Preliminary study on gap detection threshold of textured surface

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Abstract. One indicator of the tactile spatial resolution is the gap detection threshold when a person touches or traces their finger along a concave liner gap. While the gap detection threshold has previously been measured using a flat surface, such as an iron plate, we measured the gap detection threshold for four textured surfaces. The participant traced his finger along the gap proximally and answered by choosing from two alter-natives whether felt the gap or not. The gap detection threshold was found to increase as the surface texture became rougher. This is larger than the threshold for smooth surface and smaller than that for a more irregular surface. This suggests that there is a constant relationship between texture roughness and the ability to perceive gap. We discussed two explanations of the phenomenon for the large gap detection thresholds for coarse textures.

Keywords: psychophysics measurement, gap detection threshold, roughness, texture

1 Introduction

People have a superb ability to understand the roughness and irregularities of an object surface using the tactile sense. One indicator of the tactile spatial resolution is the gap detection threshold [1]. This threshold indicates the width of the gap that can be detected when touching, or sliding skin along a slit-like gap. The gap detection threshold differs between fingers statically touching the gap and fingers sliding along the gap, being 0.9 mm [1] and 0.2 mm [2] respectively. This disparity is attributed to a difference in the amount of information obtained by touching statically or dynamically.

Until now, both gap threshold measurements have been performed on a flat surface, such as an iron plate. This paper deals with the question, what if the surface has textures? Does the texture affect gap detection? On one hand, the perception of the slit might be hindered by the rough surface acting as noise. On the other hand, the slit might be clearly perceived because of the noticeable difference between the slit affording no tactile sense and the textured flat part.

The fishbone Tactile Illusion is a phenomenon related to the above question [3] [4]. This illusion makes a convex ridge feel like a concave groove when textures are ar-

ranged around the ridge. (The whole shape seems like a fish bone if the texture is a one-dimensional grating.) Nakatani et al. [4] conducted experiments on the effect of the width on the inverse fishbone pattern, which has a concave groove (that may be regarded as a slit) at the center. As a result, when tracing the slit, there was a tendency for a person to perceive that the center part is concave when the slit width is 1.5 mm or more. This is a large value, compared with the gap detection threshold for a flat surface of 0.2mm. These results suggest that a coarser surface texture increases the gap detection threshold.

The present study made a preliminary observation of the slit detection threshold for four types of textured surface.

2 Method

2.1 Experiment conditions

Four sheet of sandpapers having different grit (#60, #100, #180, and #400) provided different textures. Each sheet of sandpaper was attached to a rectangular acrylic block, having a width of 6 cm, a height of 8 cm and a thickness of 1 cm. Each sheet had a linear edge cut by a cutting machine and was glued to the acrylic block with spray adhesive, carefully matching the edge of the sandpaper with that of the acrylic block.

The gap width was set to 0.2, 0.4, 0.6, 0.8, or 1.0 mm. A thickness gauge was inserted between two acrylic blocks to achieve an accurate gap width (Fig. 1), and the two blocks were then clamped. Four adults (21-24 years old, right-handed, males) participated in the experiment.

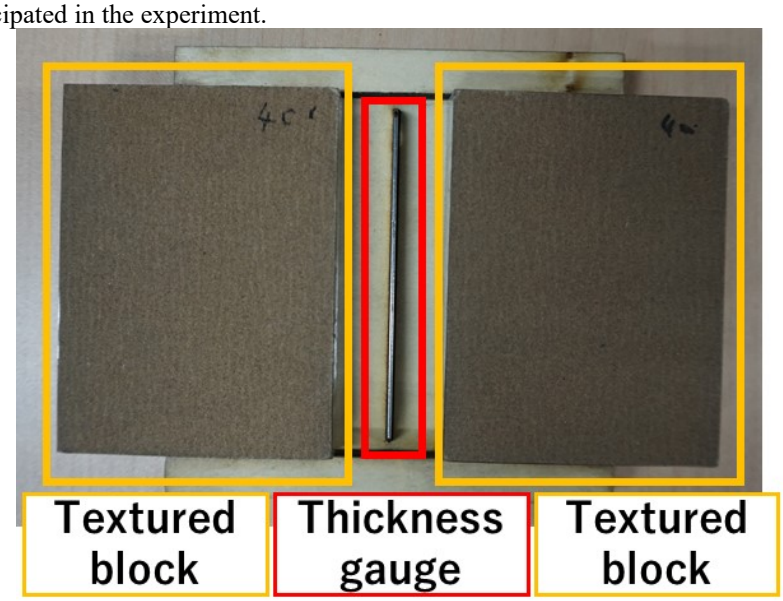

Fig. 1. Arrangement of surface-textured blocks and thickness gauge.

2.2 Experiment procedure

An overview of the experiment is shown in Fig. 2. During a trial, the texture and gap were covered with a black box to eliminate visual cues. Each participant first practiced tracing at the required speed and with the required pressing force prior to the experiment. The speed of tracing the gap was set to 8 cm/s while the pressing force was set to about 70 g. In addition, a visual graph of the pressing force was presented during the trial, and a beep sound sounded when the pressing force was greater than 40 g and less than 100 g to provide a force feedback.

At the beginning of each trial, the experimenter moved the finger of the participant onto the gap. The participant subsequently, traced his finger along the gap proximally. The participant was then whether he felt the gap, and he answered by choosing from two alternatives, "I felt the gap" or "I did not feel the gap".

The experiment comprised 10 trials for each condition, resulting in a total of 200 trials (5 gaps ×4 textures ×10 repetitions). The order of presentation of conditions was randomly decided in advance. The participants could take a break at any time. The experiment took about 1 hour per participant.

Fig. 2. (Left) Experimental equipment overview. Trace the clamped tactile piece on the weighing scale. (Right) Enlarged view of tactile piece.

3 Results

Fig. 3 shows the results of the logistic regression analysis of data obtained by averaging all results for all participants. The horizontal axis gives the gap width while vertical axis gives the ratio of answering “I felt the gap”. Each curve represents one texture. The broken line at the center of the graph shows the 50% gap detection threshold. Table 1. summarizes the 50% gap perception threshold for each condition. The results show that the gap perception threshold clearly increased with the sandpaper roughness. The perception threshold of sandpaper #400 had a negative value.

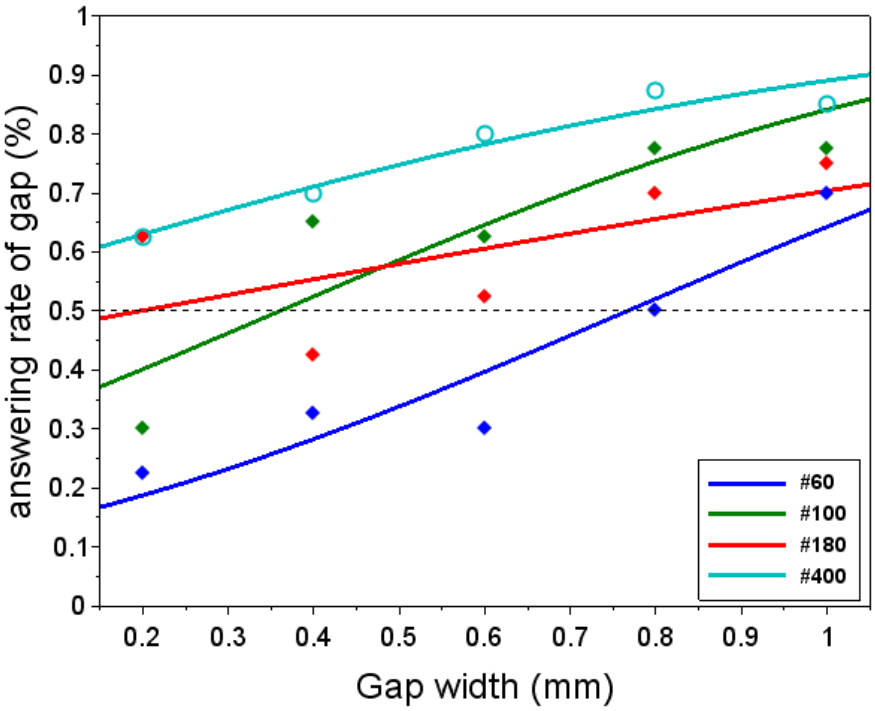

Fig. 3. Logistic regression analysis. Each point is the average rate of answering "I felt the gap" for all participants.

Table 1. Fifty-percent gap detection threshold

Sandpaper No.	50% gap detection threshold (mm)
#60	0.766
#100	0.360
#160	0.197
#400	< 0

4 Discussion

The results of the experiment show that the gap perception threshold increases and the ability to perceive the gap decreases as the surface around the gap becomes coarser. Comparing with the gap perception threshold of 0.2 mm [2] for a smooth surface, the results for the sandpapers #60 and #100 were larger and those of #160 were almost equivalent. This suggests that the slit detection capability on a rough surface is inferi-

or to that on a smooth surface. All results of the experiment were below 1.5mm, which is the gap detection threshold for a concave convex surface in the case of the Fishbone Tactile Illusion [4]. This suggests that the gap detection threshold for a finely uneven surface, like sandpaper, is lower than that for an uneven surface.

Considering the negative gap detection threshold for sandpaper #400, we should have included gaps smaller than 0.2 mm, such as 0 and 0.1 mm. There is also a possibility that the answer given by a participant was biased toward there being a gap because participants knew there was a gap under all conditions. Such bias of the response tendency could be eliminated by adding a condition without a gap.

Two explanations are considered for the large gap detection thresholds for coarse textures. The first potential explanation is physical masking due to physical skin displacement propagation. Human skin does not vibrate greatly on a smooth surface, resulting in only lateral displacement [5]. Meanwhile, skin vibrates when tracing objects with a rough surface. This skin vibration might physically hinder slit detection by propagating to the skin on the slit.

The second potential explanation is a phantom sensation produced when tracing a rough surface. A phantom sensation is an illusionary phenomenon where the intermediate part is felt as being stimulated by two separate tactile vibration stimuli, and it is known to occur at the fingertip [6]. When tracing a gap in a rough surface as in the present experiment, a vibration stimulus is presented to the fingertip across the gap. As a result, there is a phantom sensation, and the skin on the gap does not physically vibrate but is perceived as being stimulated, impeding gap detection.

The investigated phenomenon can be explained from the two viewpoints of physical and psychophysical inhibition. To clarify the cause, a method of directly observing skin displacement across the gap is effective. In other words, if skin does not vibrate when gap width is below the gap detection threshold, the psychophysical phenomenon should be key.

5 Conclusion

We measured the effect of the surface texture on the gap detection threshold and found that the tendency of the gap detection threshold increases as the texture becomes coarser. The threshold is larger than the threshold for smooth surface and smaller than that for a more irregular surface. This suggests that there is a constant relationship between texture roughness and the ability to perceive gap.

In future work, to examine the gap perception threshold in more detail, we will add more conditions of the gap width and tracing speed and pressure. We will also investigate the cause of the phenomenon by measuring skin displacement across the gap to observe the presence or absence of skin vibration.

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References

1. Phillips, J. R., Johnson K. O.: Tactile spatial resolution. II. Neural representation of bars, edges, and gratings in monkey primary afferents. Journal of Neurophysiology 46(6), 1192–1203 (1981).
2. Jeng, O.-J., Radwin, R. G.: A gap detection tactility test for sensory deficits associated with carpal tunnel syndrome. Ergonomics 38(12), 2588–2601 (1995).
3. Nakatani, M., Sato, A., Tachi, S., Hayward, V.: Tactile illusion caused by tangential skin strain and analysis in terms of skin deformation. In: International Conference on Human Haptic Sensing and Touch Enabled Computer Applications. Springer, Berlin, Heidelberg (2008).
4. Nakatani, M., Howe, R. D., Tachi, S.: Tactile depth perception examined by the Fishbone Tactile Illusion. Transactions of the Virtual Reality Society of Japan 13(1), 97–100 (2008) (in Japanese).
5. Levesque, V., Hayward, V.: Experimental evidence of lateral skin strain during tactile exploration. In: Proceedings of EUROHAPTICS 2003.
6. Ooka, T., Fujita, K.: Virtual object manipulation system with substitutive display of tangential force and slip by control of vibrotactile phantom sensation. In: Proceedings of IEEE.Haptics Symposium 2010.