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ORIGINAL ARTICLE

Visual and Sensory Properties of Textures that Appeal to Human Touch

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Abstract: Some textures and materials are appealing to our sense of touch in daily life. What makes us intuitively feel like touching these particular things? Haptic invitations of such materials have rarely been investigated. The present report identifies the relationships between the visual and sensory properties of textures and their haptic invitations. We used 24 artificial clay textures that were varied along four visual factors, and quantified the degrees of haptic invitations of these textures using a ranking approach. Multiple regression analyses were performed to investigate the relationships between the degrees of haptic invitations of textures and texture factors. The surface glossiness and shape patterns of textures strongly affected the degrees of haptic invitations of those textures, but surface colors had little impact. As to the sensory factors yielded by semantic differential method, the glossless, dry, sticky, and simple factors strongly affected the textures' degrees of haptic invitations. Furthermore, we found that apparent comfort is intimately related to the attractiveness of textures. Visual and sensory factors captured 68% and 75% of the variance in subjective attractiveness, respectively. These results suggest that the visual and sensory factors associated with textures are useful for designing textures that people find attractive. In addition to these general trends of haptic invitations, individual preferences were classified into a few groups. The preferences of majority were affected by glossiness of surfaces whereas there were roughness- and smoothness-sensitive groups.
Keywords: *Haptic Invitation, Sensory Evaluation, Normalized-rank Approach, Apparent Comfort, Textural Factors*

1. INTRODUCTION

Certain textures and materials are appealing to the human sense of touch in daily life. Well-polished metal surfaces and finely woven clothes may be examples of such materials. What types of texture properties appeal to human touch? What makes us intuitively feel like touching these? Haptic invitations of such materials have rarely been investigated. In this study, we identify the properties of materials that appeal to human touch and investigate the extent to which the linear combination of these properties can describe haptic invitations of certain textures. The findings of this study can be applied, for example, to commercial products in stores in order to improve their appeal to human touch. Such products potentially garner consumers' attention. Furthermore, in public places such as train stations or commercial facilities, poster and flyer advertisements with such textures could be used in order to attract the attentions of passersby. Peck and Wiggins suggested that textures had positive affective influences on human attitude or behavior to brochures [1]. Their study represents an availability of textures that invite human touch. The use of appealing textures would be great applications of human factors research. This study is a first step in identifying properties of such appealing textures.

Textures can induce haptic invitations through appearance alone. The visual factors of textures, which include surface colors, gloss patterns and surface roughness may directly induce haptic invitations. Moreover, haptic invitations of textures might be determined via human sensory processing. For example, perceived roughness or glossiness may influence haptic invitations of textures. Such factors are acquired through sensory evaluation of textures. This study began with the hypothesis that haptic invitations of textures were related to the visual and sensory properties of textures. Participants did not touch textures. They only looked at textures and judged their haptic invitation. We investigated general trends in the haptic invitation of textures. These avenues of investigation were grounded in the authors' pilot researches with a small number of participants [2, 3]. The present article is a report of complete experiments with a sufficient number of participants and a newly designed experiment to test the impact of surface colors that generally influence human affections. Pursuing the effects of colors is significant because the color is one of the most common factors available for package designs.

Related studies on the effects of properties of textures on preferences: Many studies have examined the effects of the physical and sensory characteristics of textures on people's preferences for them. In terms of product design, Winakor et al. studied the effect of the physical characteristics of textile materials on customer preferences for woven cotton and polyester fabrics [4]. The relationships between materials and preferences for those materials have also been studied with regard to wrapping paper [5],

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sleep wear [6], and car seat fabrics [7]. Kawabata and Niwa proposed a method for predicting human preferences for clothing fabrics from the fabrics' physical characteristics [8]. A consumer's preference is treated as an integrated sensory assessment of materials. For example, in the case of cloth for suits or t-shirts, the assessment is affected by several factors, including breathability, water absorption, weight of the cloth, or comfort to the touch. Such preferences are totally different from the haptic invitation of textures.

Related studies on desire to touch: The desire to touch products for hedonic reasons was studied by Peck and colleagues [9, 1]. They measured a hedonic-oriented aspect in which customers feel inclined to touch products for their own enjoyment. They examined personal behaviors that indicate the extent to which a person tends to touch products for enjoyment. However, the haptic invitation of textures in the present study indexes the extent to which certain texture properties invite touch, which is a measure of a texture. Therefore, the human behaviors investigated as the "desire to touch" are completely different from the textures' behaviors as the "haptic invitation" in our studies.

Recently, Klatzky and Peck [10] conducted a study related to our previous ones [2, 3]. They investigated the extent to which three-dimensional objects invited human touch whereas in the present study we investigated textures that appeal to human touch. Klatzky and Peck used an index based on subjective ratings assigned by participants to individual objects. In contrast, the degree of haptic invitation in our study was quantified using a ranking method. It is unknown that both indices capture the equal information. In terms of the time required for the measurement, our method is more participant-friendly. Nonetheless, we do not stress the novelty of our index. The major difference between our study and the one by Klatzky and Peck is in the factors to be investigated: textures or object shapes.

2. STIMULUS: VISUAL FACTORS OF TEXTURES

Haptic invitation may depend on the individual predispositions of participants. For example, those who are familiar with small mammals may feel inclined to touch animal furs. In order to limit the influence of individual background on the intensity of haptic invitation, it is best for textures used in such experiments to avoid association with specific entities. Therefore, we used simple clay plates with textured surfaces as the stimuli in this study.

It would be ideal to investigate the influence of as many visual factors as possible. However, due to practical limits, we prepared 24 textures that varied along four visual factors: surface color, gloss pattern, surface shape type, and surface ridge/groove width. These four factors are commonly studied in the design of packaging paper and plastic used in products. They are potentially available to serve as design factors for packing materials. We used light clay (Hearty Soft White, Padico; Tokyo, Japan) as the texture material. The clay was molded into 55.0 mm × 55.0 mm × 5.0 mm flat plates using aluminum frame pairs. The surface color was either blue or orange, as the clay was mixed with paint before molding. The blue-orange color variation is a complementary relationship in the Munsell color system. These colors were expected to cause larger variation in sensory evaluations. The blue (Phthalocyanine Blue, Liquitex; Ohio, USA) and orange (Scarlet Red, Liquitex; Ohio, USA) paints were (4.0BP, 1.5, 7), and (8.0R, 5.0, 13), respectively, in the Munsell color presentation. The mixing ratio was 100 g clay to 1.25 mL paint. Both glossy and glossless textures were prepared. To make the textures glossy, the plates were varnished (Sealer Super Gloss, Padico; Tokyo, Japan) after being colored, molded, and dried. The JIS (Japanese Industrial Standards) specular gloss values of the textures were 2.4% and 94.2% for the glossless and glossy blue, respectively; the same values were 1.7% and 85.1% for the glossless and glossy orange, respectively. As shown in Figure 1, we used two patterns; gridded and striped. The groove and ridge widths were 0.5, 1.0, or 2.0 mm. These factors relating to surface shapes are easily reproducible in designing products. In total, 24 types of textures were prepared (2 colors × 2 gloss patterns × 2 shape types × 3 ridge and groove widths). The photos of these textures are shown in Figure 2.

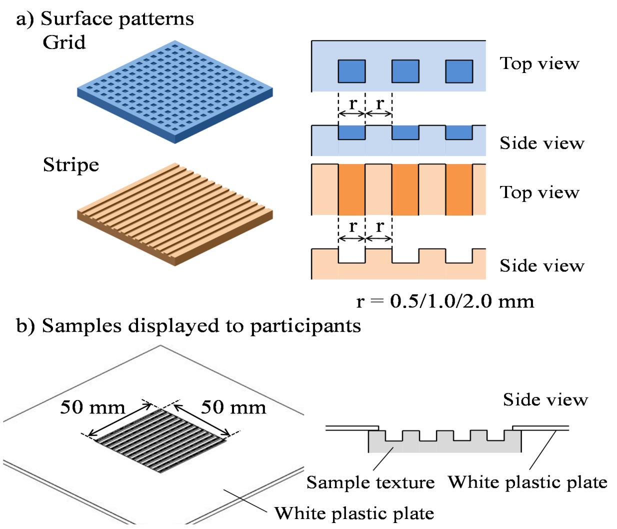

Figure 1: Clay sample textures

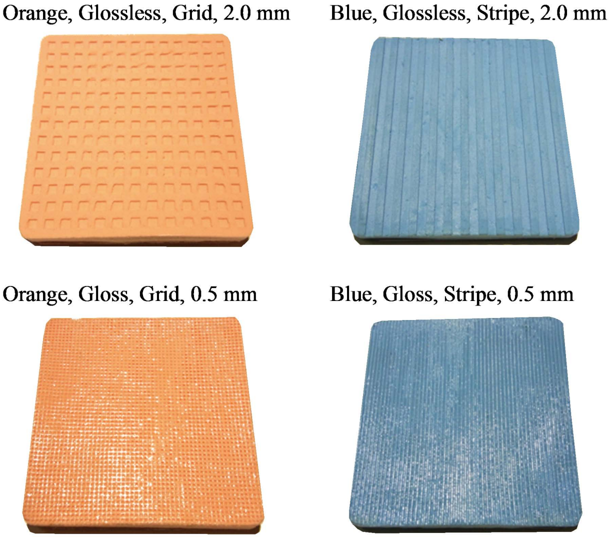

Figure 2: Photos of textures

The visual factors of the textures were quantified as scores. In order to compare regression coefficients of visual factor scores in multiple regression analysis at later sections, the scores were normalized to a mean of 0 and a variance of 1 for each of the factors: surface color (1, blue; -1, orange), gloss (1, glossless; -1, glossy), shape type (1, stripe; -1, grid), and ridge/groove width (-1.07, 0.5 mm; -0.27, 1.0 mm; 1.34, 2.0 mm).

3. EXPERIMENT 1: RELATIONSHIPS BETWEEN SENSORY/VISUAL FACTORS OF TEXTURES AND HAPTIC INVITATIONS OF TEXTURES

In experiment 1, we specified the sensory properties of textures and haptic invitations of textures through two tasks. In both tasks, participants did not touch textures but evaluated them on the basis of visual appearances. In Task 1, participants evaluated textures one after the other using a semantic differential (SD) method. We then applied factor analysis to the resulting data to extract independent sensory factors. In Task 2, participants ranked all of the textures in order of the intensity of their haptic invitations. Based on these rankings, we calculated the degrees of haptic invitation of each texture. Finally, we investigated the relationships between degrees of haptic invitation of the textures and the textures' visual and sensory factors using multiple regression analysis. The experiments and procedures described in this report, including participant recruitment, were approved by the ethical committee of Nagoya University. Sixteen university students (9 males and 7 females; approximately 20 years of ages) volunteered to participate. To avoid ordering effects, eight participants performed Task 1 first, followed by Task 2; the other eight participants performed Task 2 first, followed by Task 1.

3.1 Task 1: Sensory Factors of Textures

3.1.1 Method: Sensory evaluation

In order to quantify the sensory properties of textures, we conducted sensory evaluations using an SD method. Participants evaluated each of the 24 textures only once using five-point scales anchored in terms of adjective pairs, such as "rough-smooth" without time restriction. The adjective pairs used in the experiments were chosen in accordance with studies on visual and haptic perception [11-18]. We provided both English and Japanese terms on the evaluation sheets. We conducted preliminary experiments to remove and merge candidate adjective pairs according to their appropriateness for the textures in this study. For example, we removed adjective pairs whose scores did not vary according to differences in texture, such as "thick-thin." In addition, we merged adjective pairs with similar meanings such as "shiny-matte" and "glossy-dull." This process led to the final list of 15 adjective pairs shown in Table 1.

As shown in Figure 1b, a large matte white plate with a 50 mm × 50 mm square window was placed on top of each sample so that the participants could see only the textured surfaces and not the sides of the samples. The distance to a texture from a participant was approximately 0.5 m. The participants were instructed to keep their head positions fixed in order to maintain the relative position between the head and the samples. The textures and adjective pairs were presented to each participant in a randomly ordered fashion.

We conducted the experiments during the summer months. The laboratory temperature and humidity were approximately 28°C and 65%, respectively. The textures were placed under constant illumination of approximately 700 lx by a fluorescent light in an office room blocking sunlight.

3.1.2 Factor analysis

We used a five-point adjective scale in Task 1. The values for each adjective pair were normalized within single participants. The values were then averaged across all participants. To decrease the number of variables used in later analysis, we applied factor analysis to the values

Table 1: 15 adjective pairs used in sensory evaluation

harsh	-	not harsh	uneven	-	flat
glossy	-	glossless	elegant	-	inelegant
vague	-	clear	dark	-	light
comfortable	-	uncomfortable	soft	-	hard
dry	-	wet	vivid	-	colorless
rough	-	smooth	warm	-	cold
slippery	-	sticky	simple	-	complex
sharp	-	blunt			

and extracted the common factors that provide synthesis of strongly correlated variables. $\boldsymbol{x}_i$ was the vector of evaluation values of p (p = 15) adjective pairs for the texture specified by i. $\boldsymbol{x}_i$ was decomposed into m common factor scores f_i and unique factor scores $\boldsymbol{e}_i$:

$$\underset{p\times 1}{\boldsymbol{x}_i} = \underset{p\times m}{\boldsymbol{A}}\,\underset{m\times 1}{\boldsymbol{f}_i} + \underset{p\times 1}{\boldsymbol{e}_i} \quad (i = 1, \ldots, n) \tag{1}$$

where the factor loadings A explain the strength of the relationships between common factors and adjective pairs. The number of samples is denoted by n (n = 24). The factor loadings are estimated by the maximum likelihood method. We applied varimax rotation to the factor loadings to facilitate interpretation of the relationships between factors and adjective pairs.

3.1.3 Results: Factor loadings of 15 adjective pairs

The factor loadings and each factor's cumulative contribution rates are shown in Table 2. We adopted a four-factor model ($m = 4$) because the cumulative contribution rate was nearly saturated when $m = 4$. Cells with absolute factor loadings of 0.6 or above are highlighted in gray. We named Factor 1 the "glossless, dry and sticky factor." This factor was affected by the fine roughness of the surface, which was associated with dryness, glossiness, and slipperiness. Factor 2 was the "uneven and rough factor" characterized by the macroscopic roughness of the surface. Factors 3 and 4 were the "dark and cold factor," and "simple and comfortable factor," respectively.

Table 2: Results of factor analysis: Factor loadings of 15 adjective pairs

	Factor 1	Factor 2	Factor 3	Factor 4
Glossy	-0.918	-0.276	-0.068	-0.266
Dry	0.916	0.114	-0.135	0.289
Harsh	0.839	0.243	0.215	-0.006
Slippery	-0.726	-0.598	-0.122	-0.158
Uneven	0.115	0.861	-0.047	0.306
Rough	0.407	0.756	0.179	0.097
Soft	0.187	0.726	-0.241	0.165
Dark	0.235	-0.023	0.969	-0.034
Cold	-0.336	-0.111	0.891	0.037
Vivid	-0.423	0.026	-0.845	0.044
Simple	0.020	0.291	0.025	0.862
Comfortable	0.434	-0.094	-0.082	0.667
Elegant	0.405	-0.331	-0.538	0.483
Sharp	-0.021	-0.611	-0.018	0.349
Vague	-0.339	-0.543	0.029	-0.615
Contributing rates	0.263	0.215	0.195	0.149
Cumulative contributing rate	0.263	0.478	0.673	0.822
Featuring name	Glossless, dry & sticky fac.	Uneven & rough fac.	Dark & cold fac.	Simple & comfortable fac.

3.2 Task 2: Degrees of Haptic Invitation for Textures

We focus on the fact that it is difficult for participants to quantify degrees of haptic invitation using visual analog scales or magnitude estimation methods, although participants can confidently make judgments about which of several textures are attractive to them. Accordingly, we introduced a ranking method that allows participants to rank textures in order of intensity of their haptic invitations. We then exploited a normalized-rank approach [19] to convert the texture ranks to interval scales. This approach is applicable to the texture stimuli of this study in which we exhaustively manipulated four visual factors to produce texture stimuli. A paired comparison method is another method of estimating the magnitude of haptic invitation; however, the paired comparison method requires a large number of trials to ensure reliability.

3.2.1 Method: Ranking 24 textures

Twenty-four samples were simultaneously presented to each participant, which allowed him/her to evaluate the relative differences in the textures. At first, textures were arranged in a random array of size 4 × 6. Then, the participants ranked the textures only once in terms of the intensity of their haptic invitations without a time limit. Each participant was allowed to give the same rank to multiple textures if he/she was unable to rank all of the textures without duplicating ranks.

3.2.2 Data analysis: Normalized-rank approach

We converted the ranks of the textures to interval scales using the normalized-rank approach [19]. We defined these interval scales as the degrees of haptic invitation of the textures. The degree of the kth ranked texture was assigned as the expected value of the kth largest observation in a sample of size n from a standard normal population. The degree of the kth ranked texture was determined by

$$E\left(x_{k|n}\right) = \frac{n!}{(n-k)!(k-1)!}\int_{-\infty}^{\infty} x \cdot a(x) \cdot b(x) \cdot \phi(x)\,dx \tag{2}$$

$$a(x) = \left[1/2 - \Phi(x)\right]^{k-1} \tag{3}$$

$$b(x) = \left[1/2 + \Phi(x)\right]^{n-k} \tag{4}$$

$$\phi(x) = \frac{1}{\sqrt{2\pi}} e^{\left(-\frac{1}{2}x^2\right)} \tag{5}$$

$$\Phi(x) = \int_0^x \phi(z)\,dz. \tag{6}$$

The degrees of haptic invitation of a certain texture were averaged across the participants.

3.2.3 Results: Degrees of haptic invitation for 24 textures

Figure 3 shows the degrees of haptic invitation obtained during Task 2. The error bars indicate the standard deviations across all participants. The textures are arranged in descending order of the degree. The majority of the textures for which participants indicated high degrees of haptic invitation were glossless textures. Surface gloss was considered to affect haptic invitation more significantly than other visual factors under the experimental conditions of this study. In terms of shape type, participants' haptic invitation of striped textures was higher than that of gridded textures. In terms of ridge and groove width, the degrees of haptic invitation of textures with small widths were slightly higher than the degrees of haptic invitation of those with large widths. It was hardly possible to observe the effects of surface colors on haptic invitation.

3.3 Relationships between Degrees of Haptic Invitation and Factors of Textures

To investigate the relationships between the degrees of haptic invitation of textures and texture factors, we performed multiple regression analysis. This analysis connected the degrees of haptic invitation with the visual factors of textures and also connected the degrees of haptic invitation of the textures with the sensory factors of the textures. The analysis was applied to the standardized values. In addition, we obtained the correlation coefficients between the visual and sensory factor scores.

3.3.1 Relationships between Degrees of Haptic Invitation and Visual Factors

We conducted multiple regression analysis with the degrees of haptic invitation and the visual factor scores of textures as the objective and explanatory variables, respectively; the adjusted value of R^2 thereby obtained was 0.68. The standard partial regression coefficients are shown in Table 3.

Glossiness: We performed t-tests to see whether the standard partial regression coefficients were significantly different from zero. A significant correlation between surface gloss and degree of affinity was observed (two-tailed t-test, $t(19) = 5.29$, $p = 4.14 \times 10^{-5}$). In other words, glossiness decreased the degrees of haptic invitation of textures. One possible explanation of this result, indicated by participants' reported introspection that was recorded after all experiments, is that the majority of participants were disinclined to touch glossy textures because they are often associated with slimy surfaces. These results may vary according to the type of materials. For example, in the case of woolly materials, surface glossiness will not be associated with slimy feelings.

Shape type: There was also a significant correlation between the shape type (stripe/grid) of the textures and the degrees of haptic invitation of textures (two-tailed t-test, $t(19) = 4.69$, $p = 1.59 \times 10^{-4}$): the degrees of haptic invitation of striped textures were greater than those for gridded textures. According to the introspection, participants may have expected that striped textures would provide stronger tactile stimuli than gridded ones. This is consistent with the observation that the majority of participants reported that they would touch the striped textures so that their fingers moved perpendicularly to the groove orientation. In such a case, their perceived roughness of striped textures would exceed that of the gridded ones. Thus, we speculate that moderately intense tactile stimuli appealed to human touch.

Ridge and groove width: Ridge and groove widths (0.5/1.0/2.0 mm) did not impact the degrees of haptic invitation of textures (two-tailed t-test, $t(19) = 1.80$, $p = 0.09$).

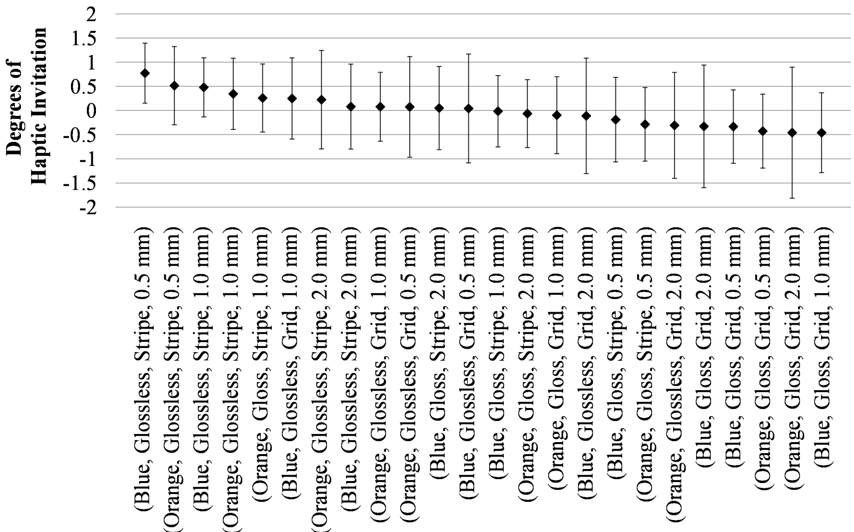

Figure 3: Degrees of haptic invitation for 24 textures

Table 3: Regression coefficients of visual factor scores and degrees of haptic invitation. The asterisk *** indicates the significance levels of $p < 0.001$.

	Color (+,Blue; -,Orange)	Gloss (+,Glossless; -,Glossy)	Shape type (+,Stripe; -,Grid)	Ridge and groove width
Regression coefficients	0.049	0.609***	0.540***	-0.207

Table 4: Regression coefficients of sensory factor scores and degrees of haptic invitation

	Factor 1 Glossless Dry Sticky	Factor 2 Uneven, Rough	Factor 3 Cold Dark	Factor 4 Simple Comfortable
Regression coefficients	0.476***	-0.159	0.004	0.773***

Surface color: Surface colors (blue/orange) also failed to impact the degrees of haptic invitation of textures (two-tailed t-test, $t(19) = 0.43$, $p = 0.67$).

According to these analyses, the degrees of haptic invitation of glossless and striped textures are expected to have high values. This estimate is consistent with the results shown in Figure 2. The four textures for which participants had the largest degrees of haptic invitation were glossless and striped textures, whereas the five textures for which participants had the five smallest degrees of haptic invitation were glossy and gridded textures.

The present effects of surface roughness on haptic invitation differ from previous findings [10], which showed that smooth surfaces invited human touch more than bumpy ones. In our study, ridge and groove widths did not impact the haptic invitations of textures. We speculate that this is due to differences in touching methods. In the study of [10], touch may have represented grasping, whereas in our study, touch meant stroking. Consequently participants in [10] may have regarded surface bumpiness as an impediment to grasping.

3.3.2 Relationships between degrees of haptic invitation and sensory factors

We conducted multiple regression analysis using degrees of haptic invitation of textures as the objective variable and the texture sensory factor score as the explanatory variable; this model yielded an adjusted R^2 value of 0.75. In this study, sensory factors had more explainable utility for haptic invitation than visual factors of which R^2 was 0.68. Table 4 lists the standard partial regression coefficients resulting from this multiple regression analysis. Significant effects of Factor 1 (glossless, dry and sticky) (two-tailed t-test, $t(19) = 4.48$, $p = 2.56 \times 10^{-4}$) and Factor 4 (simple and comfortable) (two-tailed t-test, $t(19) = 6.93$, $p = 1.33 \times 10^{-6}$) on haptic invitation of textures were found. The relationship between Factor 2 (uneven) and haptic invitation was not significant (two-tailed t-test, $t(19) = -1.45$, $p = 0.16$). Factor 3 (dark & cold) also had no significant impact on haptic invitation (two-tailed t-test, $t(19) = 0.04$, $p = 0.97$). Thus, participants reported higher degrees of haptic invitation of textures described as glossless, dry, sticky, and simple. Interestingly, though Factor 2 (uneven) was the second most significant contributing factor to visual recognition of texture, it did not contribute to the degrees of haptic invitation of textures. In contrast, Factor 4 (simple) was a minor contributing factor to texture recognition, but it strongly influenced haptic invitation.

3.3.3 Haptic invitation comes from comfort

To identify influential adjective term pairs, we investigated the correlation coefficients between the degrees of haptic invitation and the ratings of adjective term pairs. The results of this analysis revealed that the correlation coefficient for the "comfortable-uncomfortable" pair was 0.82; that was the highest value among the correlation coefficients between haptic invitation and individual adjective term pairs. The ratings for this pair indicate apparent comfort and it was included in the most influential factor of "simple and comfortable." A texture's apparent comfort potentially affects its attractiveness to human touch, consistent with results obtained by Klatzky and Peck [10]. Their index for attractiveness included the response to the statement "touching this object would feel good" which appears to yield similar results to the "comfortable-uncomfortable" pair used in the present study. The second-highest correlation coefficient was that between the haptic invitation of textures and the "dry-wet" pair (0.65); that pair was extracted as Factor 1 (glossless, dry & sticky).

3.3.4 Correlations between visual and sensory factors

The correlations between the visual and sensory factors are presented in Table 5. Factor 1 (glossless, dry & sticky) was related to the surface gloss. Glossy textures had high Factor 1 values. Factor 2 (uneven) was influenced by ridge and groove widths, indicating that coarser surface patterns were perceived as more uneven. The correlation between Factor 3 (dark & cold) and surface color was strong. Finally, Factor 4 (simple) was affected by the shape type used to create the texture, with striped textures more likely to be perceived as simple than gridded textures.

Figure 4 shows these relationships between the degrees of haptic invitation of textures and the visual and sensory factors of those textures. The line width represents relationship strength and corresponds to the absolute values in

Table 5: Correlation coefficients between visual and sensory factor scores

	Factor 1	Factor 2	Factor 3	Factor 4
Color	-0.066	-0.004	0.956	0.086
Gloss	0.913	0.276	0.033	0.301
Shape type	-0.183	-0.096	-0.062	0.807
R & G width	-0.296	0.771	-0.040	0.201

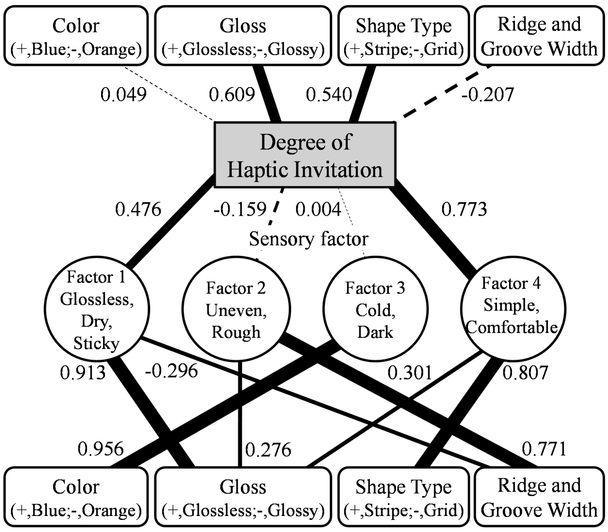

Figure 4: Relationships between sensory factors, visual factors of textures, and degrees of haptic invitation

Tables 3, 4, and 5. The relationships between the degrees of haptic invitation of textures and the visual and sensory factors of the textures were effectively quantified under the current study's stimuli set.

We found that visual and sensory factors captured 68% and 75% of the variance in haptic invitation of textures, respectively. The results support the argument that haptic invitation of textures is generally controlled by visual and sensory factors. The fact that the remaining 20%-30% of the variance could not be described by these factors may be explained by the visual and adjective terms that were omitted from this study. Individual differences in decision criteria between the two experimental tasks may have also contributed to the residuals of the regression analyses.

3.4 Individual Differences in Haptic Invitation of Textures

The standard deviations of the degrees of haptic invitation of textures in Sec. 3.2.3 were not small despite the use of only simple textures to limit the impact of personal cultural background. In order to investigate the individual differences in the degrees of haptic invitation of textures, we clustered and characterized the 16 participants in terms of their degrees of haptic invitation using factor analysis.

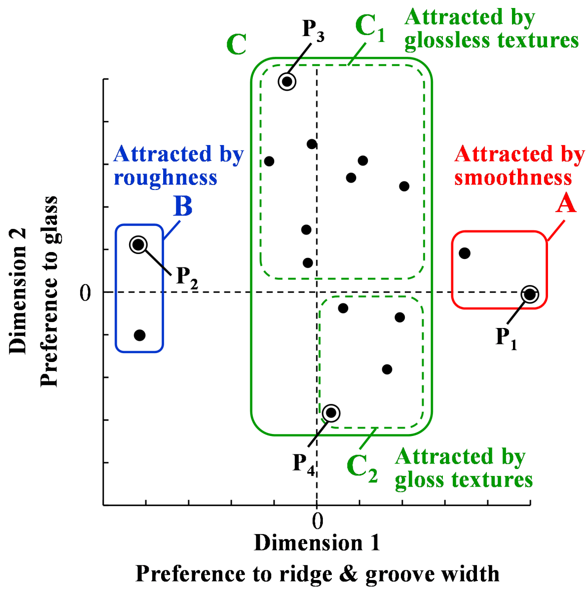

Figure 5: Distribution of participants in two dimensions. Degrees of haptic invitations of participants in Group A and B are affected by the ridge and groove width (Smooth/Rough). Those in Group C1 and C2 are affected by the glossiness (Glossless/Glossy).

We applied factor analysis to the degrees of haptic invitation of textures and placed each participant within a two-dimensional space (Figure 5). We then classified participants into three groups (A, B, and C) on the basis of the distribution of participants in two dimensions; Group C was the major group, and Groups A and B were minor groups.

The participants in Group A exhibited high haptic invitation of textures whose ridge and groove widths were small. For one participant (P_1) in Group A, the correlation coefficient between the ridge and groove width and degrees of haptic invitation was -0.886. However, for participants in Group B, the degrees of haptic invitation of uneven textures were high. For example, the correlation coefficient for one participant (P_2) in Group B was 0.786.

Most of the participants had small values on Dimension 1; we categorized these participants as Group C, but they were widely distributed in Dimension 2. Therefore, we divided Group C into Groups: C1 and C2. In Group C1, the degrees of haptic invitation of glossless textures were high. For one participant (P_3) in Group C1, the correlation coefficient between glossiness and degrees of haptic invitation was 0.672. Group C2 participants were attracted by glossy textures, with one participant (P_4) exhibiting a correlation coefficient of -0.616. Although most participants belonged to Group C1, some variations in haptic invitation were observed. Thus, while this study focused on general trends, individual differences can be an intrinsic topic of haptic invitation.

4. EXPERIMENT 2: RELATIONSHIPS BETWEEN SURFACE COLORS AND HAPTIC INVITATION

Experiment 1 did not exhibit a significant relationship between the degrees of haptic invitation of textures and the two surface colors (blue/orange). However, we should not conclude that surface colors do not influence haptic invitation, because, just two colors were tested. In addition, in the Munsell color system, color variations are not classified in one-dimensional space. Furthermore, the effects of hues on human feelings have been generally admitted [20-22]. For cases in which color yielded no significant results, we use a two-phased approach to draw conclusions about the significance of factors. In Experiment 2, we intensively focus on a single factor, i.e., color, and we increase the number of surface colors in order to test the contribution of surface color more thoroughly.

4.1 Measurement of Haptic Invitation of Five-Colored Textures

Participants ranked textures differing from those used in Experiment 1 in order of the degrees of haptic invitation of the textures. We crossed color and ridge/groove width to generate the 10 stimuli (5 colors × 2 ridge and groove widths). The textures had five different surface colors: blue, orange, purple, green, and yellow. The blue and orange paints were the same as those used in Experiment 1. The purple (Dioxazine Purple, Liquitex; Ohio, USA), green (Permanent Green Light, Liquitex; Ohio, USA) and yellow (Yellow Medium Azo, Liquitex; Ohio, USA) paints were (5.6P, 1.5, 1), (1.2G, 4.9, 10), and (3.7Y, 8.2, 13), respectively, in the Munsell color presentation. These five colors are nearly equally spaced in the Munsell color system as shown in Figure 6. The mixing ratio was the same as that used in Experiment 1. All textures were glossless and striped. The groove and ridge widths were either 1.0 or 2.0 mm. We used the same normalized-rank approach as in Experiment 1 to convert the ranks of the degrees of haptic invitation of textures.

4.2 Results of Experiment 2: Degrees of Haptic Invitation of 10 Textures

Figure 7 shows the degrees of affinity obtained during Experiment 2. The textures are arranged in descending order of haptic invitation. We performed a two-way ANOVA with surface colors and ridge and groove widths as the explanatory variables and degrees of haptic invitation as the objective variable. The results indicated no significant effect of surface color ($F(4,150) = 1.15$, $p = 0.34$; $\eta^2 = 0.030$) or ridge and groove width ($F(1,150) = 0.82$, $p = 0.37$; $\eta^2 = 0.005$) on haptic invitation. The effect of surface color on haptic invitation was therefore negligible within the textures used in this study, as was the effect of ridge and groove widths.

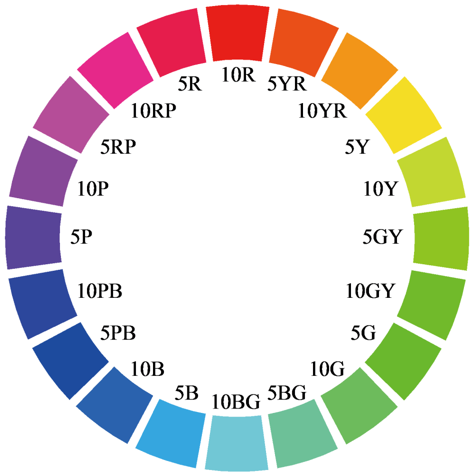

Figure 6: Hue circle in the Munsell color system

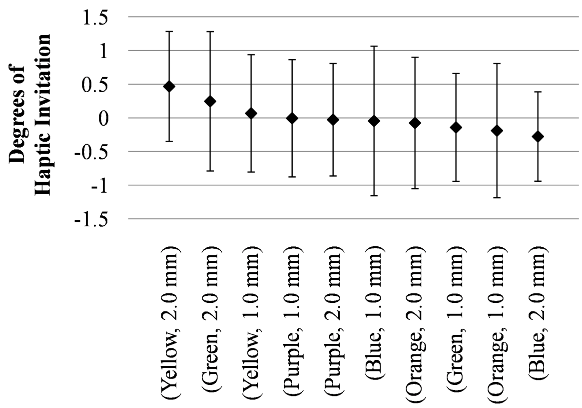

Figure 7: Degrees of haptic invitation of 10 textures: 5 different surface colors

4.3 Discussion: Effects of Surface Colors on Haptic Invitation of Textures

Colors have been reported to have a variety of effects on human feelings. Some have reported that colors with long wavelengths, such as red, yellow, and orange, are apparently warmer than colors with short wavelengths, such as violet, blue, and green [20, 21]. Also, yellow is associated with smooth and soft textures [22]. Hence, hues seem to be related to Factor 2 (uneven) and Factor 3 (dark & cold). The results of Experiment 1 showed that these two factors rarely affect the degrees of haptic invitation of textures. Therefore, from these literature and the results of both experiments, it is reasonable to conclude that the hues of textures insignificantly affect their haptic invitations. This is a good implication for package design because color design and haptic invitation can be decoupled. However, we should note that brightness (which is related to apparent surface glossiness) potentially affects the haptic invitation of textures.

5. CONCLUSION

We investigated visual and sensory properties of textures that appeal to human touch. We used sample textures in a manner that allowed us to control four visual factors (surface color, gloss, shape type, and ridge/groove width). Of the tested visual factors, glossiness and surface shape most strongly affected the degrees of haptic invitation of textures. Further experimentation indicated that surface colors did not influence the haptic invitation of textures. Regarding the influence of sensory factors, Factor 1 (glossless, dry and sticky) and Factor 4 (simple and comfortable) were strongly related to haptic invitation. These factors captured 68%-75% of the variance in haptic invitation.

In product design, the number of visual factors available for manipulation is limited. Under such conditions, the present method enables the design of products or textures that are appealing to human touch. Verification of this method through real marketing research in the design of commercial products is an upcoming challenge.

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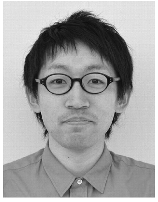

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