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RESEARCH NOTE

Surface texture can bias tactile form perception

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Abstract The sense of touch is believed to provide a reliable perception of the object's properties; however, our tactile perceptions could be illusory at times. A recently reported tactile illusion shows that a raised form can be perceived as indented when it is surrounded by textured areas. This phenomenon suggests that the form perception can be influenced by the surface textures in its adjacent areas. As perception of texture and that of form have been studied independently of each other, the present study examined whether textures, in addition to the geometric edges, contribute to the tactile form perception. We examined the perception of the flat and raised contact surface (3.0 mm width) with various heights (0.1, 0.2, 0.3 mm), which had either textured or non-textured adjacent areas, under the static, passive and active touch conditions. Our results showed that texture decreased the raised perception of the surface with a small height (0.1 mm) and decreased the flat perception of the physically flat surface under the passive and active touch conditions. We discuss a possible mechanism underlying the effect of the textures on the form perception based on previous neurophysiological findings.

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Introduction

The sense of touch is believed to provide a reliable perception of an object's properties, including its material and geometric characteristics (Klatzky and Lederman 1993). However, human tactile perception is not always an accurate assessment of the physical properties of the real world, as illustrated by tactile illusions, which have been reported from the era of Aristotle to the present (Blake and Sekuler 2006). Investigations into how the tactile illusions occur would often reveal the mechanisms underlying tactile perception. For example, Hayward and Cruz-Hernandez (2000) discovered a tactile illusion termed "the comb illusion," which suggested that the skin stretch of the fingerpad could be felt as a vertical push on the finger surface.

Very recently, a novel tactile phenomenon was reported in which a raised surface is illusionary perceived as indented (Nakatani et al. 2006). This illusion occurs with an archetypal surface geometry, which has a smooth central bar and textures (ridges and grooves) in its adjacent areas, appearing like a fishbone pattern (see in Fig. 1a). By stroking the central bar back and forth with a fingerpad as the arrow drawn in the Fig. 1b, it is perceived as indented although the bar is physically flat or even raised.

What this phenomenon suggests is that not only geometric forms but also surface textures could contribute to geometric form perception. Yet, whether tactile form perception could be affected by surface textures has been rarely examined so far. In previous psychological studies, the form perception produced by the surface geometric edges and the texture perception produced by the surface texture have been examined

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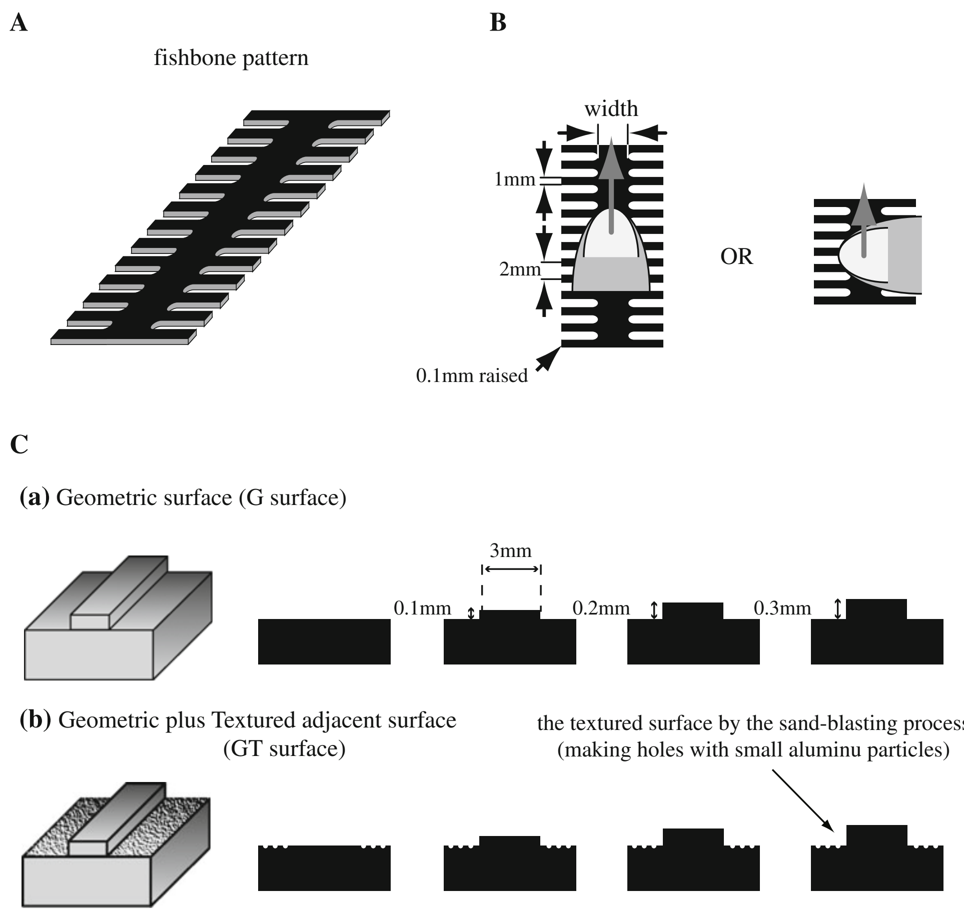


Fig. 1 The surface geometry pattern that causes a tactile illusion (Nakatani et al. 2006). **a** The fishbone pattern and (**b**) its detailed surface profile. The illusion occurs when the fingertip moves in either direction indicated in *arrows* in **b**. **c** The experimental specimen used in the experiment

independently of each other. For geometric pattern perception, Johnson and Phillips (1981) and Vega-Bermudez et al. (1991) reported the human tactile pattern recognition of embossed characters. On the other hand, textures and microgeometries such as ones in abrasive papers (Miyaoka et al. 1999; Hollins and Risner 2000, see also Lederman and Taylor 1972; Connor et al. 1990; Connor and Johnson 1992) have been utilized for examining the tactile texture roughness perception. As a few exceptions, Blake et al. (1997) showed that the roughness magnitude estimation is influenced by the height of surface dots, i.e., the surface form parameters. This is an example of form affecting texture perception, but the reverse situation (i.e., texture affects form perception) has rarely been examined. Here, we examined whether and how textures affect tactile form perception.

Experiment

Methods

Participants

Twenty participants took part in the experiment (11 men and 9 women; aged 21–30 years; right-handed). They gave informed consent based on the Declaration of Helsinki (1964) prior to participation.

Stimuli

Eight pieces of aluminum bars served as stimuli (Fig. 1c), four of which had geometric surface (G surface) and the other four had geometric plus textured adjacent surface (GT surface). The stimulus bars were 35.0 mm wide, 50.0 mm long and 5.0 mm thick. One of the four surfaces was flat, and the other three had a central bar with three levels of height (0.1, 0.2 and 0.3 mm). The width of central strip was 3.0 mm and that of adjacent regions was 16.0 mm. These sizes were determined based on the width of fingerpad of 47 people (24 men, $M = 11.0$ mm, $SD = 1.36$ mm) so that even those with relatively narrow fingerpad could cover the entire central bar and part of the adjacent areas.

Stimuli were fabricated using a manual 3D milling machine. To create textures on the adjacent areas of the GT surface stimuli, small particles of sand (1,180–1,000 μm) were blasted at 0.2 Pascal. In order to maintain a smooth surface in the central bar, it was covered with a vinyl chloride mask that was resistant to the blown sand. The surface asperity was plus/minus 0.5 micrometers in the areas with smooth surface (i.e., the central bar of GT and the entire area of G surface stimuli), and the holes of the textured area (the adjacent regions of GT surface stimuli) had 24 micrometers of depth on average. These surface height variations were measured by a surface profile meter, Surftest SJ-400, Mitutoyo Corporation.

A fixture was constructed to hold each stimuli, and it was mounted on a linear motion stage (Yokogawa Electric Corporation, LINEARSERV LM110), which moved the stimulus at a constant velocity.

Procedure

Participants cleaned their hands with liquid hand soap before the experiment. The experimenter placed the participants' right index fingers on the central bar of the stimulus piece. The participants applied contact force as light as possible to the stimulus piece to minimize the effect of non-linear contact behavior, i.e., the stick–slip phenomenon in which the fingerpad adheres to the specimen for a short period before slipping because of the stickiness of participant's fingerpad (Bhushan 2002). The applied force was not quantitatively manipulated. They touched the stimulus under three touch conditions: static, passive and active touch. Under the static touch condition, the participants were asked to feel the stimuli beneath their fingerpads without moving their finger. Under the passive touch condition, the linear motion stage was driven at 50 mm/s for a 50-mm stroke and the participants were asked to feel the tactile stimulus as it moved beneath their fingerpads without moving the fingers. Under the active touch condition, they were instructed to synchronize their finger movement with the audio signal from a metronome, so that the entire length of the stimulus pattern was covered between successive metronome beats (tempo 60 beats/min, stimulus length 50 mm) and that the finger velocity simulated that of the passive condition (50 mm/s). After touching the specimen, participants indicated which one of the three geometries, flat, raised or indented, they perceived in the central part of stimuli. Raised surface was defined as the central strip being higher than its adjacent areas, and indented surface was defined as the central strip being lower than its adjacent areas. Participants were asked to report their perception based on the central pattern.

Each of the experimental stimuli (eight varieties) was presented 12 times (96 trials in total). There were 16 practice trials and 96 experimental trials for each touch condition ($96 \times 3 = 288$ experimental trials in total). The trials were divided into a block of 24 trials of the same touch condition, and the order of blocks was randomized across participants. The order of stimuli was also randomized for each participant. After every three blocks, the participants were allowed to rest for 3 min and the stimulus set was cleaned with 90% ethanol and cleaning wipes (Kim Wipes, manufactured by Kimberly-Clark Corporation) to ensure constant stimulus intensity. Participants were also allowed to rest at any point during the experiment if necessary. Participants could not see the stimuli surface during both experimental and rest period. The experiment lasted for approximately 1 h and 30 min.

Data and statistical analysis

For each tactile stimuli and touch condition, mean percentages of perceived form and response accuracy were calculated for each participant. The calculated means for response accuracy were statistically evaluated using a two-way (surface condition (G or GT) × height (flat, 0.1, 0.2 or 0.3 mm) repeated measures ANOVA separately for each touch condition. Post hoc pairwise comparisons were made with Bonferroni adjustments.

Results

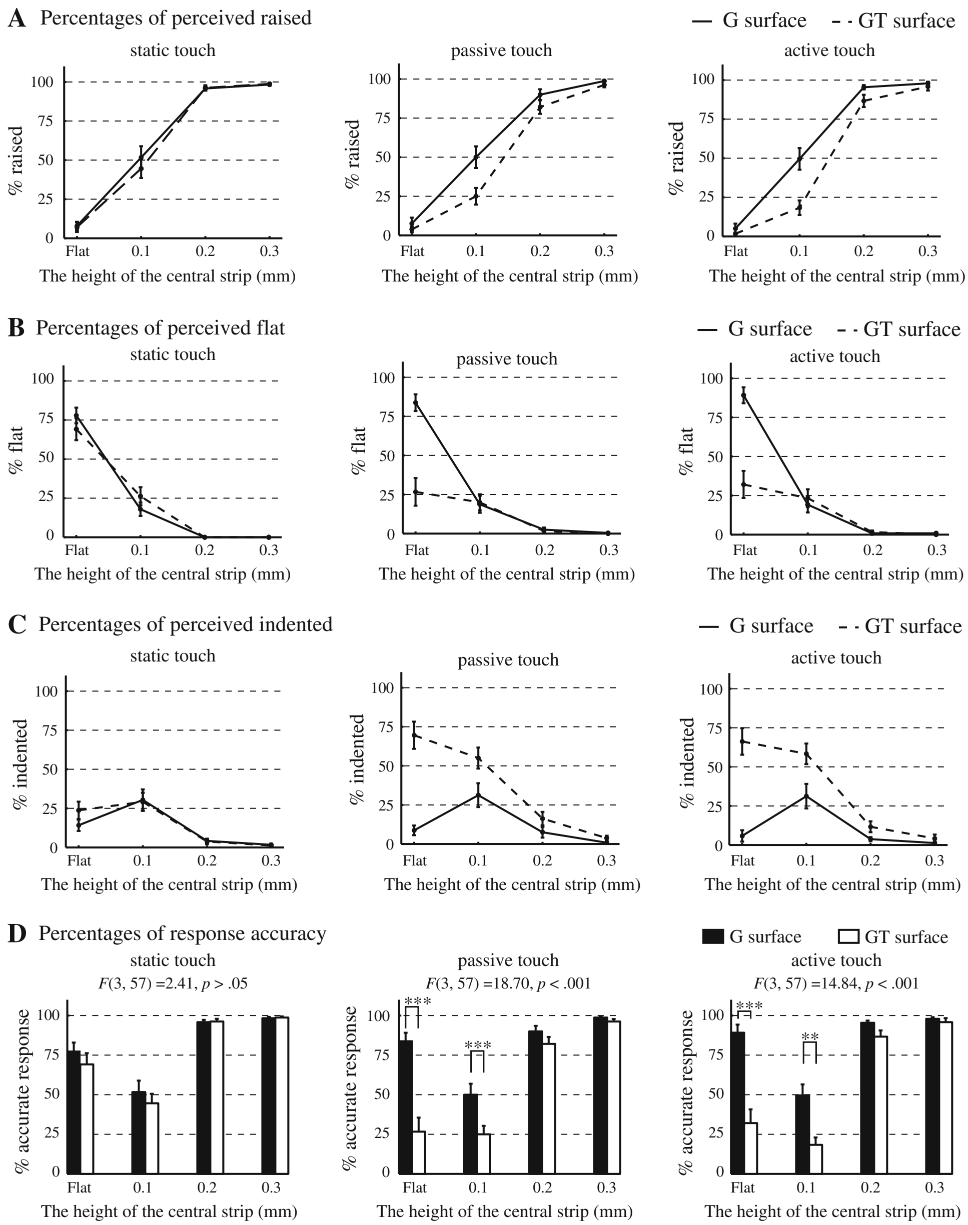
The percentages of responses with raised, flat and indented perception for each central strip height with two surface types are summarized in Fig. 2a–c, respectively, and in Table 1. Overall, the central bar was perceived as raised when its height was large and perceived as flat when it was small irrespective of surface type. Yet, the comparisons between GT and G surfaces showed the texture affected the form perception. When the height of the central bar was 0.1 mm, texture in the adjacent areas decreased the raised perception in the central bar as the contrasts between GT and G surfaces showed under passive and active touch conditions (Fig. 2a). Also, when the surface was flat, GT surface was not perceived as flat under passive and active touch conditions.

Accuracy of responses is shown in Fig. 2d. Accurate response for flat surface was flat and that for the central bar with 0.1–0.3 mm height was raised. Under static touch condition, two-way repeated ANOVA showed that there was no significant interaction ($F(3, 57) = 2.41$, $P > 0.05$) between surface and the height of the central strip. Yet, under both passive and active touch conditions, there were significant interactions for both passive ($F(3, 57) = 18.70$, $P < 0.001$) and active touch conditions ($F(3, 57) = 14.84$, $P < 0.001$). Post hoc test showed that there were significant differences between G and GT surface on response accuracy of both flat and raised surface with 0.1 mm central strip height (in Fig. 2d).

Discussion

The present study examined whether surface form perception could be influenced by surface texture. We examined

Fig. 2 The percentages of perceived form as **a** raised, **b** flat and **c** indented when participants ($N = 20$) touched the surface of each specimen under three kinds of touch conditions. **d** shows the response accuracy. ** and *** denote $P < 0.01$ and $P < 0.001$, respectively. *Error bars* indicate standard errors of the means



the perception of the raised contact surface with various heights, which had either textured (GT surface) or non-textured adjacent areas (G surface) under the static, passive and active conditions. The comparisons of the form perception between GT and G surface showed that the texture in adjacent areas affected the form perception. In case where the height of the surface was small (0.1 mm height), texture decreased the raised perception of the surface (Fig. 2a). In addition, when the surface was flat, it was not perceived as flat when the texture was present (Fig. 2b). These results showed that the participants incorrectly answered the surface geometry of below 0.1 mm raise with adjacent texture. Moreover, under these conditions, the participants perceived the surface of under 0.1 mm raise with adjacent texture as indented more frequently than as raised or flat (Fig. 2c and Table 1). It may be that texture makes the physically non-indented surface to be perceived as indented, although further studies including the physically indented surface are needed to clarify this possibility. Taken together, the current results suggest that the texture in adjacent areas affects our form perception.

These results also suggest that the touch condition influences the effect of texture on the form perception. Under the passive and active touch conditions, but not under the static condition, the relative motion between skin and specimen is involved in the surface perception. The relative motion over the texture is known to produce lateral skin stretch (Srinivasan et al. 1990), which is known to produce the perception of a vertical push in the fingerpad (Hayward and Cruz-Hernandez 2000). Thus, under the conditions in which relative

Table 1 The percentages of the surface form categorization for all participants ($N = 20$)

Surface	Height (mm)	Touch condition								
		Static			Passive			Active		
		% Indented	% Flat	% Raised	% Indented	% Flat	% Raised	% Indented	% Flat	% Raised
Geometric	Flat	14.16	**77.91**	7.91	8.75	**83.75**	7.50	5.83	**89.16**	5.00
	0.1	30.41	17.91	**51.66**	31.25	18.75	**50.00**	31.25	19.16	**49.58**
	0.2	4.16	0	**95.83**	7.50	2.50	**90.00**	3.75	0.83	**95.41**
	0.3	1.66	0	**98.33**	0.83	0.41	**98.75**	1.25	0.83	**97.91**
Geometric plus textured adjacent	Flat	23.75	**69.16**	7.08	**69.58**	26.66	3.75	**66.25**	32.08	1.66
	0.1	29.16	26.25	**44.58**	**55.00**	20.00	25.00	**58.33**	23.33	18.33
	0.2	3.75	0	**96.25**	16.25	1.66	**82.08**	11.66	1.66	**86.66**
	0.3	1.25	0	**98.75**	3.75	0	**96.25**	4.16	0	**95.83**

Bold characters indicates the most frequently answered surface form for each specimen under each touch condition, and *underlined* characters indicate the physically correct surface form

motion occurs (i.e., the passive and active touch), the texture causes lateral skin stretch in the peripheral regions in the fingerpad, which would in turn create a perception of a relative raise in the adjacent part of the fingerpad. Our result showed that we rely on the texture for judging the surface form especially when the height of the raised area was under 0.1 mm and when lateral skin stretch is present. In addition, the perceptual roughness magnitude of adjacent textures may influence the perceptual magnitude of height difference. This interaction between perceptual roughness and height difference will be examined using psychophysical procedures in the future research.

The mechanisms underlying the effect of textures on form perception reported here can be elucidated by previous neurophysiological studies in tactile perception. The physical surface shape has been shown to activate the slowly adapting type I (SA I) afferents (Johnson and Phillips 1981; Phillips and Johnson 1981). Meanwhile, the surface textures have been shown to activate the SA I afferents (Connor et al. 1990; Connor and Johnson 1992; Blake et al. 1997). Based on these results, Johnson and Hsiao (1992) hypothesized that both tactual form and texture perception were mediated by SA I afferents (see also Johnson et al. 2000). Our result that textures can affect surface form perception supports, and can be explained by, their hypothesis that both form and texture perception are mediated by SA I afferents. The further study should examine the hypothesis by directly recording the SA I afferents' activity evoked by G and GT surface. Blake et al. (1997) showed that the dot heights of the surface texture can influence the texture roughness perception, and this implied that surface form can also affect the texture perception. Thus, it would be also worth examining the mutual interactions between the surface form and texture on form and texture roughness perception by comparing psychological result and neural recordings of various afferents in order to comprehensively appreciate the roles of the rapidly adapting type I (RA I) afferents and Pacinian corpuscle (PC) afferents in addition to that of SA I afferents.

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