FINE-SURFACE-TEXTURE DISCRIMINATION BY INDIRECT TOUCH

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Abstract

The purpose of the study was to determine the ability of subjects to discriminate fine-surface textures by indirect touch. Four experiments were performed. Two were active-touch and two were passive-touch experiments. In the active-touch experiments, sheets of fine-abrasive paper with particle sizes between 0.3 and 9 μm were used as stimuli. The subject touched the stimuli with a custom-made ballpoint pen. A tungsten-carbide ball was attached and fixed to its tip. The subject moved the pen on the stimuli and evaluated the roughness using the two-alternative, forced-choice technique. The detection threshold was 1.92 μm when it was determined. In the passive-touch experiments, the subject touched the moving stimuli with the ballpoint pen and evaluated the roughness. The detection thresholds were 0.74 and 0.79 μm. The detection thresholds of passive touch were smaller than the threshold of active touch.

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 (2008) determined the detection thresholds of very-fine textures and found that the threshold values reached 0.84 μm. He inferred from the sensitivities of mechanoreceptors that the mechanoreceptor which detected submicron textures was the Pacinian corpuscle.

The purpose of the study was to ascertain the tactile-detection thresholds of fine textures in indirect touch using a custom-made ballpoint pen. Two active-touch experiments and two passive-touch experiments were conducted.

Experiment 1

The purpose of Experiment 1 was to determine the detection thresholds of fine textures by indirect and active touch. Two subordinate experiments were performed and the effect of skin temperature on the threshold values was also studied. In Experiment 1-1, the skin temperature of the subject was maintained equal to or higher than 33˚C. In Experiment 1-2, the skin temperature was maintained at 18˚C using a temperature-control device.

Method

Subjects: Four males and two females in their 20s participated in Experiment 1.
Stimuli and apparatus: The stimuli were six abrasive papers (Sumitomo 3-M). The grit values assigned to them by the manufacturer were 1200, 2000, 4000, 8000, 10000, and 15000, representing corresponding average-particle sizes of 12, 9, 3, 1, 0.5, and 0.3 μm. Observation by a scanning-electron microscope (JEOL, JSM-5610LV) confirmed that the sizes of the particles of each abrasive paper corresponded to the particle sizes stated by the manufacturer. The abrasive papers were cut into 20 × 50-mm rectangles and each piece was stuck onto an aluminum plate sized 20 × 150 mm. In the experimental trial, two of the six abrasive papers

were selected and placed on an experimental device.

The subject touched the stimuli with a ballpoint pen. The ballpoint pen was a custom-made device with a tungsten-carbide ball attached and fixed to the tip of it. The diameter of the ball was 0.7 mm.

In Experiment 1-1, the temperature of the skin and pen was controlled by an air conditioner. In Experiment 1-2, the temperature of the skin and pen was controlled by a temperature-control device. The temperature-control device was connected to a water circulator (Yamato, CTE82W) which controlled the temperature of the device to any value between 5 and 45˚C.

Procedure: The subject was seated in a chair and wore an eye-mask to prevent visual inspection of the test material. The subject wore earplugs and pink noise was presented by a loudspeaker to mask auditory clues that may have aided the evaluation of roughness. The subject held the ballpoint pen with the thumb and four fingers of the preferred hand and kept it perpendicular to the stimuli. The subject moved the pen on the stimuli and determined which abrasive paper felt rougher using the two-alternative, forced-choice technique.

In Experiment 1-1, the temperature in the laboratory was maintained at no less than 26˚C using the air conditioner. At a room temperature of 26˚C, the glabrous skin temperature of the subjects was maintained equal to or higher than 33˚C. The sensitivities of mechanoreceptors are highest when the skin temperature is 33˚C or more. The temperature of the skin was checked using a thermometer. In Experiment 1-2, the temperature of the skin and the pen was maintained at 18˚C by the temperature-control device.

The number of combinations of stimuli was 42. The number of pair-wise combinations of six distinct stimuli plus self-combinations was equal to 21. Since it was necessary to counterbalance the top and bottom positions of the stimuli, the total number of combinations became 42. The maximum time allowed for determination was 20 s for each combination. The inter-stimulus interval was 20 s. Each subject performed 10 trials for each combination of abrasive-paper stimuli; therefore, the total number of experimental trials was 420 for each subject for each experiment.

Results and discussion

The experimental data of the six subjects were accumulated for each combination and for each experiment. The psychometric functions were calculated from the accumulated data. The psychometric functions of Experiment 1-1 and Experiment 1-2 are shown in Fig. 1 and Fig. 2, respectively.

When the standard stimuli were between 0.3 and 1 μm, the psychometric functions overlapped each other and the psychometric function of the 3-μm-standard stimulus positioned lower than them in both of Experiment 1-1 and Experiment 1-2. This means that detection thresholds are between 1 μm and 3 μm. The average detection threshold of Experiment 1-2 was 1.92 μm. The average detection threshold of Experiment 1-1 could not be calculated, but it was estimated to be around 2 μm. The skin temperatures were different between Experiment 1-1 and Experiment 1-2. However the detection threshold values were similar to each other. The results showed that the mechanoreceptor that participated in the detection was not the Pacinian corpuscle, because the Pacinian corpuscle is very sensitive to temperature changes and its sensitivity decreases when the skin temperature is below 25˚C.

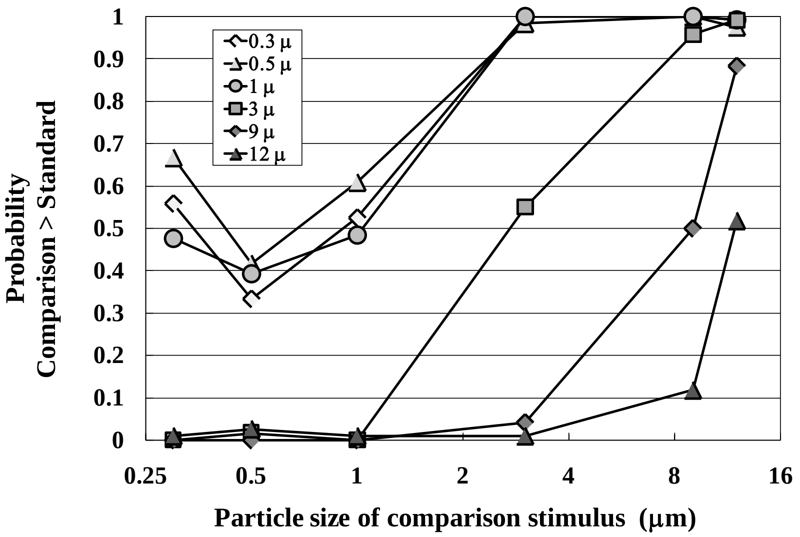

Fig. 1. Psychometric functions based on data from Experiment 1-1. The vertical axis shows the probability that the comparison stimuli were judged to be rougher than the standard stimuli. The horizontal axis shows the particle sizes of the comparison stimulus. Each symbol in the figure shows the particle size of standard stimulus. The unit of the values in the legend is μm.

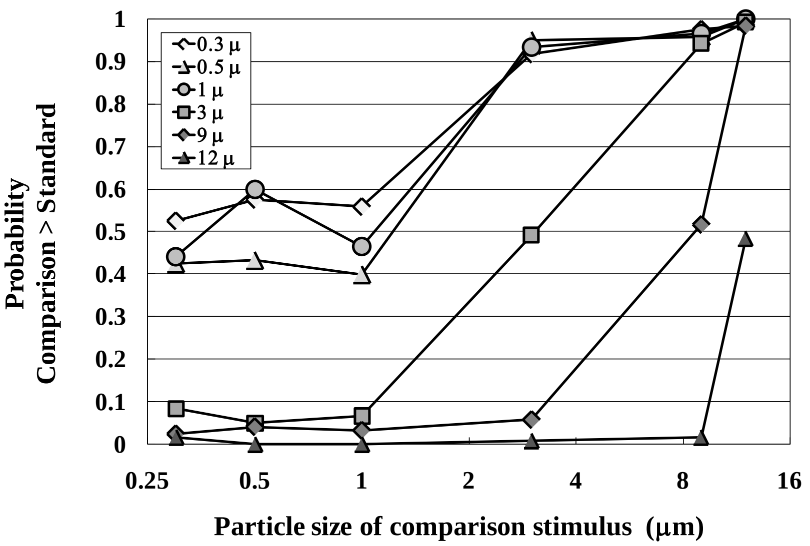

Fig. 2. Psychometric functions based on data from Experiment 1-2. Each symbol in the figure shows the particle size of standard stimulus.

Experiment 2

The purpose of Experiment 2 was to determine the detection thresholds of fine textures by indirect and passive touch. Two subordinate experiments were performed and the effects of stimulus-moving speeds on the values of detection threshold were also investigated. The stimulus-moving speeds were 10 and 20 mm/s for Experiment 2-1 and Experiment 2-2, respectively.

Method

Subjects: Five males and one female in their 20s participated in Experiment 2.
Stimuli and apparatus: Six sheets of abrasive paper were used as stimuli. Their grit values were 1200, 2000, 4000, 8000, 10000, and 15000, representing corresponding average particle sizes of 12, 9, 3, 1, 0.5, and 0.3 μm. The abrasive papers were cut into 30 × 110-mm rectangles and each piece was stuck onto a board sized 30 × 220 mm. In the experimental trial, two of the six abrasive papers were selected and placed on an experimental device.

The experimental device was a box that had a stepper motor inside it. The stepper motor (Oriental Motor, PX534MH-B) and its controller (Melec, 870V1) were connected to a personal computer and the computer controlled the rotational speed of the stepper motor. A platform for securing the stimuli was mounted atop the stepper motor. The top surface of the box was an aluminum plate with two identically shaped holes in the center measuring 18 mm by 10 mm. They were arranged away from the subject in the depth direction and the distance between the centers of the holes was 50 mm.

The subject touched the stimuli with a ballpoint pen and judged their roughness. The ballpoint pen was the same type as used in Experiment 1.
Procedure: The subject was seated in a chair and wore an eye mask and earplugs and pink noise was presented by a loudspeaker to mask auditory clue that may have aided the evaluation of roughness. The subject held the pen with the thumb and four fingers of the preferred hand. The pen was held perpendicular to the stimuli at the holes. The stimuli were placed on the moving device. The device moved at a speed of 10 mm/s in Experiment 2-1 and 20 mm/s in Experiment 2-2. The subject touched the moving stimuli and determined which abrasive paper felt rougher using the two-alternative, forced-choice technique. The number of combinations of the six stimuli was 42. The maximum time allowed for determination was 24 s for each combination. The inter-stimulus interval was 20 s. Each subject performed 10 trials for each combination of abrasive-paper stimuli for each experiment; therefore, the total number of experimental trials was 420 for each subject for each experiment. During the experiment, the temperature in the laboratory was maintained at no less than 26˚C. Under these temperature conditions, the glabrous skin temperature of the subjects was maintained equal to or higher than 33˚C.

Results and discussion

The experimental data of the six subjects were accumulated for each combination and for each experiment. The psychometric functions were calculated from the accumulated data. The psychometric functions of Experiment 2-1 and Experiment 2-2 are shown in Fig. 3 and Fig. 4, respectively.

The patterns of psychometric functions of Experiment 2-1 and 2-2 were similar to each other. When the standard stimuli were 0.3 and 0.5 μm, the two psychometric functions overlapped each other and were nearly flat when the comparison stimuli were between 0.3 and 0.5 μm. The 1-μm-standard stimulus was judged to be rougher than the 0.3 and 0.5 comparison stimuli, and the psychometric function of 1-μm-standard stimulus was positioned lower than the psychometric functions of the 0.3- and 0.5-μm-standard stimuli. The average detection thresholds calculated from the experimental data were 0.74 μm for Experiment 2-1 and 0.79 μm for Experiment 2-2. The results of the experiments showed that humans can detect submicron roughness via indirect touch.

The stimuli moved 10 mm/s in Experiment 2-1 and moved 20 mm/s in Experiment

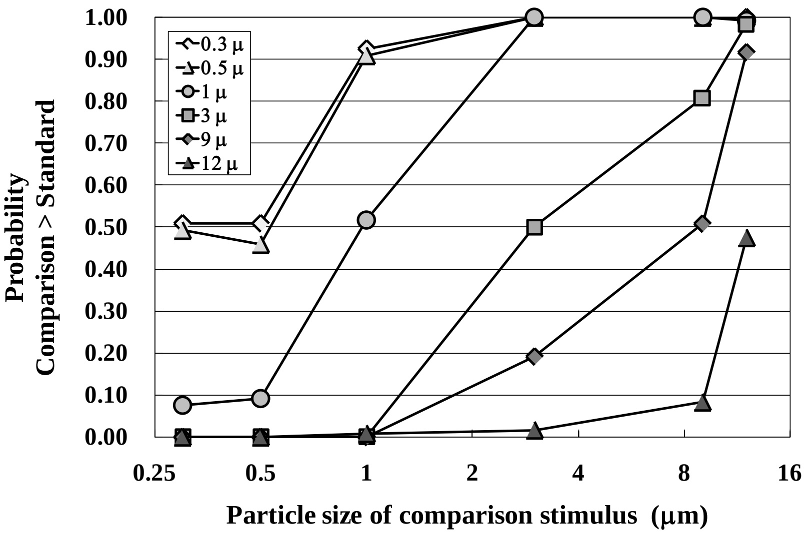

Fig. 3. Psychometric functions based on data from Experiment 2-1. The vertical axis shows the probability that the comparison stimuli were judged to be rougher than the standard stimuli. The horizontal axis shows the particle sizes of the comparison stimulus. Each symbol in the figure shows the particle size of standard stimulus. The unit of the values in the legend is μm.

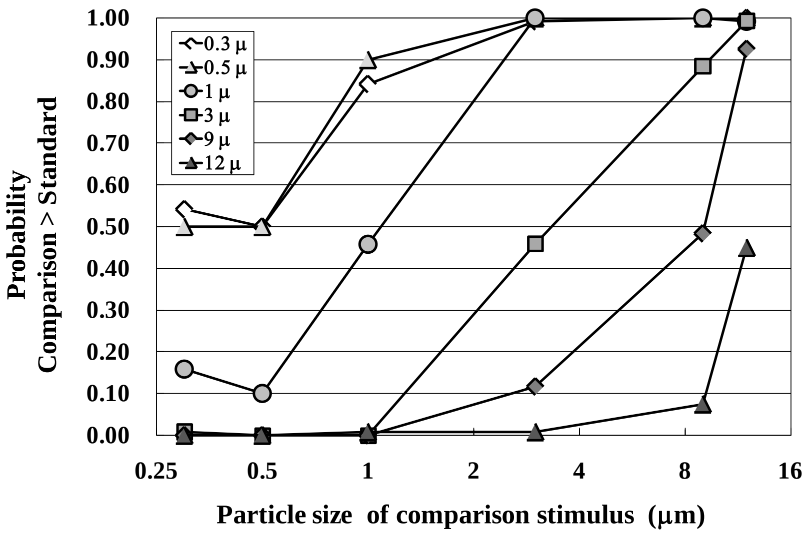

Fig. 4. Psychometric functions based on data from Experiment 2-2. Each symbol in the figure shows the particle size of standard stimulus.

2-2. The subject touched the moving stimuli and judged their roughness. The experimental results showed that the difference in the moving speeds of the stimuli had no effect on the accuracy of roughness evaluations. The results demonstrated that the subjects determined fine-texture roughness using amplitude information of stimuli that passed through the low-pass filter as Miyaoka et al (2007) suggested.

General discussion

This study revealed that humans can detect fine-surface textures by indirect touch as well as by direct touch. The detection thresholds of active touch, however, were larger than those of passive touch. The detection thresholds of fine textures were 1.92 μm in the active-touch experiment (Experiment 1-2) and 0.74 μm and 0.79 μm in the passive-touch experiments. We inferred that the difference of threshold values of the active and passive touch was caused by the speed difference in relative motion between the ballpoint pen and the stimuli. The average-moving speed of the pen was 101 mm/s in the active-touch experiment and the moving speeds of the stimuli were 10 mm/s and 20 mm/s in the passive-touch experiment. Miyaoka (Miyaoka et al., 1999; Miyaoka et al., 2007) proposed an “amplitude-information hypothesis” for the detection of fine-surface textures. Humans detect fine-surface roughness using amplitude information of stimulus-surface unevenness that passes through a low-pass filter. When the moving speed of the pen is too high — as in the active-touch experiments — the information needed for very-fine-roughness detection is dropped and the subject fails to detect the submicron roughness. On the other hand, when the moving speed of stimuli is slow — as in the passive-touch experiments — the information needed to detect submicron textures is obtained and the subject detects them. We need to carry out active-touch experiments at lower pen-moving speeds to confirm this theory.

References

Hollins, M., Bensmaïa, S. J., and Washburn, S. (2001). Vibrotactile adaptation impairs discrimination of fine, but not coarse, textures. *Somatosensory & Motor Research*, **18**, 253-262.

Miyaoka, T. (1994). Module mechanisms in tactile sensation. *The Bulletin of the Shizuoka Institute of Science and Technology*, **3**, 85-98. (In Japanese with English abstract)

Miyaoka, T. (2008). Submicron-texture discrimination mechanisms in human tactile perception. *Proceedings of the 24th Annual Meeting of the International Society for Psychophysics*, **24**, 151-156.

Miyaoka, T., Mano, T., and Ohka, M. (1999). Mechanisms of fine-surface-texture discrimination in human tactile sensation. *The Journal of the Acoustical Society of America*, **105**, 2485-2492.

Miyaoka, T. and Nakamura, T. (2007). Tactile-information-processing mechanisms of fine-surface-texture discrimination. *Proceedings of the 23rd Annual Meeting of the International Society for Psychophysics*, **24**, 391-396.