caused fewer-counting effect in means (it is rephrased as a speed-caused foreshortening effect from the viewpoint of the length dimension) can be seen clearly. However, it should be noted that there can be seen little mean errors in the case of the 25 mm/s velocity. This characteristic will be useful to develop the motion presenting interfaces in the future. To make clear actual and counted dot number relationship, changing the parameters from the lengths to speeds, we got Figure 5(b) from Figure 5(a). From this figure, we can see the length-related foreshortening effect, especially, in high speed conditions. As a whole, it can be said that, the more the velocity/length is, the bigger the mean error grows. On the other hand, as for random errors, the longer the actual length was, the more the STD of the actual dots number increased.

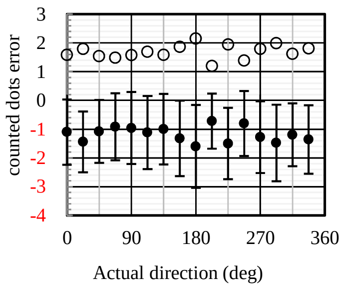
Figure 5(c) shows a directional variation in dot counting. We couldn't clearly find any directional characteristic.



(a) Means of perceived lengths (symbols), together with their standard errors(error bars): actual lengths were taken as a parameter.



(b) Means of perceived lengths: speed was taken as a parameter.



(c) Directional characteristic of perceived dot number: filled circles, error bars, and open circles were mean errors, standard devitions, and RMSE

Figure 5. Experimental results with the 20.1 mm period raised dots

The other experimental result is shown in Figure 6 for the 2.5 mm period raised dots.

For each of the 20.1 mm and 2.5 mm period dot experiments, we formulated a model for the perceived length l_{est_perc} by using a power function of actual length l_{act} and velocity v.

$$l_{est\_perc} = \alpha\, v^{\beta}\, l_{act}^{\gamma}. \quad (1)$$

The power function model is a variation of Stevens' law, and it represents contraction effects along with increased speed and length. In the ideal case that there are no such effects, the exponents with respect to l_{act} and v, i.e., β and γ, are respectively 1 and 0, and the proportional coefficient is 1. When estimating the unknown parameters, we took logarithms of the both sides of Eq. (1). That is,

$$\ln l_{est\_perc} = \ln\alpha + \beta \ln v + \gamma \ln l_{act} . (2)$$

For the 20.1 mm period experiment, after converting the counted dot numbers into lengths, we got

$$l_{est\_perc} = 2.2\, v^{-0.20}\, l_{act}^{0.95}. \quad (3)$$

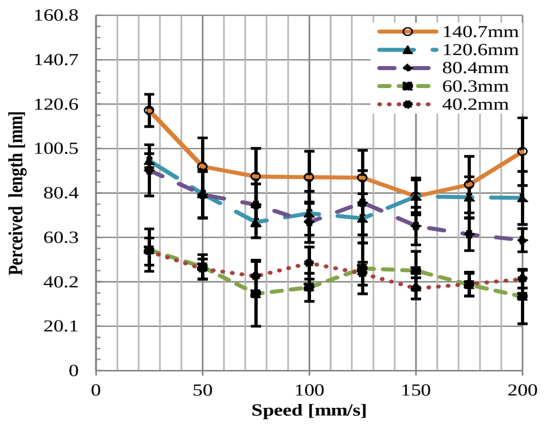
For the 2.5 mm period experiment, we got

$$l_{est\_perc} = 6.7\, v^{-0.11}\, l_{act}^{0.62}. \quad (4)$$

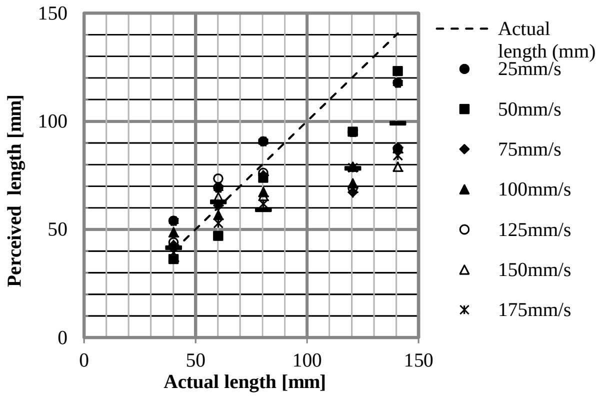
Since the coefficients of determination for each of the above simple two models accounts for 99%, the models were considered to be adequate.

The length-related exponent γ of 0.95 for the 20.1 mm period was very close to 1, and was much superior to that of 0.62 for the 2.5 mm period.

On the other hand, the speed-related exponent β of -0.20 for the 20.1 mm period was a little different from the ideal value of 0, and was inferior to that of -0.11 for the 2.5 mm period. It was considered that, even for the 20.1 mm period, the subjects were no longer able to count dot number in the increased speeds, and suffered larger speed-induced contraction effect. Therefore, it was recommended to employ enough low speeds when using the 20.1 mm period.



(a) Means of perceived lengths (symbols), together with their standard errors(error bars): actual lengths were taken as a parameter.



(b) Means of perceived lengths: speed was taken as a parameter.

Figure 6. Experimental results with the 2.5 mm period raised dots

B. *Discussion (Comparison to Existing Works)*

In this section, the above explained perceptual models with raised dots were compared with the existing two haptic length perceptual models.

One was a Terada model [3] that was obtained under the cutaneous-sensation-only framework as same as this work, that is, the Terada model was obtained by a cutaneous only sensation for flat sliding surfaces. The model was similar to the Najib model [5]. In Figure 7, the Terada-modeled perceived-lengths are shown by lines, and the 2.5mm period experimental values in this work were shown by symbols. It was interesting that, as a whole, this work of 2.5mm period was good conformity with Terada model except for the data with 140.7 mm length. It suggested that the dot period of 2.5 mm no longer worked as dot planes but as simple planes practically.

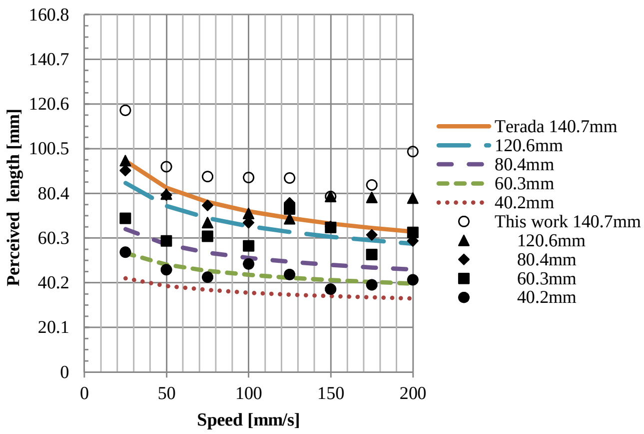


Figure 7. Comparison of the 2.5 mm period experiments to Terada work: the symbols show the means in this work, and the lines show the calculated values by the Terada model.

The other was Hollins model [1] that was obtained under an advantageous framework employing both the cutaneous and proprioceptive sensations. In Figure 8, the Hollins-modeled perceived-lengths are shown by lines, and the 20.1mm period experimental values in this work are shown the symbols. For both the length and speed variations, the 20.1mm period experimental values well agreed to the Hollins model. In Hollins' experiment, not only the cutaneous sensation but also the proprioceptive one being effective in haptic length perceptions was employed. Contrary to the advantageous Hollins framework employing both the cutaneous and proprioceptive sensations, this work of the cutaneous-sensation-only framework might inherently have poor sensitivity. Nevertheless the dot period of 20.1 mm worked as well as the advantageous Hollins model as shown in Figure 7. For reference, the cutaneous sensation was reported to be not much effective by Wouter et al. [5]

Finally, relating to the perception of moving dots, there were some significant works using Braille interfaces, e.g., [10~12]. Using 2×4 dot Braile cells (6.42mm in width, 16.7mm in height), Tahir et al. [11, 12] conducted some experiments on dot pattern selection tasks where 8 kinds of dot patterns were presented either by impulsive way or by 3 Hz of vibration. They obtained an elapsed time of 823ms in average for the vibrating patterns that was a little bit longer than that of 642ms for the impulsive patterns: the comparative merit of impulse to vibration had been agreed with the former work by Pietrzak et al. based on 4×4 dot Braile cells[10]. Here, it would be remarked that the 3 Hz vibration chosen in [11, 12] and the 1/0.6 Hz vibration in [10] respectively corresponded to a speed of 60.3mm/s and 33.5mm/s in the case of 20.1 mm period specimen in this work. The correspondence supported our results that the subjects showed the best performance at the 25 mm/s speed condition in dot number counting task and subject reports. That is, subjects reported that they were no longer able to count the dots when the speed was increased to 50 mm/s and over, and that have changed their perceptual strategy from counting strategy into another cutaneous sensation of depressed point movement perception as in the 2.5mm period dot spacing.

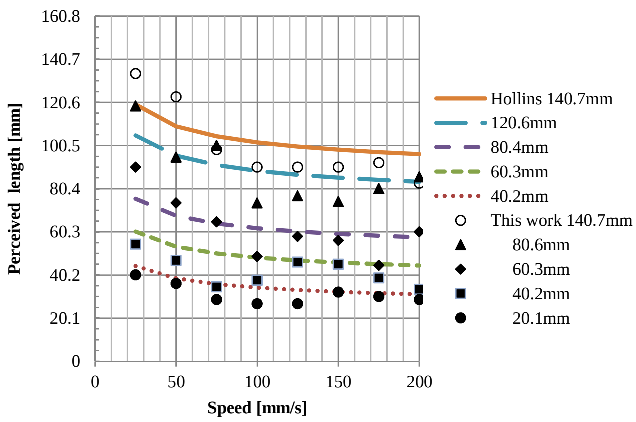


Figure 8. Comparison of 20.1 mm period dot experiments to Hollins work: the symbols show the means in this work, and the lines show the calculated values by the Hollins model.

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IV. CONCLUSION AND FUTURE WORK

Paying notice to the sliding raised dot pathway perception in the passive touch framework, the authors have studied the cutaneous sensation characteristics on index fingerpad.

- By using a power function of actual length l_{act} and velocity v, we formulated a model for the perceived length l_{est_perc} for each of the 20.1 mm and 2.5 mm period dots.
- The length-related exponent γ of 0.95 for the 20.1 mm period was very close to the ideal value of 1, and is much superior to that of 0.62 for the 2.5 mm period. On the other hand, the speed-related exponent β of -0.20 for the 20.1 mm period was a little different from the ideal value of 0, and was inferior to that of -0.11 for the 2.5 mm period.
- In comparisons from relating works, under the cutaneous-sensation-only framework, this work of the 20.1mm period dot showed such a high length perceptual performance as another advantageous framework employing both the cutaneous and proprioceptive sensations. Meanwhile, this work of the 2.5mm period dot showed almost similar performance as with other cutaneous-sensation-only works based on simple planes.

In the future, the authors will make a profound study on the raised-dot-based line perceptual characteristics: increasing sample number, expanding variations of dot period, and extending from one-dimensional lines to two dimensional lines. Furthermore, by using raised dots, they will develop computer-human interfaces, i.e., fingerpad-based line displays.

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