TACTILE-INFORMATION-PROCESSING MECHANISMS OF FINE-SURFACE-TEXTURE DISCRIMINATION

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Abstract

The purpose of the present study was to investigate low-pass filter characteristics and to verify the "amplitude-information hypothesis" of fine-surface-texture discrimination in human tactile perception. Two experiments were performed. In Experiment 1, six diffraction gratings were used as stimuli. Their wavelengths were 6.7, 13.3, 25.0, 33.3, 50.0, and 75.2 μm. Six subjects touched the stimuli, which were moving at three different velocities, and judged the roughness of the stimuli with the two-alternative, forced-choice technique. Psychometric functions, calculated from the experimental data, clearly showed the existence of the low-pass filter. In Experiment 2, five abrasive papers with particle sizes between 1 and 30 μm were used as stimuli. The six subjects who participated in Experiment 1 also participated in Experiment 2. Patterns of psychometric functions obtained in the experiment were similar to each other despite the change in the velocities of the stimuli. The obtained results support the amplitude-information hypothesis.

Tactile texture perception is divided into two types: coarse-texture perception and fine-texture perception (Hollins et al., 2001; Miyaoka, 1994; Miyaoka et al., 1999). Miyaoka et al. (1999) studied the discrimination ability of fine textures in human tactile perception using abrasive papers with particle sizes between 1 and 40 μm. They found that difference thresholds of fine-surface textures were between 2.4 and 3.3 μm and proposed the "amplitude-information hypothesis" for the roughness-discrimination mechanisms of fine-surface textures. The amplitude information hypothesis asserts that the tactile system has a low-pass filter, and when discriminating stimulus roughness, the tactile system uses only surface-amplitude information that passes through the filter.

The present study had two purposes. The first was to investigate the low-pass filter characteristics in the fine-texture perception and to determine an upper-limit of the passing frequency. The second was to evaluate the validity of the amplitude-information hypothesis as a mechanism to discriminate fine-surface textures.

A low-pass filter model for fine-surface-texture discrimination

We consider roughness discrimination of two stimuli, each of which has grooves on the surface. The cross sections of the grooves are sine waves. The subject judges the roughness of the surfaces with the two-alternative forced-choice technique. We denote the psychometric function of the roughness judgments as

$$y = \frac{1}{1 + \exp(-x + s)} \quad , \tag{1}$$

where s and x are the wavelengths of the standard and comparison stimuli, respectively ($s > 0$,

$x > 0$). When the subject touches a stimulus that is moving at a constant velocity, vibration information that is caused by the stimuli is not detected if frequencies are higher than the upper limit of the low-pass filter. If the frequencies are lower than the upper limit of the filter, the stimulus information passes the filter and the subject detects the surface texture. When the velocity of the stimuli is constant and the upper limit frequency is f_0, we denote the corresponding wavelength as x_0. When $s \leq x_0$ and $x \leq x_0$,

$$y = \frac{1}{1+\exp(-x_0 + x_0)} = \frac{1}{2} \quad . \tag{2}$$

When $s \leq x_0$ and $x > x_0$,

$$y = \frac{1}{1+\exp(-x + x_0)} \quad . \tag{3}$$

When $s > x_0$ and $x \leq x_0$,

$$y = \frac{1}{1+\exp(-x_0 + s)} \quad . \tag{4}$$

When $s > x_0$ and $x > x_0$,

$$y = \frac{1}{1+\exp(-x + s)} \quad . \tag{5}$$

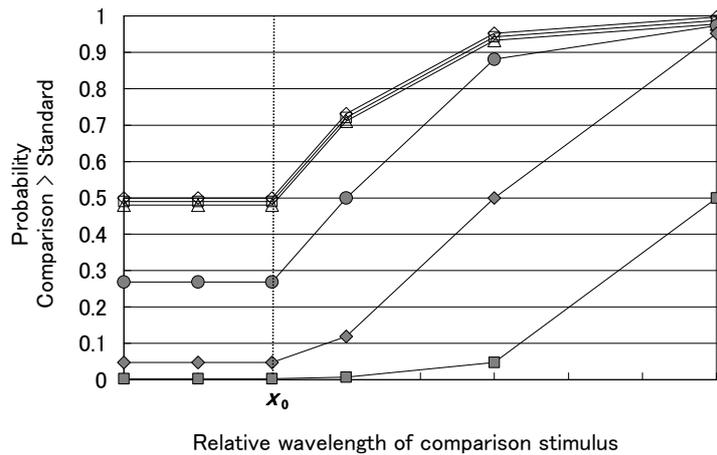A graphical representation of equations (2) ~ (5) is shown in Fig. 1.

Fig. 1. Simulation results based on equations (2) ~ (5). The vertical axis shows the probability that comparison stimuli are judged rougher than standard stimuli. The horizontal axis shows the relative wavelength of the comparison stimuli. Each symbol in the figure represents the results of a standard stimulus. The line labeled x_0 in the figure shows the absolute threshold.

Experiment 1

The purpose of Experiment 1 was to investigate the low-pass filter characteristics of the fine-surface discrimination and to determine the upper limit frequency of the filter using diffraction gratings as stimuli.

Method

Subjects: Six males in their twenties participated in Experiment 1.
Stimuli: Six diffraction gratings were used as stimuli. The shapes of the gratings were squares of 30 mm. Grooves were cut on the surfaces of the gratings. The cross sections of the grooves were triangular waves, and the wavelengths were 6.7, 13.3, 25.0, 33.3, 50.0, and 75.2 μm. In the experimental trial, two of the six gratings were selected and placed on the experimental apparatus.
Apparatus: A stepper motor (Oriental Motor, PX534MH-B) and its controller (Melec, 870V1) were connected to a personal computer. The computer controlled the rotating speeds of the stepper motor. The part for setting the stimuli was mounted on the stepper motor. The stepper motor was placed inside a box on which the subject placed his hand. The top surface of the box was an aluminum plate that had two holes near the center. The two holes were of the same shape and were 18 mm in length by 10 mm in width. They were arranged in the depth direction from the subject, and the distance between the centers of the holes was 50 mm.
Procedure: The number of the combinations of stimuli was 42. The number of pairwise combinations of six distinct stimuli plus self-combinations was equal to 21. Since it was necessary to counterbalance the right and left positions of the stimuli, the total number of combinations became 42.

The subject was seated in a chair and wore a mask to prevent visual inspection of the test materials. The subject touched the stimuli moving just beneath the holes with the index finger or the middle finger (whichever the subject preferred) and determined which gratings felt rougher with the two-alternative, forced-choice technique. The surfaces of stimuli were applied with silicone oil to reduce friction. The inter-stimulus interval was 20 s. The moving velocities of the stimuli were 5 mm/s, 10 mm/s, and 20 mm/s. Each subject participated in eight trials for each combination and each stimulus velocity. Therefore, the total number of experimental trials was 1,008. During the experiment, the temperature of the laboratory was maintained between 25°C and 27°C, and the temperature of the stimulated skin of subjects was greater than 30°C.

Results and Discussion

Data were accumulated for all subjects for each condition, and psychometric functions were calculated. The results for the velocities of 5 mm/s and 20 mm/s are shown in Figs. 2-(a) and 2-(b), respectively.

As shown in the figures, the patterns of psychometric functions varied depending on the changes in the velocities of the stimuli. In Fig. 2-(a), flat parts of the psychometric functions were observed only at the left end of the functions. In Fig. 2-(b), however, the flat parts extended to the right. Furthermore, the number of psychometric functions overlapped at upper parts of the figures increased when the velocity multiplied. These results satisfied equations (2) ~ (5) and basically supported the low-pass filter model.

When the velocity of the stimuli was 5 mm/s (Fig. 2-(a)), the two psychometric functions with 6.7 and 13.3 μm standard stimuli were very similar, from which the psychometric function with a 25 μm standard stimulus considerably differed. The absolute
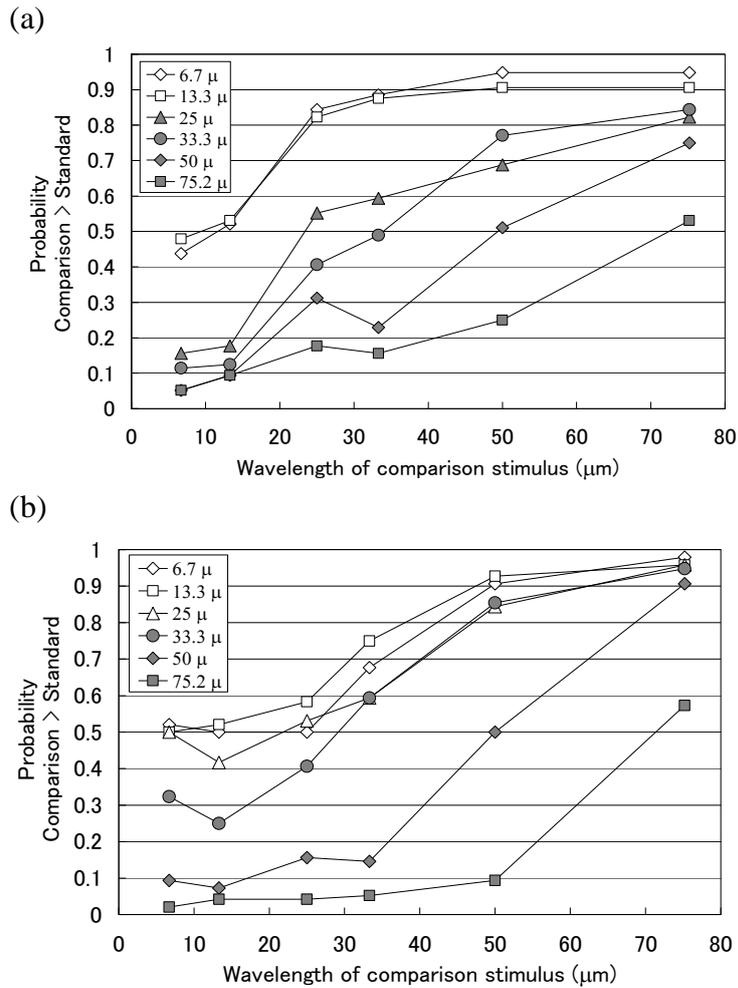
(a)

(b)

Fig. 2. Psychometric functions based on the data of the diffraction-grating-discrimination experiment. The velocities of the stimuli are (a) 5 mm/s and (b) 20 mm/s. The vertical axis in each figure shows the probability that the comparison stimuli were judged to be rougher than the standard stimuli. The horizontal axis shows the wavelength of the comparison stimulus. Each symbol in the figure represents the results for a standard stimulus. The unit of the values in the legend is micrometers.

threshold of detection was thus approximately 13.3 μm or 400 Hz. When the velocity was 20 mm/s (Fig. 2-(b)), the three psychometric functions with the 6.7, 13.3, and 25 μm standard stimuli overlapped and the psychometric function of 33.3 μm approached these ones. The absolute threshold was approximately 33.3μm or 600 Hz.

The results of Experiment 1 showed the existence of the low-pass filter, and its upper limit was estimated to be approximately 400 ~ 600 Hz.

Experiment 2

The purpose of Experiment 2 was to evaluate the validity of the amplitude information hypothesis.

Method

<u>Subjects</u>: Six subjects participated in Experiment 2 (same subjects that participated in Experiment 1).

<u>Stimuli</u>: The stimuli were five aluminum-oxide abrasive papers (Sumitomo 3-M). The grit values assigned by the manufacturer were 600, 1200, 2000, 4000, and 8000, representing corresponding average particle sizes of 30, 12, 9, 3, and 1 μm, respectively. The abrasive papers were cut to squares of 30 mm and were attached to boards of the same size. During the experimental trials, two of the five abrasive papers were selected and placed on the experiment apparatus.

<u>Apparatus</u>: The apparatus used in Experiment 1 was also used in Experiment 2.

<u>Procedure</u>: The number of the combinations of stimuli was 30. The number of pairwise combinations of five distinct stimuli plus self-combinations was equal to 15. Since it was necessary to counterbalance the right and left positions of the stimuli, the total number of combinations became 30.
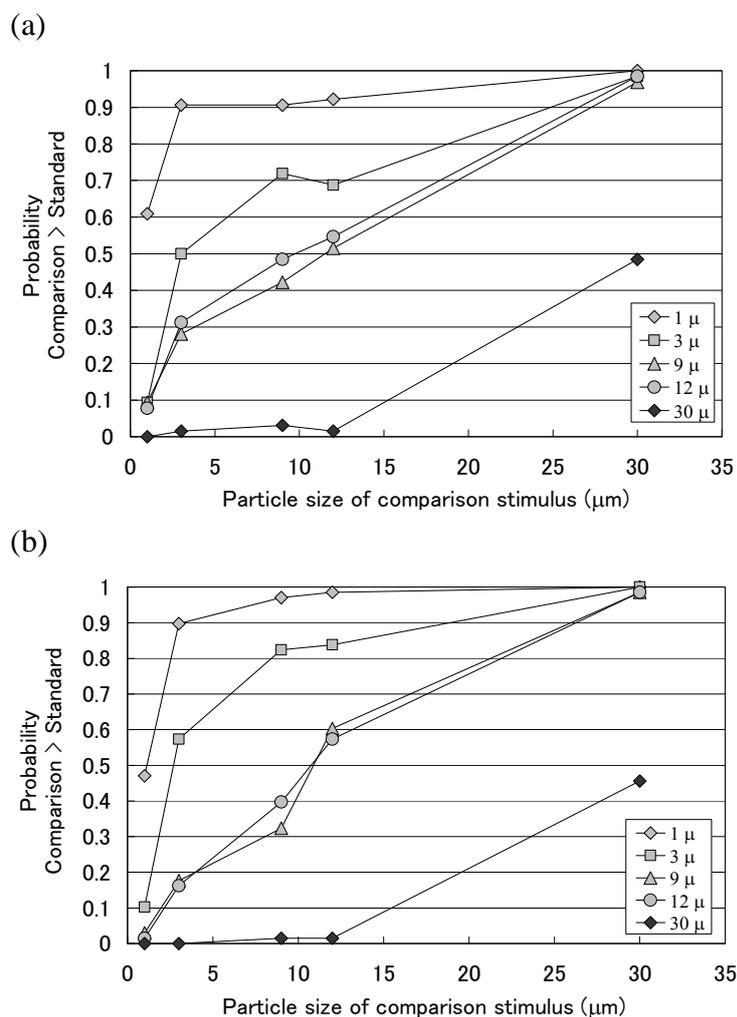
(a)

(b)

Fig. 3. Psychometric functions based on the data of the abrasive-paper-discrimination experiment. The velocities of the stimuli are (a) 5 mm/s and (b) 20 mm/s. The vertical axis in each figure shows the probability that the comparison stimuli were judged rougher than the standard stimuli. The horizontal axis shows the particle sizes of comparison stimuli. Each symbol in the figure represents the results for a standard stimulus. The unit of the values in the legend is micrometers.

The stimulus-presentation procedures, the response methods, and the stimulus-moving velocities were the same as in Experiment 1. Each subject participated in eight trials for each combination and each stimulus velocity. Therefore the total number of experimental trials was 450. During the experiment, the temperature of the laboratory was maintained as described for Experiment 1.

Results and discussion

The psychometric functions were calculated using the same method as in Experiment 1. The results for the velocities of 5 mm/s and 20 mm/s are shown in Fig. 3-(a) and 3-(b), respectively. The patterns of the psychometric functions of Fig. 3-(b) were the same as those of Fig. 3-(a) despite the change in the velocity. These results are very different from the results of Experiment 1, in which diffraction gratings were used as stimuli.

The roughness discrimination ability of the abrasive papers was independent of the velocity of the stimuli. As mentioned above, the subjects were able to discriminate the surface roughness using only the amplitude information that passed through the tactile low-pass filter. The abrasive papers have many wavelength elements on their surfaces and some elements are able to pass through the filter. The subjects used only the information that passed through the filter and discriminated fine textures. On the other hand, the gratings do not have waves with wavelengths longer than the fundamental wavelengths. Therefore, the subject does not detect texture if the fundamental wave information cannot pass through the tactile filter.

Conclusion

The results of Experiment 1 indicated the existence of a low-pass filter in fine-surface-discrimination tasks and that the upper limit of the passing frequency was 400 ~ 600 Hz. The results of Experiment 2 showed that the subjects were able to discriminate fine surfaces and support the validity of the amplitude information hypothesis.

In the future, it will be necessary to obtain more data in order to acquire accurate values of the upper limit of the low-pass filter. It is also important to continue to examine the validity of the amplitude information hypothesis.

References

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