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The effect of surface roughness on human stiffness feeling

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Abstract. This study aims to elucidate the effect of surface roughness on feeling of stiffness. In order to clarify the effect of surface roughness, we focus on the fingertip motion during the sensory evaluation of stiffness feeling. In this paper, the pair comparison method was used in sensory evaluation with two kinds of instruction. One is that subjects evaluated stiffness of samples freely. The other is that subjects evaluated them with feeling the surface roughness. During the sensory evaluation, subject's fingertip trajectories and contact force with the samples were measured. From the results of sensory evaluation, it was found that surface roughness obviously affected feeling of stiffness in the case of instruction that subjects evaluated them with feeling the surface roughness.
Keywords: Tactile sensation, Stiffness, Roughness, Sensory evaluation, Pair comparison method

1. Introduction

Humans perceive various sensory information including tactile sensation by touching objects. For example, a doctor diagnoses diseases and skin conditions by palpation that uses the tactile sensation [1]. Also, a customer estimates texture of cloths in the industry fields. However, since human touch feeling is subjective [2], it is hard to share the result with other people. Therefore, it is necessary to investigate how humans feel tactile sensation.

The tactile sensation is perceived by mechanical interaction between the finger and the object. Several factors, such as the ways to touch objects [3] and the arrangement of sensory receptors [4], are involved to the sensation. However, the mechanism of perception has not been sufficiently elucidated. Furthermore, various mechanical properties of the object influence tactile sensation complexly. For example, it has been reported that texture and touching comfort can be improved by embossing an uneven shape on the surface of the object without changing the material [5]. However, the influence of the embossed shape on the tactile sensation has not been sufficiently elucidated.

In this paper, we focus on the relationship between surface roughness and stiffness feeling. We investigate the influence of the surface roughness on stiffness feeling. Specifically, five types of samples with different surface roughness are fabricated. Then the sensory evaluation about stiffness and the measurement of fingertip motion are conducted.

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Table 1 Condition of samples

Diameter (mm)	50				
Height (mm)	20				
Young's modulus (kPa)	347				
Surface texture (JIS)	#120	#320	#600	#1000	OHP
Particle size (μm)	212	94	72	63	0

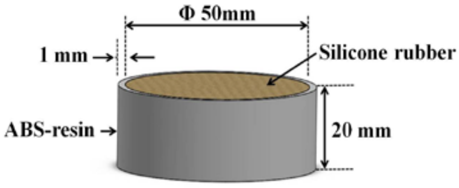


Fig. 1. Dimension of silicone sample

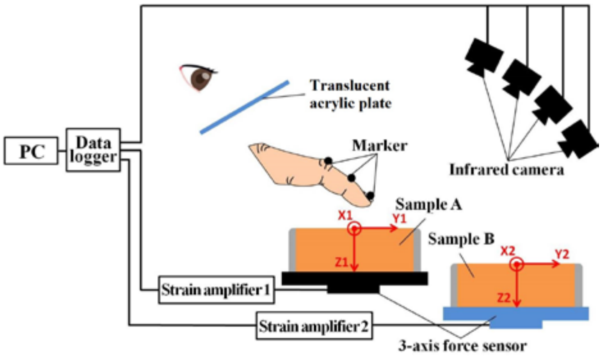


Fig. 2. Schematic of experimental setup

2. Experiments

2-1 Silicone samples

In this study, five samples with different surface roughness were fabricated as shown in Table 1. Samples were made of silicone rubber with Young's modulus of 347 kPa. The dimension of silicone part is cylindrical shape with radius of 50 mm, and height of 20mm as shown in Fig. 1. The samples were placed in the ABS-resin cup. Four kinds of abrasive paper and OHP sheet were transferred onto the surface of each sample as shown in Table 1. Abrasive paper number defined by Japanese Industrial Standards (JIS) R6001 corresponds to size of particle on the abrasive paper.

2-2 Experimental setup

To investigate the influence of fingertip motion during the sensory evaluation experiment, experimental setup was constructed as shown in Fig. 2. The experimental system consists of an optical 3-dimensional motion analysis system (Inter Reha Co., VICON) and two 3-axis force sensors (Tec Gihan Co., USL 06-H5-50N-C). The subjects attached markers on their forefinger of handedness for capturing fingertip trajectory with four infrared cameras. The 3-axis force sensor was placed under each sample for measuring contact force. In addition, the translucent acrylic plate was set between the samples and the subject to remove the visual information of samples when the subject evaluates the samples.

2-3 Methods

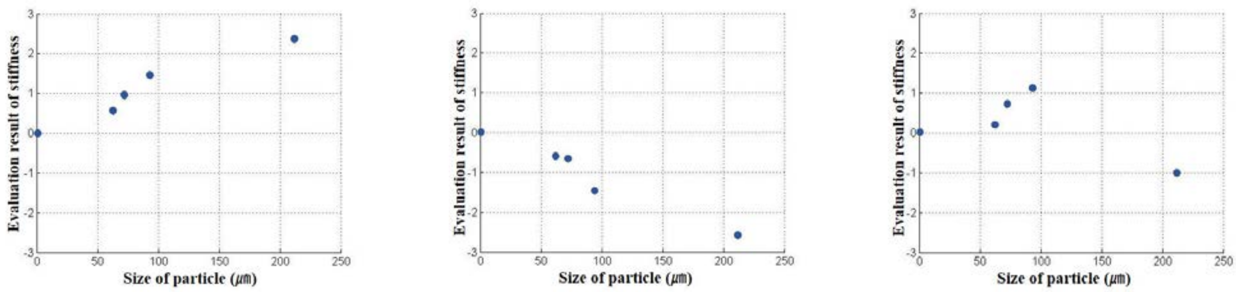
Ten subjects (Nine male and one female) participated in the experiment. In this experiment, the subject estimates tactile stiffness of the samples using the Scheffe's paired comparison method [6] that all subjects evaluate all samples, and the influence of the sample presentation order is ignored. Specifically, the subject evaluates the stiffness feeling by comparing two presented samples. In sensory evaluation, the subject touches the samples by their own forefinger of handedness until the end of evaluation. Concerning the touch motion in sensory evaluation, the experimenter asks the subject two kinds of instruction, "Evaluate the stiffness freely" and "Evaluate the stiffness with feeling the surface roughness of the samples".

Table 2
Score of the sensory evaluation with freely touch motion

Sample A	Sample B	Subject a	b	c	d	e	f	g	h	i	j
#120	#320	0	2	1	0	0	1	2	0	-1	2
#120	#600	0	0	1	-1	-1	-1	2	1	1	-1
#120	#1000	1	1	1	-1	1	-1	0	-2	1	-1
#120	OHP	0	1	1	0	2	1	1	-2	2	-2
#320	#600	-1	1	2	1	-1	-1	1	-1	-1	0
#320	#1000	-2	1	1	1	1	1	1	-2	2	1
#320	OHP	2	1	2	1	-1	1	0	-1	2	0
#600	#1000	-2	0	1	1	0	-2	0	2	-1	1
#600	OHP	0	0	0	0	0	1	0	-1	-1	-1
#1000	OHP	-1	2	1	-1	0	2	0	0	1	-1

Table 3
Score of the sensory evaluation with feeling surface roughness touch motion

Sample A	Sample B	Subject a	b	c	d	e	f	g	h	I	J
#120	#320	2	2	1	1	1	-2	-1	-2	-1	-2
#120	#600	2	1	1	2	1	-2	-2	-2	-1	-2
#120	#1000	2	2	2	2	1	-2	-2	-2	-1	-1
#120	OHP	2	2	2	2	1	-2	-2	-2	-2	-2
#320	#600	1	0	1	1	1	-1	-1	-2	1	1
#320	#1000	1	1	2	1	1	-1	-1	-1	1	1
#320	OHP	1	2	2	1	1	-1	-2	-1	1	1
#600	#1000	1	1	1	0	0	0	0	0	1	1
#600	OHP	0	0	2	1	1	-1	0	-1	1	1
#1000	OHP	0	1	1	1	1	0	0	0	1	1



(a) Group 1 (b) Group 2 (c) Group 3

Fig. 3. Scaled evaluation score of stiffness (motion with feeling the surface roughness)

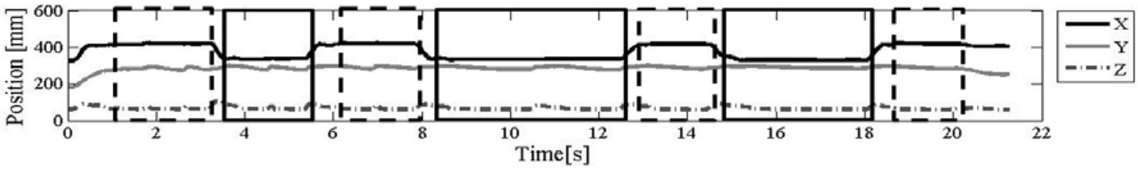
In the experiments, the combination of sample #120, which is the roughest, and sample OHP, which is the smoothest, was presented first. And then combinations of the others sample were presented at random. The experimenter places sample A on the left and sample B on the right of the subject and sample A is arranged that rougher surface than sample B. The subject evaluates the stiffness of sample A against sample B with five phases score from -2 to 2. If the subject feels that sample A is softer than sample B, the subject answers positive number. If the subject feels that the sample A is harder than sample B, the subject answers negative number. And if the subject feels that sample A is the same as sample B, the subject answers zero.

3. Results and discussions

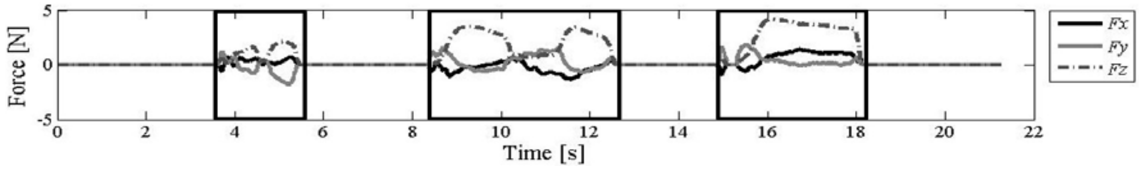
3-1 Sensory evaluation

The sensory evaluation scores for each instruction of touch motion are shown in Table 2 and Table 3. From the results of sensory evaluation with freely touch motion shown in Table 2, it was found that the subjects b, c and g anwser positive number. They evaluate that the rougher surface sample is softer. But the similar tendency is not observed in the results of other subjects.

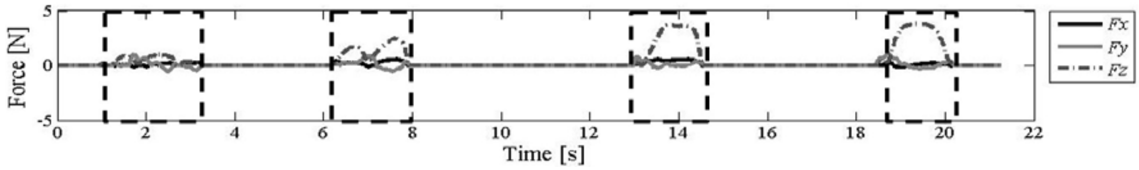
On the other hand, from the results of sensory evaluation with feeling the surface roughness touch motion, it was classified into three groups. Subject a, b, c, d, and e (called Group 1) answer positive number for all presented pairs. They evaluate that the rougher surface sample is softer. Subject f, g, and h (called Group 2) answer negative number for all presented pairs. They evaluate that the rougher surface sample is harder. Subject i and j (called Group 3) answer positive and negative number. They evaluate that the sample #120 is the hardest, but they evaluate that the rougher surface sample is softer for the other pairs.



(a) Fingertip position



(b) Force sensor output of sample #120



(c) Force sensor output of sample OHP

Fig. 4. Representative results of finger motion (subject g, sample #120 and sample OHP)

For the scores of the sensory evaluation with feeling surface roughness touch motion, psychological scaling of the Nakaya variation for each groups was conducted [7]. The relationship between the scaled psychological stiffness score of each group and the surface roughness of the sample are shown in Fig. 3. The horizontal axis represents the average particle size of the abrasive paper transferred to the sample surface. The scaled sensory evaluation scores are offset so that the scaled score of the sample OHP becomes zero. The vertical axis represents the scaled stiffness feeling. The scaled stiffness becomes positive when subject feels softer than OHP sample, and it becomes negative when subject feels harder than OHP sample. From the resutls shown in the Fig. 3, it is confirmed that stiffness was changed by the surface roughness from each group. And the variation of stiffness feeling between samples are confirmed.

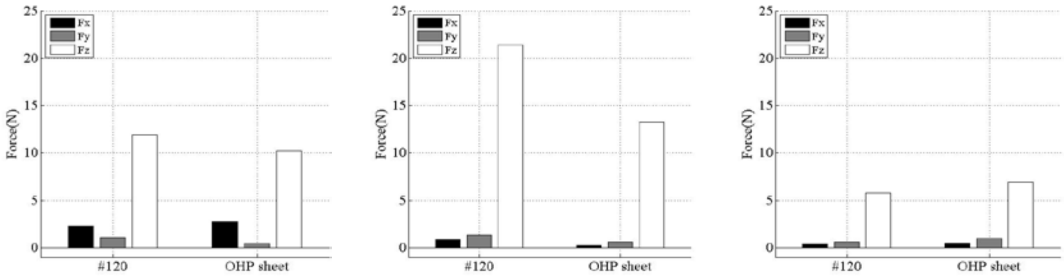
From the results, it was found that surface roughness obviously affects stiffness feeling in the case of instruction that subjects evaluated them with feeling the surface roughness.

3-2 Fingertip motion

Fig. 4 shows representative results of nail position and contact force when subject g evaluates stiffness feeling with feeling the surface roughness for the conbination of sample #120 and sample OHP. Regarding the coordinate axes, the X axis is the lateral direction of the subject, the Y axis is the anteroposterior direction, and the Z axis is the up and down direction.

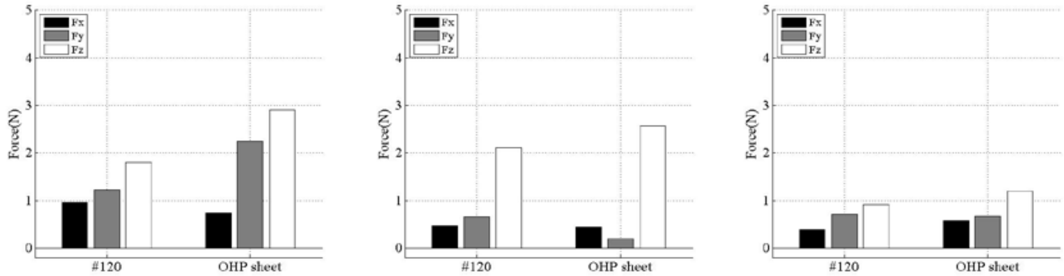
From the results of contact force shown in Fig. 4 (b) and (c), it is confirmed that the subject touches two samples alternately since the timing at the value of Fz fluctuates alternately. Therefore, the contact section with each sample is extracted and cut out in order to analyze the fingertip motion for each sample.

In this experiment, the section with the contact force $Fz \geqq 0.1$N is regarded as touching the sample. The squares of thick line and dotted line in Fig. 4 indicate the sections when the subject



(a) Subject b (b) Subject g (c) Subject i

Fig. 5. Contact force with freely touch motion



(a) Subject b (b) Subject g (c) Subject i

Fig. 6. Contact force with feeling surface roughness touch motion

contacted to sample #120 and sample OHP, respectively. The second and third section from the last of the section were extracted since we considered that the subject determine the score for each sample in the sections. And then fingertip trajectory and contact force for the extracted section were analyzed. In the analysis, the origin of the coordinate is set to be the center of each sample from two extracted section.

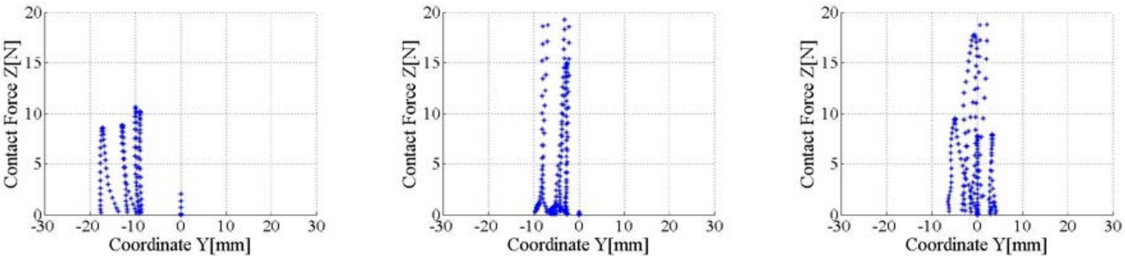
3-3 Contact force

The contact force of each axis are averaged for the extracted section. The averaged contact force of subject b belonging to group 1, subject g belonging to group 2 and subject i belonging to group 3 are shown in Fig. 5 and Fig. 6. From the resutls shown in Fig. 5, the contact force in Z axis direction (Fz) is larger than the contact force in the X axis direction (Fx) and Y axis direction (Fy). From the results shown in Fig. 6, although the contact force Fz is larger than contact force in the Fx and Fy, the difference between Fz and other contact force is smaller than that shown in Fig. 5.

From the results, the difference of contact force in the instructed touch motion were confirmed. And, it is confirmed that the contact force in the Fz is small when the subjects evaluate the stiffness of sample with feeling surface roughness.

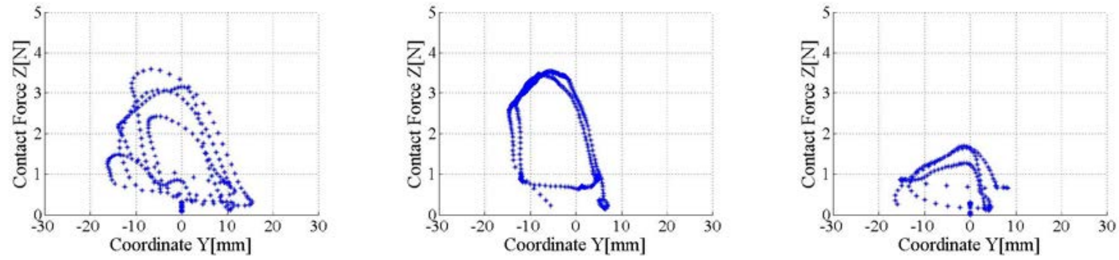
3-4 Relationship between fingertip trajectory and contact force Fz

The relationship between the fingertip position in Y coordinate and contact force Fz are shown in Fig. 7 and Fig. 8. From the results shown in Fig. 7, it is confirmed that the finger position in Y coordinate is not moved when the subject push the sample. On the othe hand, from the results shown in Fig. 8, it is confirmed that the finger position in Y coordinate is moved when the subject push the sample.



(a) Subject b (b) Subject g (c) Subject i

Fig. 7. Relationship between fingertip trajectory and contact force *Fz* with freely touch motion for sample #120



(a) Subject b (b) Subject g (c) Subject i

Fig. 8. Relationship between fingertip trajectory and contact force *Fz* with feeling surface roughness touch motion for sample #120

In the comparing with the instructed touch motion, differences in the relationship between the fingertip position of the Y coordinate and the contact force *Fz* were confirmed.

In the result of sensory evaluation with feeling surface roughness, it was found that surface roughness obviously affects feeling of stiffness. It is considered that the surface roughness influences the human stiffness feeling when the subject evaluates the sample with pushing the fingertip weakly and pulling it toward own side.

4. Conclusions

In this study, sensory evaluation experiment on two kinds of touching instructions were conducted to clarify the influence of the surface roughness on stiffness feeling. During the sensory evaluation, the fingertip motion and contact force were measured. From the result, it was confirmed that the surface roughness influences the human stiffness feeling when the subject evaluates the sample with pushing the fingertip and pulling it toward own side. In future, it is necessary to experiment with more subjects to improve the validity of the experimental results.

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