Identification of Principal Factors of Fabric Aesthetics by the Evaluation of Experts on Textile and Untrained Consumers

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Abstract

One of the important end-use performance measures of fabrics and other textile products is the handle, which measures the quality of fabrics as evaluated by reactions obtained not only tactilely but also visually. The well-known Kawabata Evaluation System (KES) includes both an objective evaluation and a prediction method of the handle. However, objective evaluations of the handle based on a visual perception of fabric aesthetics have not been investigated systematically. Thus, as the first step of a systematic study, we attempted to carry out a sensory evaluation of fabric aesthetics by experts on textile and untrained consumers using worsted and spun silk woven fabrics, which have different material effect and structural effect. Thereafter, the mean preference scores were examined by factor analysis to identify the principal factors of fabric aesthetics. From the result, it was found that two common factors—"Luster and depth sensation" and "Surface roughness sensation"—were identified tentatively as the principal factors of fabric aesthetics.

Key words: Fabric aesthetics, Principal factor, Sensory evaluation, Factor analysis, Material effect, Structural effect

1. Introduction

Based on the analysis of the Establishment and Enterprise Census [1], a survey conducted every 5 years by the Ministry of Internal Affairs and Communications (MIAC) of Japan, the numbers of establishments and employees in the Japanese textile industry have been decreasing almost 30% every 5 years since 1996. The decrease in the number of skilled technicians, who are important to the quality maintenance of textile products, is an especially serious problem. Hence, there is a strong need for a technology that can contribute to the quality maintenance of textile products.

The Kawabata evaluation system (KES) is one technology aimed at improving the quality of textile products. Kawabata et al. [2] developed a measurement system for dynamic properties of woven fabrics (i.e., the tensile, shear, bending, compression and the friction properties), and proposed a characterization method as a means of estimating the hand property by evaluation of the reactions obtained from tactile perception. The estimation technique of the sensory-based, subjective hand property using physical properties contributes to the clarification of quality control standards and the promotion of efficiency in the development process of new products.

However, a consumer's impression of a woven fabric is influenced by not only the hand property perceived tactilely, but also the aesthetic properties perceived visually. Hence, designers at production companies and technicians at fabric manufacturers must have detailed meetings on the fabric aesthetics at an early stage of the manufacturing development process. Technicians produce a fabric by trial and error and then confirm that the fabric satisfies the requirement of the designer. This process increases of development cost of new woven fabrics.

In spite of its importance in the actual manufacturing process, the systematic study on fabric aesthetics has been quite few by comparison with study on fabric handle.

Howorth et. al. [3] attempted to obtain the adjectives that affect the fabric handle

using multiple factor analysis, and identified tentatively as smoothness, stiffness and thickness. Similarly, Kawabata [2] also suggested four adjectives as smoothness, stiffness, crispness, fullness and softness. Based on this report, these adjectives are prescribed as principal factors which affect the fabric handle in Japanese industrial standards [4].

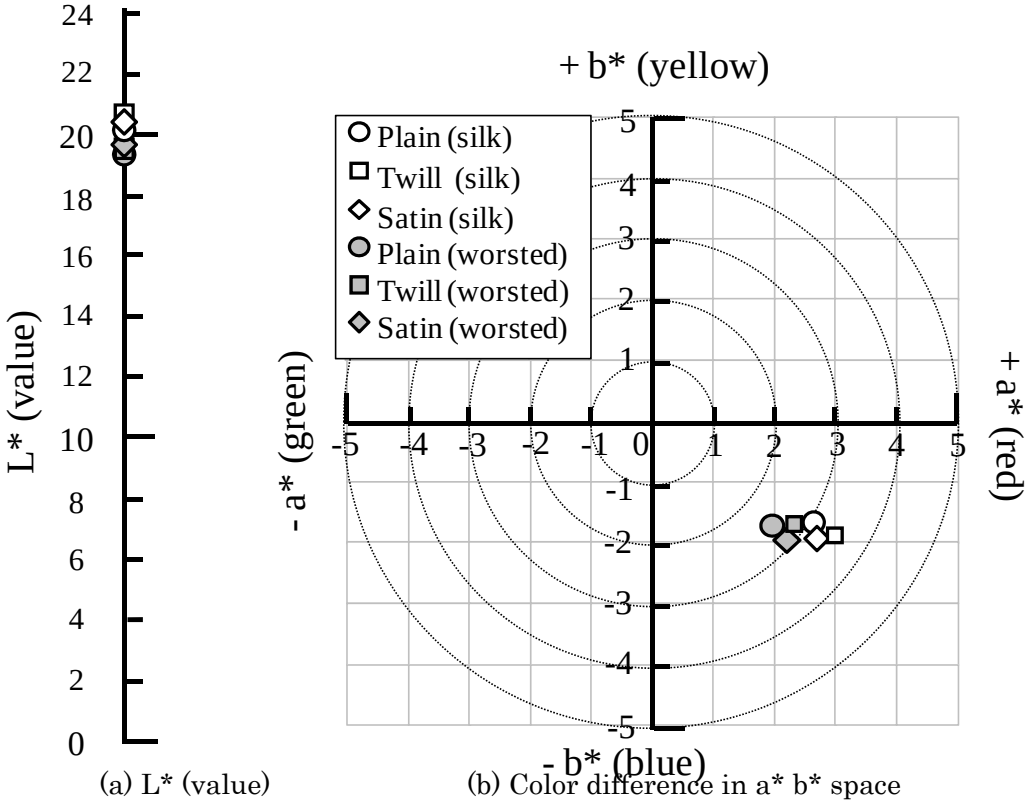
As one of a few study on fabric aesthetics, Brand [5] considered fabric aesthetics as a relationship among a minimum of six concepts (i.e., Style, Body, Cover, Surface texture, Drape, and Resilience). Hoffman [6] suggested 36 effective adjectives representing a good or bad fabric aesthetics for subjective evaluation. Binns [7] focused on the problem involved in judgment according to the attribute of persons, and compared among experts in the textile trade, untrained adults and children on the quality judgment of wool fibers.

There are some extensive theoretical and practical investigation for defining and measuring the fabric aesthetics. Nevertheless, fabric aesthetics has not been defined in a standard way, because the principal factors that determine fabric aesthetics have not been identified.

Thus, as a first step in a systematic study, we have attempted to carry out a sensory evaluation of fabric aesthetics by groups of experts on textile industry and untrained consumers using worsted and spun silk woven fabrics, which have different material effect and structural effect. Thereafter, factor analysis has been applied to the mean preference scores to identify the principal factors of fabric aesthetics. Furthermore, the differences in evaluation between the two tester groups have been investigated.

2. Samples

Six samples were woven experimentally in three different weaves—plain, twill, and satin—using worsted and spun silk yarn. The yarn count of worsted and spun silk yarn are both 16.7×2 tex. The weave density is 60 ends and 55 picks per 2.54 cm on the plain, 90 ends and 70 picks per 2.54 cm on the twill, 110 ends and 65 picks per 2.54 cm on the satin. These samples were dyed black with a reactive dye and a mordant dye in order that the black color was similar between samples. The color of the samples (i.e., L*a*b*, as prescribed by CIE [8]) was measured with five specimens for each sample by a colorimeter (KONICA MINOLTA CR-400), as shown in Figure 1. As the differences of the value, the hue and the chroma of six woven fabrics were quite low, the samples were judged to be the same color.



(a) L* (value) (b) Color difference in a* b* space

Figure 1. Result of L*a*b* measurement of samples

3. Experimental

3.1 Persons

Nine Japanese individuals skilled in color inspection of fabrics were recruited as experts on textile industry (hereinafter referred to as the “experts”). Color inspection is one of the fabric inspection steps in the dyeing process. The inspectors judge the agreement between a color in a color table and the color of a dyed fabric. The experts consisted of five men and four women. Their experience as inspectors was between 5 and 25 years. Twenty untrained Japanese individuals were recruited as the untrained consumers (hereinafter referred to as the “consumers”). The consumers consisted of 20 male university students, aged 20 to 29, all in their twenties.

3.2 Sensory evaluation

Sensory evaluation is a method for assigning a score according to the impression obtained from a fabric sample using several adjectives with a prescribed scale. Nakaya’s paired comparison method [9] was applied. The persons evaluated fifteen paired specimens, consisting of pairs of the six samples (i.e., ${}_6C_2$), by only visual sensation using 26 adjectives referred to in conventional studies [5-6, 10] on a 5-point scale (e.g., +2 pt: specimen A is much rougher, +1 pt: specimen A is slightly rougher, 0 pt: neither, -1 pt: specimen B is slightly rougher, -2 pt: specimen B is much rougher). As described below, these adjectives were classified into sub categories as “Luster”, “Depth of dyeing”, “Roughness”, “Handling” and “Preference”. Where the 6 adjectives relate to the “Handling” are the impressions that arise when fabrics are touched, squeezed, rubbed. But in this study, the persons predicted and judged these evaluations by only the sense of sight. In contrast, other adjectives relate to “Luster”, “Depth of dyeing”, “Roughness” and “Preference” are the impressions that arise when fabrics are observed visually. Where the adjectives relate to the “Preference” are the inclusive impression obtained

not only tactilely but also visually in general. But in this study, the evaluation was carried out by only sense of sight.

A sample stand was illuminated by a CIE standard light source unit with standard illuminant D65 (manufactured by Intec) at an angle of 30° with respect to the horizontal. Consequently, the angle of the incidence was set to 30°. The sitting heights of the testers were set to give angles of observation of 0°. The observation distance between the position of person's eyes and sample stand was about 70 ± 5 cm.

The 200-milimeter-square specimen was set so that the warp yarn was aligned vertically with the sample stand. Illuminance perpendicular to the horizontal plane at the center of the sample stand was 1446 ± 98 lx. To remove the influence of tactile perception on the evaluation, the persons were given instructions not to touch the samples. The experiment room was maintained at 23 ± 3°C, and 50 ± 4%R.H. .

(1) Adjectives related to "Luster" (5 words)

"Glossy", "Rich (with respect to highlights)", "Garish", "Glittery", and "Shiny

(2) Adjectives related to "Depth of dyeing" (6 words)

"Deep", "Dark", "Regular (with respect to contrast)", "Vivid", "Red", and "Blue"

(3) Adjectives related to "Roughness" (4 words)

"Rough", "Fine", "Smooth", and "Sleek"

(4) Adjectives related to "Handling" (6 words)

"Soft", "Sandy-looking", "Damp-looking", "Light", "Full", and "*NUMERI* *"

(5) Adjectives related to "Preference" (5 words)

"High-class", "Delicate", "Elegant", "Beautiful" and "Composed"

*"*NUMERI*" represents a response to factors such as smoothness, flexibility, and softness obtained from the tactile perception of a fine worsted fabric [11].

4. Results and Discussion

4.1 Coefficient of consistency

In the sensory evaluation, the evaluation of the persons is based on individual criteria, which are subjective and often ambiguous. In cases in which evaluation criterions are vague, the evaluation of individuals may not be consistent. Hence, the extent of the consistency of the evaluation of individuals was investigated in this study by calculating the "coefficient of consistency" (ζ) [9] using equation 1.

Where "d" is the circular triad. Suppose there are three samples A_1, A_2 and A_3 among which the comparisons are to be made. An inconsistency for this triad occurs if "A_1 is superior to A_2", "A_2 is superior to A_3", "A_3 is superior to A_1". Such a triad is called a circular triad.

Thereafter, within the groups of testers, the mean values of the coefficients of consistency ($\overline{\zeta}_{Group}^{each\ adj.}$) were calculated for each adjective using equation 2 (cf. Figure 2).

As shown in Figure 2, the mean value of coefficient of consistency for each adjective was over 0.88 (i.e., $\overline{\zeta}_{experts}^{each\ adj.} \geq 0.88$ in the experts and over 0.83 (i.e., $\overline{\zeta}_{Consumers}^{each\ adj.} \geq 0.83$) in the consumers. Thus, significant consistency of the evaluations was observed in both groups (Significance Level (S.L.) = 0.10). In particular, the mean value of the evaluation of five adjectives related to "Luster" and that of six adjectives related to "Dyeing depth" were $\overline{\zeta}_{Consumers}^{adj.\ of\ Luster} \geq 0.93$ and $\overline{\zeta}_{Consumer}^{adj.\ of\ Depth\ of\ dyeing} \geq 0.93$ in the consumers and (indicating a superior consistency) $\overline{\zeta}_{experts}^{adj.\ of\ Luster} \geq 0.98$ and $\overline{\zeta}_{experts}^{adj.\ of\ Depth\ of\ dyeing} \geq 0.97$ in the experts. From these results, it was concluded that persons in the experts evaluated fabric aesthetics based on a precise criterion.

$$\zeta_{person}^{adj.} = 1 - \frac{24\,d}{k^3 - 4k} \quad \cdots (1)$$

d: number of circular triads[9]

k: number of samples

$$\overline{\zeta}_{group.}^{adj.} = \frac{\sum_{sub.=1}^{n} \zeta_{sub.}^{adj.}}{n} \quad \cdots (2)$$

n: number of persons (experts: n = 9, consumers: n = 20)

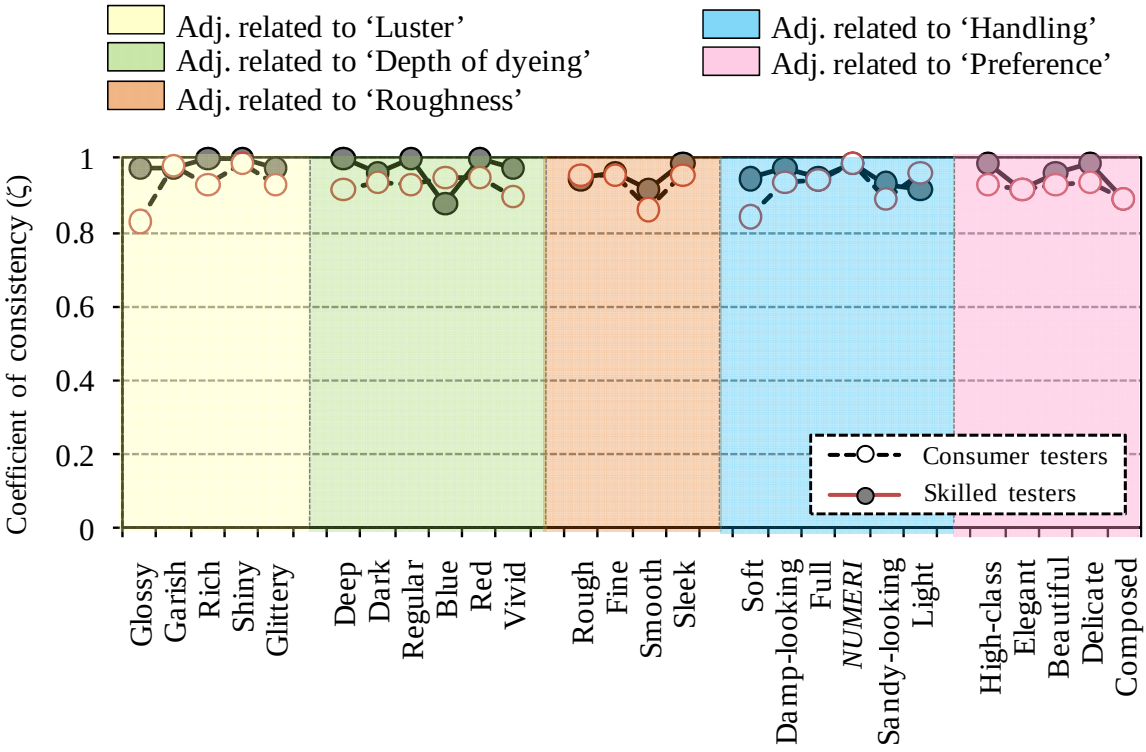


Figure 2. Mean value of coefficient of consistency in both groups

4.2 Coefficient of agreement

As mentioned above, the persons in both groups showed significant consistency in their evaluations. It is also necessary to analyze the agreement of the criterion among the individuals in each group. Consequently, the coefficient of agreement (υ) [9] was calculated for each adjective using equation 3. The significance on coefficient of agreement was investigated statistically. From the result, the coefficient of agreement on all adjectives reached significance level (S.L. = 0.01) in both groups.

Furthermore the difference of coefficients of agreement among the experts and consumers was analyzed using the t-test whether the difference of the coefficient of agreement statistically reach the significance level. 15 numbers of the coefficient of agreement were calculated with score of each comparison pair of sample (i.e. υ_k where "k" was the number from 1 to 15). Then the difference of the mean value of the coefficient of agreement ($\bar{\upsilon}_k = \upsilon$) between the experts and consumers were assessed by the parametric independent t-test as shown in Table1. From the result, the mean value ($\bar{\upsilon}_k$) of coefficients of agreement on each comparison pair of samples and the significant differences (S.L. = 0.01 '**', S.L. = 0.05 '*') were shown in Figure 3.

As shown in figure 3, the mean value of coefficient of agreement ($\bar{\upsilon}_k$) of the experts was superior to that of the consumers on four adjectives related to "Luster" and "Depth of dyeing" (S.L. =0.05). In contrast, the coefficient of agreement ($\bar{\upsilon}_k$) of the consumers was superior to that of the experts on four adjectives related to "Handling" and "Preference" (S.L. < 0.05). Thus, although the persons belonging to the experts had a common criterion for "Luster" and "Depth of dyeing", because these are related to their occupations, they did not show agreement on their criteria for other adjectives.

$$\bar{\upsilon}_{group.}^{adj.} = \frac{2 \times \sum}{{}_nC_2 \times {}_kC_2} - 1 \quad \cdots (3)$$

$$\sum = {}_nC_2 \times {}_kC_2 - \sum_{j>i} x_{ij} \left(n - x_{ij} \right)$$

i, j: sample number

x_{ij}: number of persons who evaluated "sample i was superior than sample j"

n: number of persons (experts: $n = 9$, consumers: $n = 20$)

k: number of samples ($k = 6$)

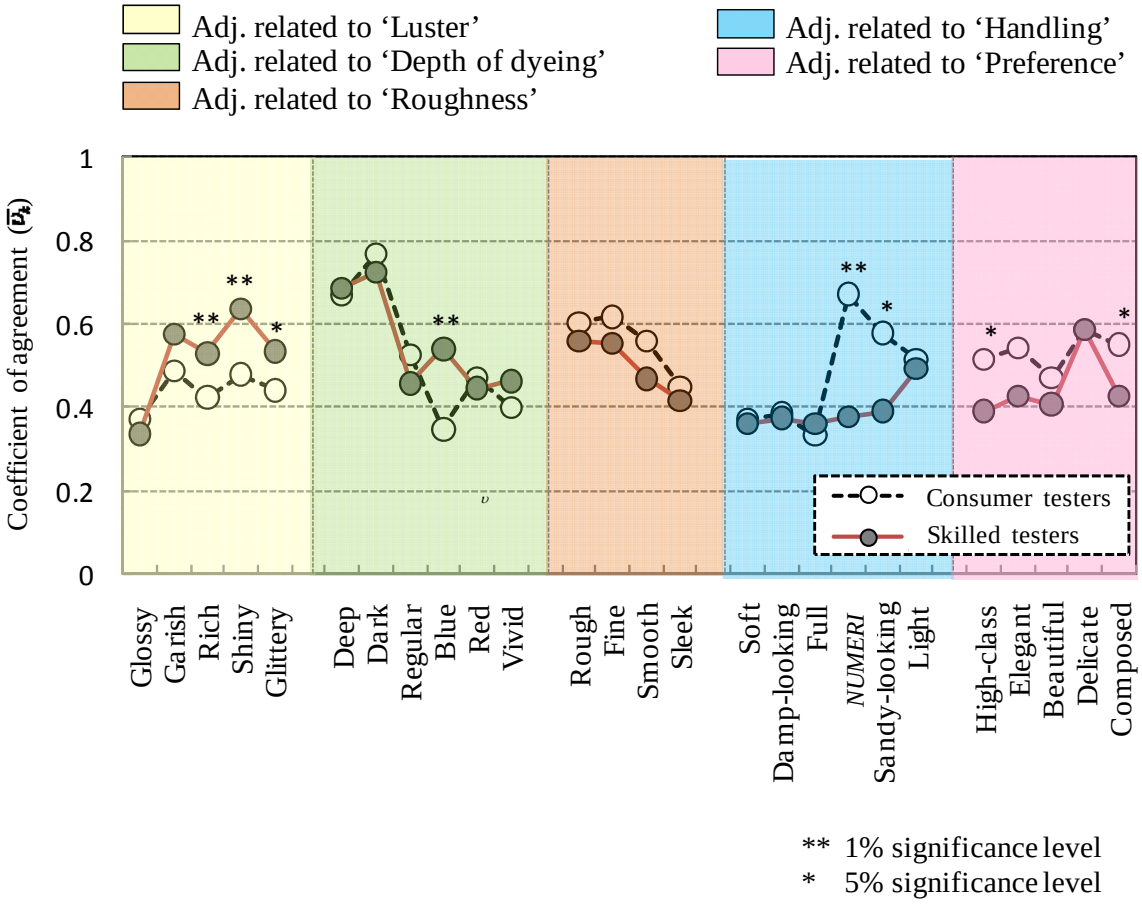


Figure 3. Mean value of coefficient of agreement in both groups

Table1. t-test of mean value ($\bar{\upsilon}_k$) of coefficients of agreement in both groups

Adjective		T-value	P-Value	Significance
Luster	Glossy	1.752	0.091	
	Garish	1.703	0.100	
	Rich	2.992	0.006	**
	Shiny	3.548	0.001	**
	Glittery	2.221	0.035	*
Depth of dyeing	Deep	0.134	0.895	
	Dark	0.400	0.692	
	Regular	1.029	0.312	
	Blue	3.113	0.004	**
	Red	0.691	0.495	
	Vivid	1.353	0.187	
Roughness	Rough	0.519	0.608	
	Fine	0.683	0.500	
	Smooth	1.227	0.230	
	Sleek	0.853	0.401	
Handling	Soft	0.444	0.660	
	Damp-looking	0.370	0.714	
	Full	0.867	0.393	
	NUMERI	8.987	> 0.001	**
	Sandy-looking	2.539	0.017	*
	Light	0.317	0.753	
Preference	High-class	2.175	0.038	*
	Elegant	1.815	0.080	
	Beautiful	1.248	0.222	
	Delicate	0.001	0.999	
	Composed	0.048	0.024	*

4.3 Mean preference score and ANOVA

The mean preference score is an average evaluation score of each group. Assuming the evaluation score of persons against the comparison pair of certain samples is even, the evaluation score agree with the difference of mean preference score of the two samples. But the mean preference score satisfy the following condition： $\Sigma_{t=1}^{6}\alpha_t$ （t：Number of samples, α ：Mean preference score).

The profiles of the mean preference scores for each adjective are shown in figure 4. The signs (plus or minus) of the mean preference scores for the adjectives related to “Luster” and “Depth of dyeing” differed by yarn material. Hence, the evaluations of these adjectives were mainly influenced by material effect. On the other hand, the signs of the mean preference scores for the adjectives related to “Roughness” differed by weave types. Hence, the evaluations of these adjectives were mainly influenced by structural effect. In addition, the signs of the mean preference scores for the adjectives related to “Handling” and “Preference” were not significantly affected by either yarn material or weave types. Hence, the evaluations of these adjectives were influenced by both material effect and structural effect.

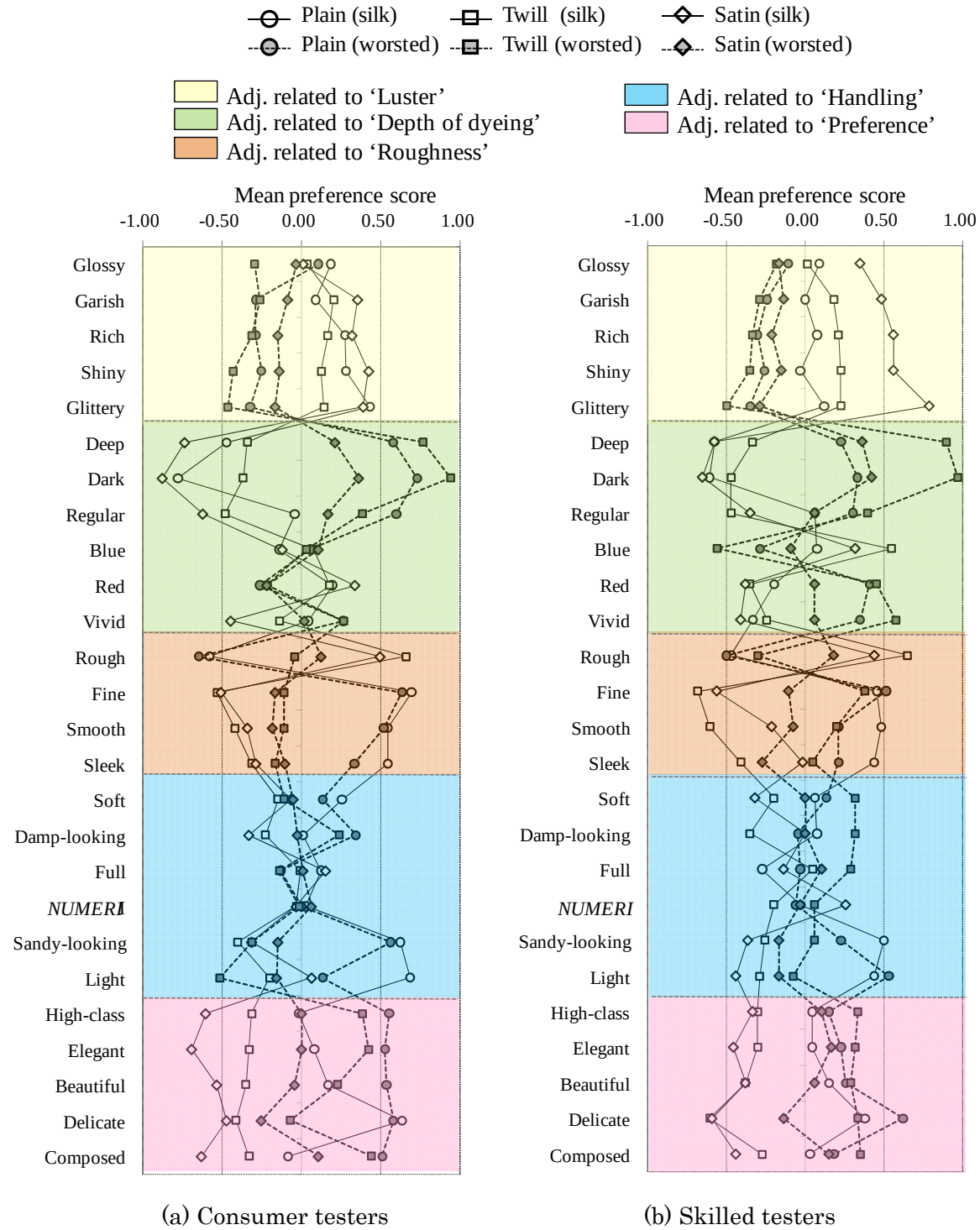
The tendencies mentioned above were found in both groups. There were also some differences between two groups with regard to adjectives related to “Depth of dyeing”. Namely, in the evaluations by the experts, the darker and deeper the sample, the redder it was evaluated. In contrast, in the evaluations by the consumers, the darker and the deeper the sample, the bluer it was evaluated.

When a fabric is dyed black, several dyes are combined. Thus, the dyed black color of fabrics was classified according to extraction of redness and that of blueness. Because of this, a common way of thinking may be behind the results observed from the experts. Namely, samples dyed to a black including more red was evaluated darker and deeper than those dyed to a black including bluer. Consequently the criterion of the experts on

the evaluation of depth (“Deep”) depend their classification of the blackness with respect to red or blue. On the other hand, the criterion of the consumers depended on the vividness of the black color rather than redness or blueness.

Analysis of variance (ANOVA) was applied to the evaluation scores for assessing the main effect and combination effect. The main effect shows the effect due to the characteristics of each sample. And the combination effect which is included in the unexplainable standard error shows the effect due to the comparison pair of samples.

From the results of ANOVA on the mean preference score, the combination effects were not significant for any adjectives in either group (S.L. > 0.01). The main effect on *“NUMERI”* was not significant (S.L. > 0.01) in the consumers. Therefore, the following analysis was carried excluding *"NUMERI"* for the consumers.



(a) Consumer testers (b) Skilled testers

Figure 4. Profiles of mean preference score

4.4 Identification of principal factors of fabric aesthetics

Factor analysis [12] was applied to the mean preference scores of the twenty-six adjectives for the experts and those of twenty-five adjectives (*"NUMERI"* excluded) for the consumers.

The first stage of factor analysis is to calculate the correlation coefficients between mean preference scores of each adjective. Then the factor matrix is obtained using the principal factor solutions with repeated assumption of communality which is the proportion of the variance ascribed to the action of the common factors. Communality ranges from 0 to 1, and the degree of the difference between communality and unity is explained by the experimental error.

Axes of the factor matrix are rotated by Varimax method so that the structure of the sensory evaluation relations is indicated more clearly.

Two components with eigenvalues greater than 1.0, representing 89% of the cumulative percentage of the experts and 95% of that of the consumers, were obtained. The rotated factor matrices are shown in Tables 2 and 3.

In both groups, factor 1 has a high positive loading for adjectives related to the "Luster" (i.e., "Rich (with respect to highlights)", "Too shiny", and "Glittery") and a high negative loading for adjectives related to the "Depth of dyeing" (i.e., "Dark", and "Deep"); therefore, the first principal factor was interpreted as "Luster and depth sensation". Similarly, factor 2 has either a high positive or high negative factor loading for adjectives related to "Roughness" (i.e., "Rough", "Sleek", "Smooth", and "Fine"); therefore, the second principal factor was interpreted as "Surface roughness sensation".

The factor scores of each sample are shown in figure 5. As mentioned above, because the adjectives related to "Luster" and "Depth of dyeing" were influenced by material effect, the factor score "Luster and depth sensation" was affected mainly by material effect. The spun silk fabrics gave a strong impression of luster because these fabrics had

positive factor scores. In contrast, the worsted fabrics gave a strong impression of depth because the worsted fabrics had negative scores.

These impressions were the reactions obtained from observation of light reflectivity which occurred at the surface of fabrics as stimuli.

The differences in light reflectivity caused by the surface texture of fibers are related to the material effect. Specifically, specular reflection occurs due to the sleek surface of silk fibers, and diffusion reflection occurs due to the existence of scales on the surface of worsted fibers. Because of the increase in diffusion reflection, black appears deeper in worsted fabrics. Therefore in other words, the “Luster and depth sensation” is the sense which is due to the intensity of light reflectivity.

The factor score “Luster and depth sensation” was also affected slightly by structural effect. Specifically, the factor scores increase in the order of satin, plain, twill in both the spun silk and the worsted fabrics.

We considered that the affect of the structural effect is due to the length of the floating yarn. Specifically, the floating yarn appears shorter in the plain weave because the warp and weft yarn are interlaced. In contrast, the floating yarn appears longer in the satin weave because the satin weave repeats on three ends. Because of the increase in the specular reflection of the floating yarn, the color of the incident lighting appears on the samples. Thus, the satin gave a stronger impression of luster.

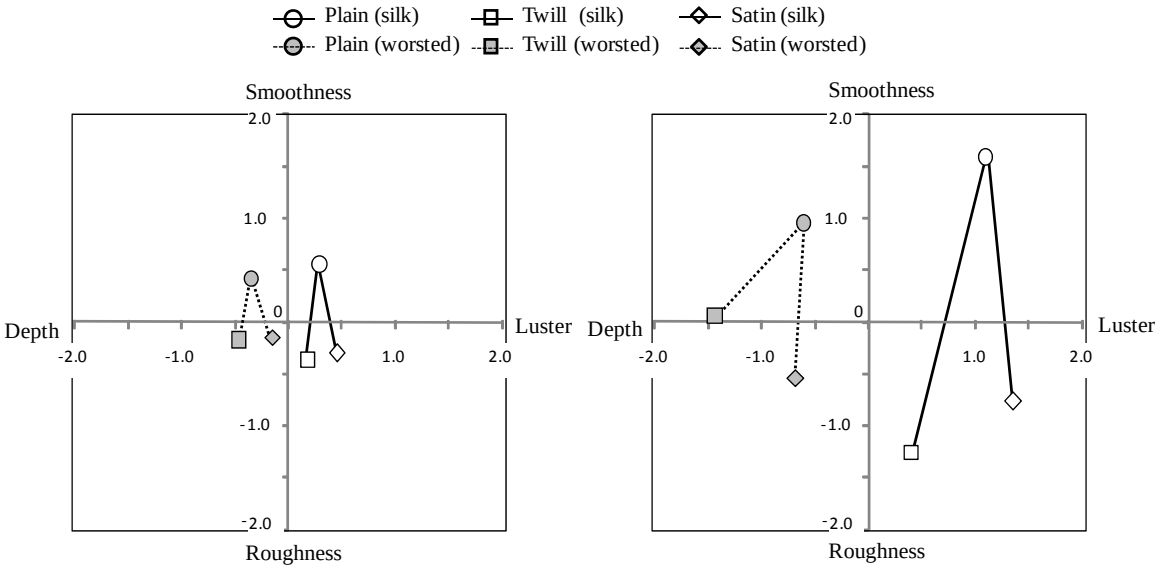
Similarly, the factor score “Surface roughness sensation” was affected mainly by the structural effect. The surface of the plain weave was evaluated as smooth relative to the twill and the satin weaves by both groups. In other words, “Surface roughness sensation” is the sense which is due to the pattern of light reflectivity.

Table2. Factor loading for the consumer testers

		Factor loading (after varimax rotation)			
Factor	Adjective	Factor 1	Factor 2	Communality	Adjective category
1	Deep	-1.00	0.02	1.00	Depth of dyeing
	Dark	-1.00	-0.08	1.00	
	Red	0.95	-0.08	0.92	
	Vivid	-0.87	0.42	0.94	
	Regular	-0.89	0.43	0.98	
	Shiny	1.00	0.07	1.00	Luster
	Rich	0.99	0.02	0.98	
	Glittery	0.96	-0.28	1.00	
	Garish	0.98	0.17	0.99	
	Composed	-0.94	0.34	1.00	Preference
	High-class	-0.89	0.44	0.99	
	Elegant	-0.86	0.49	0.98	
	Full	0.94	0.08	0.89	Handling
	Damp-looking	-0.86	0.49	0.98	
2	Rough	0.40	-0.91	0.98	Roughness
	Fine	-0.26	0.97	1.00	
	Smooth	-0.21	0.98	1.00	
	Sleek	-0.08	0.99	0.99	
	Light	0.55	0.83	1.00	Handling
	Sandy-looking	-0.07	0.99	0.98	
	Soft	0.11	0.99	1.00	
	Delicate	-0.26	0.96	0.99	Preference
	Blue	-0.65	-0.39	0.58	
	Glossy	0.54	0.62	0.68	
	Beautiful	-0.74	0.67	1.00	

Table3 Factor loading for the skilled testers

		Factor loading (after varimax rotation)			
Factor	Adjective	Factor 1	Factor 2	Communality	Adjective category
1	Deep	-0.99	0	1.00	Depth of dyeing
	Dark	-0.98	0.04	1.00	
	Red	-0.90	0.34	1.00	
	Vivid	-0.95	0.21	0.98	
	Blue	0.82	-0.44	0.89	
	Shiny	0.83	-0.51	0.99	Luster
	Rich	0.87	-0.43	1.00	
	Glittery	0.85	-0.49	1.00	
	Garish	0.91	-0.34	1.00	
	Glossy	0.90	-0.17	1.00	
	Composed	-0.81	0.55	0.98	Preference
	Elegant	-0.80	0.57	1.00	
	Full	-0.92	-0.16	0.99	Handling
2	Rough	0.33	-0.92	1.00	Roughness
	Fine	-0.40	0.91	1.00	
	Smooth	-0.19	0.95	0.96	
	Sleek	0.12	0.94	0.96	
	Light	-0.18	0.91	1.00	Handling
	Sandy-looking	-0.07	0.96	0.98	
	Delicate	-0.45	0.89	1.00	Preference
	Regular	-0.72	0.65	1.00	
	Soft	-0.72	0.66	1.00	
	Damp-looking	-0.43	0.52	1.00	
	NUMERI	0.15	0.02	1.00	
	High-class	-0.78	0.58	1.00	
	Beautiful	-0.67	0.73	0.95	



(a) Consumer testers (b) Skilled testers

Figure 5. Dispersion diagrams of factor scores

5. Conclusions

In this study, in order to identify the principal factor of the fabric aesthetics evaluated by the reaction obtained from visual examination, the sensory evaluation of six samples having different material and structural effect was attempted by a group of experts and a group of consumers. Thereafter, factor analysis was applied. Furthermore, the differences in the evaluations of two groups were analyzed and the following conclusions were obtained.

In order to compare the reliability of the criterion used between experts and consumers, the coefficients of consistency (ζ) and agreement (υ) were calculated. Because “Luster” and “Depth of dyeing” properties require expertise, the consistency (ζ) and agreement (υ) of the criteria of the experts is superior to that of the consumers. However, the agreement (υ) of the criteria among the persons is not necessarily for other adjectives.

From the result of factor analysis applied to the mean preference scores, two common factors—“Luster and depth sensation” and “Surface roughness sensation”—were extracted from both groups of testers. Consequently, these factors were identified as the principal factors of fabric aesthetics for the tested samples. “Luster and depth sensation” is mainly due to the intensity of light reflectivity such as material effect. In contrast, “Surface roughness sensation" is mainly due to the pattern of light reflectivity such as structural effect.

Acknowledgments

This study was supported by a Grant-in-Aid for Scientific Research Program (No. 16700203) by the Ministry of Education, Science, Sports, and Culture of Japan. This paper is dedicated to the first principal, Chotaro Harizuka, on the occasion of the 100th anniversary of the Faculty of Textile Science and Technology, Shinshu University. We wish to thank Mr Eiken Kuzutani and Mr Shouji Uesaka, students at Shinshu University, for their assistance.

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