Physical and sensory factors of textures that appeal to human touch

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***Abstract*. Some textures appeal to human touch, the reasons for which have not been investigated. We investigate the relationship between the physical and sensory factors of 24 clay textures. Experimental results reveal that 70%–80% of the textures' appeal to human touch can be explained on the basis of these factors.**

***Keywords*: affinity to texture, sensory evaluation, textural dimension.**

I. Introduction

CERTAIN textures and materials that are used on a daily basis appeal to human touch. Well-polished metal surfaces and finely woven clothes are examples of such materials. Discovering the reason for this affinity could enable us to design products that attract customers. In this study, we investigated the properties of materials that appeal to human touch.

To the best of our knowledge, human affinity to such materials has not been investigated. We assumed that our affinity is related to the physical and sensory characteristics of the textures. In previous studies, tactile sensations had been explained by the sensory factors of textures [1], [2], [3], [4]. Other studies have investigated the relationship between the physical and sensory characteristics of textures [5], [6]. From the viewpoint of product design, Winakor et al. studied the effect of the textiles' physical characteristics on their sensory evaluation [7]. In addition, the physical and sensory characteristics of some specific materials were investigated. For example, Chen et al., Kim et al., and Matsuoka et al. and Picard et al. investigated the characteristics of wrapping paper [8], sleeping wear [9] and car sheets [10], [11], respectively. Kawabata et al. proposed a method to estimate sensory factors from the physical factors of clothing fabrics [12]. However, the relationship between the physical and sensory factors of the textures and their appeal to human touch has not been reported thus far.

The objective of this study is to investigate to what extent and how the physical and sensory factors of textures correlate their appeal to human touch. When we see a texture, our affinity to them is induced via its appearances. Therefore, the physical factors of the textures may directly induce human affinity. On the other hand, the affinity to textures may be determined through human sensory processing. We experimentally verify the hypothesis that the affinity is attributable to the physical and sensory factors of the textures. This affinity may depend on personal predispositions of participants, but we average individual responses to investigate a potential trend in the relationships between the factors of the textures and their appeal to human touch.

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II. Definitions of Appeal to Human Touch

In this study, we assume that the textures' visual appearance contribute to their appeal to human touch. Therefore, in the experiment, participants evaluate textures without touching them. In order to prevent the variations in cultural background from affecting the intensity of the affinity, the sample textures should not be associated with something specific. To this end, in this study, we use simple clay plates with textured surfaces.

The participants rank all the sample textures in the order of the intensity of their affinity to the textures, and we quantitatively assess the intensity of the affinity from the rank. Finally, "touch" does not imply pushing, or holding an object; it simply implies stroking the surface of textures.

III. Stimulation: physical factors of texture

Rather than finely investigating the effect of single physical factor, we are going to see the possible influence of some physical factors. We made 24 different textures

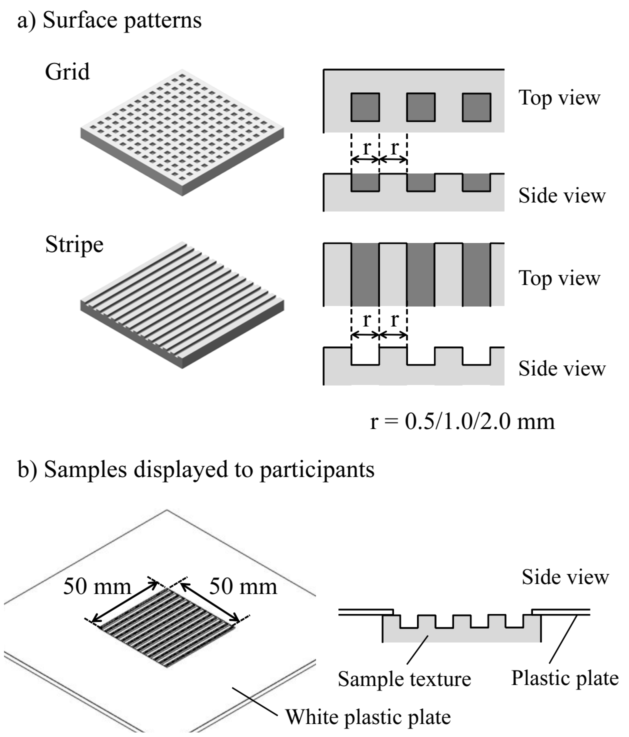

Fig. 1. Clay sample texture

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controlled by four physical factors: surface colors, surface gloss patterns, surface shape-types, and surface ridge and groove widths. We adopted light clay (Hearty Soft White, PADICO, Tokyo, Japan) as the texture material. The clay was mold into 55.0 mm × 55.0 mm × 5.0 mm flat plates using aluminum frame pairs. The surface color was either blue or orange; the clay was mixed with paint colors before molding. The color variation of blue and orange is a complementary relationship. These colors should cause a larger deviation in sensory evaluations. The blue (Phthalocyanine Blue, Liquitex, Ohio, USA) and orange paints (Scarlet Red, Liquitex, Ohio, USA) were (4.0BP, 1.5, 7), and (8.0R, 5.0, 13), respectively, in the Munsell color presentation. A mixing ratio for the clay and paints was 100 g clay to 1.25 ml paint. For the glossiness of the textures, glossy and glossless textures were prepared. To make the textures glossy, the plates were varnished (SEALER Super Gloss, PADICO, Tokyo, Japan) after being colored, mold, and dried. The JIS specular gloss of the textures were 2.4% , 94.2% , 1.7% , and 85.1% for the glossless and glossy blue and glossless and glossy orange, respectively. As shown in Fig. 1, two shape types were used: grid and striped. The groove and ridge widths were 0.5, 1.0, or 2.0 mm. In total, 24 types of textures were prepared (2 colors × 2 gloss patterns × 2 shape types × 3 ridge and groove widths).

The physical factors of the textures were quantified by physical factor scores. The physical factor scores were normalized values with a mean of 0 and variance of 1 for each of the four physical factors: surface color (1: blue, -1: orange), gloss (1: glossless, -1: gloss), shape type (1: stripe, -1: grid), ridge and groove width (-1.07: 0.5 mm, -0.27: 1.0 mm, 1.34: 2.0 mm).

IV. Experiment

In Task 1, the participants evaluated textures one after the other using the semantic differential (SD) method. Using the scores given by the participants, we quantified the sensory properties of each texture. We then applied factor analysis to these properties to obtain the independent sensory factors.

After Task 1, the participants ranked all 24 textures in order of the intensity of their affinity to the textures (Task 2). Based on the ranks of the textures, we calculated the degrees of affinity to each texture. Finally, we investigated the relationships between the degrees of affinity and the physical and sensory factors using multiple regression analysis.

A. Task 1: sensory evaluation of textures

In order to quantify the sensory properties of the textures, we conducted sensory evaluations by using the SD method. The participants evaluated the textures using five-point scales in terms of a pair of adjective terms, such as "rough-smooth". The adjective terms used in the experiments were chosen in reference to studies on visual and haptic perception. In the experiments, we showed both English and Japanese terms on evaluation sheets. We conducted preliminary experiments to remove and merge the candidate terms in terms of their appropriateness for the textures in this study. For example, we removed the terms whose scores did not deviate, such as "thick-thin". In addition, we merged adjective terms with similar meanings such as "shiny-matte" and "glossy-dull". In the end, 16 adjective pairs were left, as shown in Table I.

The participants were 12 voluntary students in their 20s from the authors' laboratory. As shown in Fig. 1b, a large white plate with a 50 mm × 50 mm square window was placed on the sample texture so that the participants would see only the textured surfaces and not the sides of the samples. The participants were instructed to attempt to keep their head positions fixed in order to retain the relative position between the head and texture samples.

The order in which the textures and adjective terms used to sort them were presented to each participant random. We conducted experiments in a laboratory environment where the temperature was approximately 24 °C, and the textures were placed at approximately 460 lx.

B. Factor analysis: data analysis of Task 1

We assigned values of 1–5 on the five-point adjective scales obtained in Task 1. In order to reduce the effects of individual differences in sensory evaluation, the evaluation values were normalized to within a single participant. To decrease the number of variables used for the later analysis, we applied a factor analysis on the evaluation values and extracted common factors as a synthesis of variables that were strongly correlated. The evaluation values $\boldsymbol{x}_i$ for p adjective term pairs were broken down into common factors $\boldsymbol{f}_i$ and unique factors $\boldsymbol{e}_i$:

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

where the factor loadings $\boldsymbol{A}$ explain the strength of the relationships between common factors and adjective terms. In this model, the correlation matrix $\boldsymbol{R}$ of x can be represented as

$$\underset{p\times p}{\boldsymbol{R}} = \underset{p\times m}{\boldsymbol{A}}\,\underset{m\times p}{\boldsymbol{A}^{\mathsf{T}}} + \underset{p\times p}{\boldsymbol{D}} \tag{2}$$

where $\boldsymbol{D}$ =diag$({d_1}^2, \cdots, \mathrm{d}_p^2)$ are unique factors. Matrix $\boldsymbol{R}^*$, where diagonal elements of the correlation matrix $\boldsymbol{R}$ are replaced by the estimated communality ${h_j}^2$, is

$$\boldsymbol{R}^* = \begin{bmatrix} {h_1}^2 & r_{12} & \dots & r_{1p} \\ r_{21} & {h_2}^2 & \dots & r_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ r_{p1} & r_{p2} & \dots & {h_p}^2 \end{bmatrix} (= \boldsymbol{R} - \boldsymbol{D}). \tag{3}$$

$\boldsymbol{R}^*$ is approximated by

$$\boldsymbol{R}^* = \hat{\boldsymbol{A}}\hat{\boldsymbol{A}}^{\mathsf{T}} \tag{4}$$

TABLE I
Adjective terms

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	predictable	-	unpredictable

where $\hat{\boldsymbol{A}}$ is the approximation of $\boldsymbol{A}$. $\hat{\boldsymbol{A}}$ is given by $\boldsymbol{R}^*$'s m largest eigenvalues $\hat{\lambda}_1, \cdots, _m$ and their corresponding eigenvectors $\hat{\boldsymbol{c}}_1, \cdots, _m$. $\hat{\boldsymbol{A}}$ is

$$\hat{\boldsymbol{A}} = \left[\sqrt{\hat{\lambda}_1}\hat{\boldsymbol{c}}_1, \cdots, \sqrt{\hat{\lambda}_m}\hat{\boldsymbol{c}}_m\right]. \tag{5}$$

We extracted the potential factors that explain textures by applying factor analysis to 15 adjective pairs excluding "predictable-unpredictable." We applied varimax rotation to the factor loadings $\hat{\boldsymbol{A}}$ to facilitate interpretation of the relationships between factors and adjective terms.

C. Task 2: texture ranking

After Task 1, all sample textures were simultaneously presented to each participant. The participants ranked the textures in terms of the intensity of their affinity to the textures. He was allowed to give the same rank to a few different textures if he felt it difficult to rank all of the textures without any duplicate ranks. By being presented with all 24 different textures at once, participants could evaluate the relative differences in textures.

D. Normalized-rank approach: data analysis of Task 2

Because the ranks of the textures are ordinal scales, we converted the ranks to interval scales using normalized-rank approach [13]. We defined these interval scales as the degrees of affinity. The textures did not include any that might include intense affinity. Hence, we assumed that the population of degrees followed a normal distribution.

The degree of the kth ranked texture was assigned to the expected value of the kth largest observation in samples of size n from a standard normal population. The degree of the kth ranked texture was determined by

$$E(x_{k|n}) = \frac{n!}{(n-k)!(k-1)!}\int_{-\infty}^{\infty} x \cdot a(x) \cdot b(x) \cdot \phi(x)dx \tag{6}$$

$$a(x) = \left[\tfrac{1}{2} - \Phi(x)\right]^{k-1} \tag{7}$$

$$b(x) = \left[\tfrac{1}{2} + \Phi(x)\right]^{n-k} \tag{8}$$

$$\phi(x) = \tfrac{1}{\sqrt{2\pi}} \exp\left(-\tfrac{1}{2}x^2\right) \tag{9}$$

$$\Phi(x) = \int_0^x \phi(z)dz. \tag{10}$$

The degrees of affinity computed for each participant were averaged.

V. Results

A. Results of factor analysis

The factor loadings and each factor's eigenvalues and cumulative contributing rates calculated through the factor analysis are shown in Table II. Eigenvalues mean the size of the factors' effects. Cumulative contributing rate is a percentage that represents the degree to which the textures are explained by the obtained factors. We adopted the five-factor model ($m = 5$) because the cumulative rate was almost saturated when m was 5. Cells showing 0.7 or larger absolute factor loadings were painted gray. Because the adjective terms with large factor loadings represent the property of the factor, we named factor 1 as the "glossless, rough, and dry factor," factor 2 as the "comfortable and elegant factor," factor 3 as the "cold and dark factor," factor 4 as the "complex factor," and factor 5 as the "uneven factor." Factor 1 was assumed to be affected by the fine roughness of the surface, which is associated with dryness, glossiness, and slipperiness. In contrast, factor 5 is affected by the macro/coarse roughness of the surface, which is related with the groove and ridge widths of the surface. According to Table II, the cumulative contributing rate of the five factors is approximately 0.87; therefore, the dimension space of the texture sensations was well established.

B. Degrees of affinity to textures

The degrees of affinity that resulted from Task 2 are shown in Fig. 2. The textures are arranged in descending order of degree. In terms of the surface gloss, the degree of glossless textures was larger than that of glossy textures. Textures with the top ten degrees are glossless textures. Surface gloss was assumed to greatly affect the degrees compared with the other physical factors. In terms of the effects of the shape type, degrees of striped textures are larger than those of grid textures. As to the surface color, the degrees of blue textures are slightly larger than those of orange textures; for the ridge and groove width, degrees slightly increase in proportion to the width.

VI. Relationships between Degrees of Affinity and Factors of Textures

To investigate the relationships between the degrees of affinity and factors of textures, we performed multiple regression analysis. We performed analysis in two ways: objective variables are degrees, and explanatory variables are physical factor scores of textures; and objective variables are degrees, and explanatory variables are sensory factor scores of textures. Multiple regression analysis was applied to the standardized values. In addition, we obtained the correlation coefficients between the physical and sensory factor scores and attempted to connect both factors using these coefficients.

A. Relationships between degrees of affinity and physical factors

We conducted the multiple regression analysis with the objective and explanatory variables being the degrees of

TABLE II
Result of factor analysis: Factor loadings of adjective terms

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Glossy	−0.940	−0.183	−0.115	0.210	0.024
Dry	0.926	0.250	−0.117	−0.144	0.067
Rough	0.833	−0.152	0.091	0.012	0.159
Slippery	−0.758	0.048	−0.014	0.030	−0.388
Harsh	0.734	0.199	0.109	0.454	−0.259
Comfortable	0.124	0.893	−0.029	0.019	0.231
Elegant	−0.034	0.869	0.026	0.222	−0.015
Sharp	0.214	0.747	0.104	0.480	−0.096
Dark	0.328	−0.028	0.941	0.002	0.009
Cold	−0.197	0.079	0.938	0.136	0.130
Complex	−0.110	0.199	−0.009	0.960	−0.146
Uneven	0.186	0.040	0.121	−0.145	0.903
Soft	0.270	−0.373	−0.523	−0.556	0.210
Vivid	−0.559	0.253	−0.649	0.387	0.065
Vague	−0.014	−0.515	0.087	0.122	−0.574
Eigenvalue	4.657	3.667	2.561	1.913	0.850
Cumulative Contribut. rates	0.279	0.465	0.634	0.767	0.870

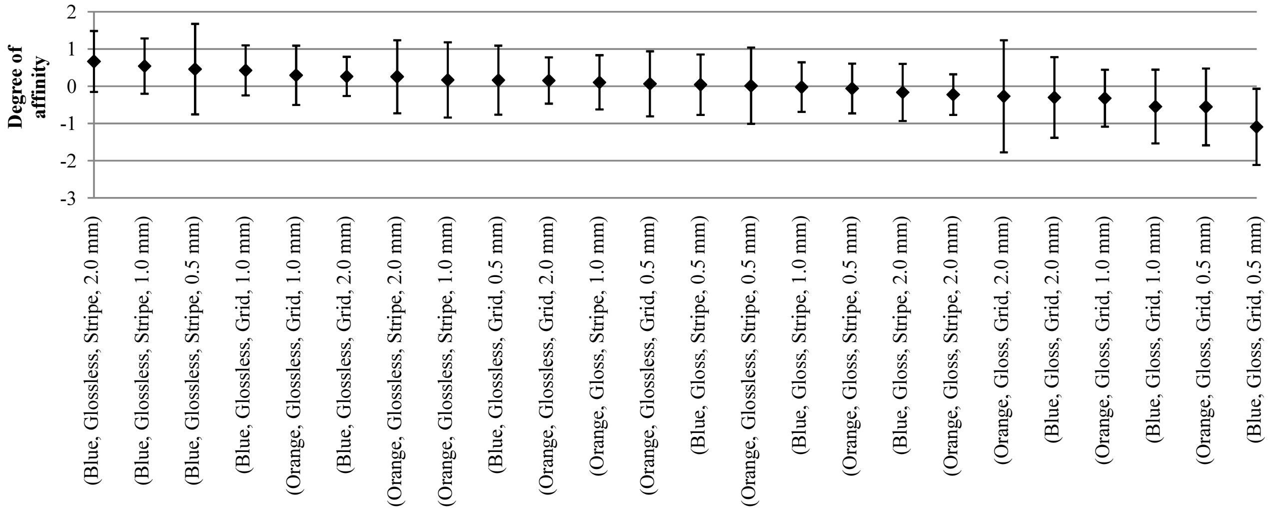

Fig. 2. Degrees of affinity to textures. Error bars are standard deviations among the participants.

affinity and physical factor scores of textures, respectively. The standard partial regression coefficients are shown in Table III. We found a significant negative correlation between the surface gloss and degrees. In other words, being glossy decreases the degrees of affinity. Next, we determined the correlation between the shape type (stripe/grid) of textures and the degrees: the degrees for striped textures were greater than the degrees for grid textures.

In contrast, there was not much of a correlation between the degrees and surface color (blue/orange) or ridge and groove width (0.5/1.0/2.0 mm). Therefore, we estimated that the degrees of glossless and striped textures are high values. This estimate is consistent with the results shown in Fig. 2. In this case, R^2 was 0.72: therefore, physical factors explain the degrees of affinity as 72% of the variance in the data.

B. Relationships between degrees of affinity and sensory factors

We describe the relationships between the degrees of affinity and sensory factor scores of textures that resulted from factor analysis. We conducted the multiple regression analysis with the objective and explanatory variables being the former and latter types of variables, respectively. Sensory factor scores are degrees of correlations between each factor and texture, as shown in Table IV. We show standard partial regression coefficients in Table V that resulted from multiple regression analysis. We found strong correlations between factors 1 (glossless, rough, dry) and 2 (comfortable, elegant) and the degrees of affinity. Slight correlations between factors 4 (complex) and 5 (uneven)

TABLE III
REGRESSION COEFFICIENTS OF PHYSICAL FACTOR SCORES AND DEGREES OF AFFINITY

	Color (+:Blue/ -:Orange)	Gloss (+:Glossless/ -:Glossy)	Shape Type (+:Stripe/ -:Grid)	Ridge and groove wid.
Degrees of affinity to textures	0.087	0.741	0.376	0.147

and the degrees were observed. Factor 3 (cold, dark) did not show any effects on the degrees. Thus, textures that are dry, glossless, comfortable, and elegant showed high degrees of affinity. The degrees of affinity were not determined only by the evaluation of comfort. In this regression analysis, R^2 was 0.78; therefore sensory factors explain the degrees of affinity as 78% of the total. Interestingly, factor 3 is the third factor that contributes to the recognition of textures, while it does not contribute to the degrees. In contrast, while factors 4 and 5 are minor factors for texture recognition, they more strongly influence the degrees of affinity.

TABLE IV
SENSORY FACTOR SCORES

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Blue, Gloss, Stripe, 0.5mm	0.564	0.517	1.138	0.756	−0.156
Blue, Glossless, Stripe, 0.5mm	0.535	1.135	1.054	0.702	0.461
Blue, Gloss, Stripe, 1.0mm	0.393	−0.492	1.197	0.045	−0.225
Blue, Glossless, Stripe, 1.0mm	0.084	1.821	0.963	−0.742	0.088
Blue, Gloss, Stripe, 2.0mm	0.764	−1.447	0.732	−0.991	−0.196
Blue, Glossless, Stripe, 2.0mm	0.160	0.417	1.062	−2.150	−0.675
Blue, Gloss, Grid, 0.5mm	−0.649	−1.834	1.394	1.276	−1.754
Blue, Glossless, Grid, 0.5mm	0.321	0.283	1.099	1.134	−0.525
Blue, Gloss, Stripe, 1.0mm	−1.976	0.220	0.430	0.185	1.340
Blue, Glossless, Stripe, 1.0mm	0.689	0.810	0.449	1.191	1.758
Blue, Gloss, Stripe, 2.0mm	−1.950	−0.689	0.770	−0.928	0.439
Blue, Glossless, Stripe, 2.0mm	0.418	−0.577	1.070	0.034	1.002
Orange, Gloss, Stripe, 0.5mm	0.294	1.474	−0.671	−0.001	−1.269
Orange, Glossless, Stripe, 0.5mm	0.789	−0.162	−0.937	1.008	−0.031
Orange, Gloss, Stripe, 1.0mm	0.458	0.493	−1.040	−0.537	−0.562
Orange, Glossless, Stripe, 1.0mm	0.021	1.350	−0.993	−0.573	0.529
Orange, Gloss, Stripe, 2.0mm	0.641	−0.622	−0.682	−1.644	−0.108
Orange, Glossless, Stripe, 2.0mm	0.621	−0.663	−0.731	−1.587	0.641
Orange, Gloss, Grid, 0.5mm	−1.540	0.002	−0.929	0.474	−1.585
Orange, Glossless, Grid, 0.5mm	0.591	0.232	−1.080	0.641	−1.866
Orange, Gloss, Grid, 1.0mm	−1.105	−0.635	−1.298	1.231	0.811
Orange, Glossless, Grid, 1.0mm	0.631	0.195	−1.049	1.002	0.668
Orange, Gloss, Grid, 2.0mm	−2.111	0.074	−0.920	−0.482	0.356
Orange, Glossless, Grid, 2.0mm	1.357	−1.901	−1.029	−0.042	0.860

TABLE V
REGRESSION COEFFICIENTS OF SENSORY FACTOR SCORES AND DEGREES OF AFFINITY

	Factor 1 (Rough, Glossless, Dry)	Factor 2 (Elegant, Comfort.)	Factor 3 (Cold, Dark)	Factor 4 (Complex)	Factor 5 (Uneven)
Degrees of affinity to textures	0.591	0.503	0.069	−0.244	0.318

TABLE VI
CORRELATION COEFFICIENTS BETWEEN PHYSICAL AND SENSORY FACTOR SCORES

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Color	−0.055	0.014	0.971	0.044	0.139
Gloss	0.534	0.258	−0.010	0.053	0.260
Shape type	0.457	0.336	0.093	−0.490	−0.134
R & G width	−0.038	−0.439	−0.018	−0.741	0.408

C. Correlations between physical and sensory factors

We show the correlations between physical and sensory factors in Table VI. Factor 1 (glossless, rough, dry) is related to the surface gloss and shape type. Glossy and striped textures had higher values in terms of factor 1. Factor 2 (comfortable, elegant) is influenced by the shape type and ridge and groove widths; this indicates that striped textures with finer surface patterns are perceived to be more comfortable and elegant. The correlations between factor 3 (cold, dark) and the surface color was strong, while the other physical factors had little effect on this factor. Factor 4 (complex) was strongly affected by the ridge and groove widths in that smaller widths cause higher complexity. Further, grid textures tended to be more complex than the striped textures. Finally, factor 5 (uneven) was dominantly impacted by the ridge and groove widths of the texture surfaces.

Fig. 3 shows the above mentioned relationships between the degrees of affinity and physical and sensory factors of textures. The line width represents the strength of the relationships, which correspond to the absolute values of the standard partial regression coefficients and correlation coefficients. As shown by this figure, although it is limited to the sample textures used in this study, the relationships between the degrees of affinity and physical and sensory factors of textures were quantitatively clarified.

VII. DISCUSSIONS

A. Physical and sensory factors of textures effectively explained our affinity to the textures

We found that the physical and sensory factors of the textures explained the degrees of affinity by 72% and 78%, respectively, which indicates that these factors effectively explain our affinity to the textures. Although the acquired relationships between the intensity of the affinity and these factors were limited to the sample textures used in this study, the results support the argument that affinity to the textures is generally determined by their physical and sensory factors. Because the linear combination of the physical factors accounted for 72% of the deviations in affinity, the affinity may be intuitively driven by the visual appearances of the textures. On the other hand, the sensory factors explain the affinity as well as the physical factors, which suggest that our internal sensory evaluation process mediates the affinity. The remaining 20%–30% of the deviations that these factors could not describe may be due to the physical and adjective terms that this study did not consider. Individual differences in decision criteria at the two experimental tasks may also have led to the residuals of the regression analyses.

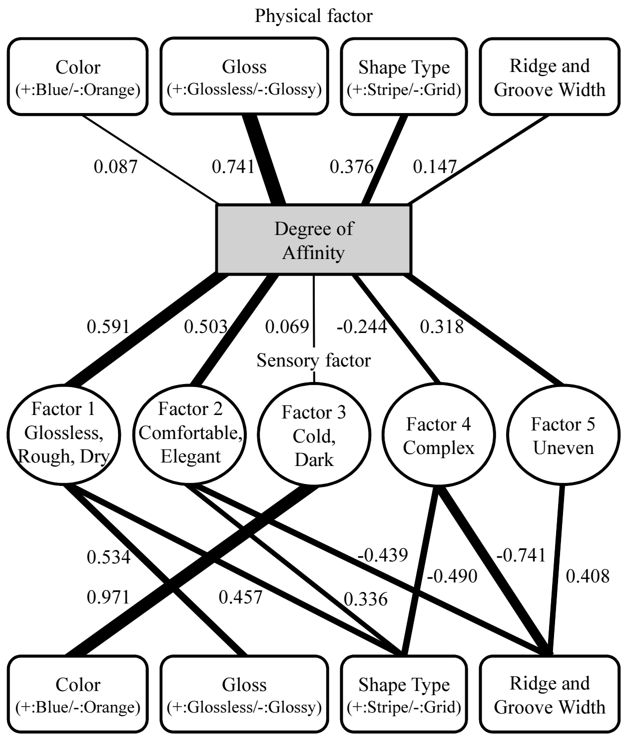

Fig. 3. Relationships between sensory factors, and physical factors of textures, and degrees of affinity to textures

B. Textural dimensions: comparison with related studies

In this study, five factors/axes were identified as the textural dimensions. Several researchers also attempted to extract these haptic dimensions in material or texture recognition. Here, we compare our results with those of the related studies. Table VII shows a reference table for the studies on haptic-textural dimensions.

Yoshida [1], [2] investigated the dimensions for haptic perception of 50 materials by multidimensional scaling (MDS). Interestingly, he studied the differences of such dimensions between the cases of haptic-only, visual-only, and visuo-haptic conditions. For the visuo-haptic condition, he found that three dimensions, heaviness-coldness, wet-smoothness, and hardness, well established the dissimilarity space of the materials. Hollins et al. [3] concluded that the textural dimensions of materials are composed of smooth-rough, hard-soft, and sticky-slippery axes using MDS. Shirado et al. [5] used a factory analysis method and identified four dimensions for 20 materials: roughness, coldness, moisture, and hardness. Yoshioka et al. [6] found three dimensions using MDS for haptic exploration by bare fingers: roughness, hardness, and stickiness. Although it was limited to car sheet materials, Picard et al. [11] found four textural dimensions: soft-harsh, thin-thick, relief, and hardness. Tanaka et al. [14] found two dimensions using factor analysis: moist and downy-warm.

Because the dimensions of roughness/harshness, softness/hardness, and warmth/coldness were reported most often, these three factors should be major factors in textural recognition. Our results included the roughness and cold factors, while the softness/hardness factor was not

TABLE VII
REFERENCE TABLE OF TEXTURAL FACTORS

Author	Year	Method	Texture	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
M. Yoshida [1], [2]	1968	MDS	50 materials	Heavy, Cold	Smooth, Wet	Hard		
M. Hollins et al. [3]	2000	MDS	17 materials	Smooth/Rough	Hard/Soft	Sticky/Slippery		
H. Shirado et al. [5]	2007	Factor analysis	20 materials	Rough	Cold	Moist	Hard	
T. Yoshioka et al. [6]	2007	MDS	17 materials	Rough	Hard	Sticky		
D. Picard et al. [11]	2003	MDS	24 car seat materials	Soft/Harsh	Thin/Thick	Relief (Uneven)	Hard	
Y. Tanaka et al. [14]	2006	Factor analysis	13 fabrics	Moist	Downy,Warm			
H. Nagano et al.	2011	Factor analysis	24 textures	Glossless Rough,Dry	Comfortable,Elegant	Cold,Dark	Complex	Uneven

clearly observed. This may be because in our study, the sample textures were made of the same materials and just their surface geometric patterns varied. In addition, the participants did not touch the textures but visually judged their properties. These specific experimental conditions may have hidden the factor of softness/hardness.

Another major difference between this study and related studies was the presence of comfortable-elegant (factor 2) and complex (factor 4). None of the related studies reported such textural dimensions. These two factors may have been found because we adopted the adjective terms of elegant-inelegant, comfortable-uncomfortable, and complex-simple, which are usually used for explaining visual impressions of textures.

Finally, in this study, two types of roughness were extracted as different dimensions: harshness and unevenness. Because harshness was coupled to dry and glossless in factor 1, harshness may indicate the fine surface roughness of the textures. On the other hand, unevenness (factor 5) was correlated with the ridge and groove widths of the surfaces. Hence, in this study, unevenness may have been recognized as an adjective term for coarse roughness. Fine and coarse roughness were perceived by different dimensions. The same tendency was suggested by Picard et al. [11] as harsh and relief factors.

VIII. CONCLUSIONS

In this study, we investigated the properties of specified textures that appeal to human touch. To determine the cause for such affinity, we investigated the relationship between the physical and sensory factors of the textures and their appeal to human touch. The textures were fabricated using clay, paints, textured molds, and sealers which enabled us to control their physical and sensory factors. The intensity of the affinity was measured by a ranking system and normalized-rank method. In order to quantify the sensory factors of the textures, we conducted sensory evaluation using 15 adjective term pairs, and the results were analyzed via factor analysis. Consequently, five orthogonal sensory factors were identified: glossless-rough-dry, comfortable-elegant, cold-dark, complex, and uneven. Multiple regression analyses, revealed that the physical and sensory factors effectively explained the degrees of affinity by 72% and 78%, respectively. In terms of the physical factors of the textures, their glossiness and surface shape patterns strongly affected the degrees of affinity. In terms of the influence of the sensory factors, glossless-rough-dry and comfortable-elegant were observed to strongly relate with the degrees.

The methodology of this study is useful for determining the best combinations among limited physical factors in terms of the textures' appeal to human touch. In product design, limited physical factors are available; hence, the proposed method can potentially enable us to design products or textures for shops or amusement centers, which appeal to human touch.

REFERENCES

[1] M. Yoshida, "Dimensions of Tactual Impressions (1)," Japanese Psychological Research, vol. 10, pp. 123–137, 1968.

[2] M. Yoshida, "Dimensions of Tactual Impressions (2)," Japanese Psychological Research, vol. 10, pp. 157–173, 1968.

[3] M. Hollins, S. Bensmaia, K. Karlof and F. Young, "Individual Differences in Perceptual Space for Tactile Textures: Evidence from Multidimensional Scaling," Perception and Psychophysics, vol. 62, pp. 1534–1544, 2000.

[4] W.M.B. Tiest and A.M.L. Kappers, "Analysis of Haptic Perception of Materials by Multidimensional Scaling and Physical Measurements of Roughness and Compressibility," Acta Psychologica, vol. 121, no. 1, pp. 1–20, 2006.

[5] H. Shirado and T. Maeno, "Modeling of Human Texture Perception for Tactile Displays and Sensors," Proc. World Haptics Conference, pp. 629–630, 2005.

[6] T. Yoshioka, S. J. Bensmaia, J. C. Craig and S. S. Hsiao, "Texture Perception through Direct and Indirect Touch: An Analysis of Perceptual Space for Tactile Textures in Two Modes of Exploration," Somatosensory and Motor Research, vol. 24, pp. 53–70, 2007.

[7] G. Winakor, C. J. Kim, and L. Wolins, "Fabric Hand: Tactile Sensory Assessment," Textile Research Journal, vol. 50, pp. 601–610, 1980.

[8] X. Chen, F. Shao, C. Barnes, T. Childs, and B. Henson, "Exploring Relationships between Touch Perception and Surface Physical Properties," International Journal of Design, vol. 3, pp. 67–76, 2009.

[9] C. J. Kim, and K. Piromthamsiri, "Sensory and Physical Hand Properties of Inherently Flame-Retardant Sleepwear Fabrics," Textile Research Institute, vol. 54, no. 1, pp. 61–68, 1984.

[10] T. Matsuoka, H. Kanai, H. Tsuji, T. Shinya and T. Nishimatsu, "Predicting Texture Image of Covering Fabric for Car Seat by Physical Properties," Journal of Textile Engineering, vol. 54, no. 3, pp. 63–74, 2008.

[11] D. Picard, C. Dacremont, D. Valentin and A. Giboreau, "Perceptual Dimensions of Tactile Textures," Acta psychologica, vol. 114, pp. 165–184, 2003.

[12] S. Kawabata, and M. Niwa, "Fabric Performance in Clothing and Clothing Manufacture," Journal of the Textile Institute, vol. 80, no. 1, pp. 19–50, 1989.

[13] H. L. Harter, "Expected Values of Normal Order Statistics," Biometrika, vol. 48, no. 1 and 2, pp. 151–165, 1961.

[14] Y. Tanaka, M. Tanaka and S. Chonan, "Development of a Sensor System for Measuring Tactile Sensation," Proc. IEEE Sensors, pp. 554–557, 2006.