Sensibility Evaluation of an Exfoliating Lotion with Supreme Tactile Impression during Wiping Motions

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ABSTRACT

We aim to provide cosmetics that appeal to users' "sensibility" and have accordingly developed cosmetics based on a sensibility evaluation. We examined exfoliating lotions that can be applied to a cotton pad and gently wiped across the stratum corneum, i.e., the outermost layer of the skin. Our method correlates the visualized psychological structure with measured physical quantities.

To visualize the psychological structure when using an exfoliating lotion, we selected appropriate evaluation words and conducted a one-month usage test. Using factor analysis, we evaluated nine factors that are related to the value judgments of subjects using the exfoliating lotions. Next, we analyzed the causal relationships between these factors via structural equation modeling and modeled the psychological structures of the users. The model fit indices were satisfactory (GFI = 0.952; RMSEA = 0.000). The subconsciously important perceptions appeared to be "frictional feeling" and "wiped-off feeling," both of which are derived from the tactile impression imposed by the wiping motion.

Next, we analyzed the relationship between the frictional force and the tactile impression. To evaluate the physical quantities related to the "frictional feeling" and the "wiped-off feeling," we examined the frictional force of wiping. For 12 types of exfoliating lotions, we measured the dynamic friction coefficient and the time profile of the frictional force. The dynamic friction coefficient was measured using a friction tester while mechanically wiping the artificial skin. The time profile was measured using an in-house designed dedicated device while subjects wiped the lotions from the artificial skin. The factor scores calculated from the subjective evaluation were then correlated with the dynamic friction coefficients. The "frictional feeling" and "wiped-off feeling" showed inverse correlations with the dynamic friction coefficient, and we found that they could not be evaluated as independent elements (with correlation coefficients of $r = -0.820$ and 0.744, respectively). Therefore, to identify physical quantities that can independently affect the two factors, we extracted the eight-dimensional vibrational feature quantities in the time–frequency domain from the time profile and correlated them with the factor scores in a multiple regression analysis. The factor scores of the "frictional feeling" and the "wiped-off feeling" were estimated with high accuracy ($r^2 = 0.672$ and 0.722, respectively). Each factor corresponded to a different vibrational feature, confirming that the factors are physically independent. This result suggests that both factors can be simultaneously increased by controlling the frictional force. Based on this result, we attempted to develop an exfoliating lotion that enhances the vibration features and consequently intensifies the two examined factors.

INTRODUCTION

Recently, the term “KANSEI value” has been recognized as a keyword in Japanese manufacturing industries. KANSEI is a Japanese term resembling the English word “sensibility”. The Ministry of Economy, Trade and Industry of Japan defined the “KANSEI value” as a value that materializes when a product appeals to a person’s aesthetic sense and arouses their emotions and empathy. Examples in which the “KANSEI value” was applied as a manufacturing measure have been reported[1)-3)].

To develop cosmetic products with high KANSEI value, it is necessary to visualize the psychological structure that extends to the subconsciousness concerning sensibility. For example, Shimoda et al. researched the comfort of lotions. They analyzed the sensory evaluation results for various types of skin lotions and examined the structure of the impression that a user feels[4)]. However, the current study was limited to grasping the impression of a single use and did not formulate the causal relationship between the multiple impressions that lead to value judgments of cosmetics, including impressions with continued use. However, predicting subjective evaluations via physical measurements is important for developing cosmetics with a high KANSEI value. For example, Ishikubo et al. examined the relationship between the friction behavior and the penetrative feeling when applying cosmetics using a friction tester[5)]. However, the current study was limited to analyzing only a single sensory evaluation item against a physical measurement and did not analyze the relationship with the complicated impressions that a user feels when actually using cosmetics.

In this study, we examine the causal relationships between multiple impressions that lead to value judgments of cosmetics and predict impressions that show large contributions via physical measurements. As the research subject, we chose exfoliating lotions, which have the function of removing the unnecessary outermost layers of skin when applied to cotton pads and gently wiped against the stratum corneum[6)]. Then, we formulated a design based on sensibility using the relationship between the physical quantities of the frictional force and the impression evaluation during the wiping motion.

Experiment 1: Visualization of the psychological structure

MATERIALS AND METHODS

In preparation for the usage test, we selected appropriate evaluation words. First, we chose evaluation areas or “scenes” for the users evaluating the exfoliating lotions, i.e., S1) the texture of the exfoliating lotion, S2) the texture of the next skincare item, S3) skin changes with repeated use, and S4) the KANSEI value. Impression words and value words for each scene were collected via a free description questionnaire of 17 normal healthy women (23–57-year old) who regularly use exfoliating lotions in their daily regimes. Using statistical methods, we selected a total of 53 representative evaluation words.

Next, we conducted a one-month usage test with 43 healthy women (30–49-year old), from whom we obtained informed consent. We divided the study participants into four groups and assigned different exfoliating lotions to each group. The study participants were required to assign one of the seven grades to each evaluation word.

RESULTS AND DISCUSSION

We analyzed the factor structure of each scene by conducting a factor analysis on the evaluation results. Under the

condition that the eigenvalue is 1.0 or greater, three factors, two factors, one factor, and three factors were extracted for S1, S2, S3, and S4, respectively. We named the factors interpreted from the factor structure. From this result, nine factors were assumed in relation to the value judgments of the subjects using the exfoliating lotion. Table−1 summarizes the factor structure.

Next, we analyzed the structural equations modeled with the factor scores of each factor as observed variables and modeled the psychological structure of the users (Figure−1). The model fit indices were satisfactory (GFI = 0.952; RMSEA = 0.000). For example, we found that the "frictional feeling" has a direct influence on "skin comfort" and "desire to continue exfoliation" in S4 as well as an indirect influence on all three factors of S4 via "moisturizing sensation" and "smooth sensation". From Figure−1, the subconsciously important perceptions appear to be "frictional feeling" and "wiped-off feeling," both of which are derived from the tactile impression imposed by the wiping motion.

In Experiment 2, to examine the physical quantities related to the "frictional feeling" and the "wiped-off feeling," we examined the frictional force of the wiping motion. In particular, we measured the dynamic friction coefficient and the vibrational features that contribute to the formation of the tactile sensation.

Table−1. Factor structure of each evaluation scene.

S1)

Factor name	Evaluation word	Factor 1	2	3
frictional feeling	Easy wipe	**.985**	-.289	-.012
	slides smoothly with cotton pad	**.845**	-.007	-.052
	good feeling on the skin	**.812**	.109	-.011
	smooth feeling on the skin	**.768**	.047	.081
	low friction of cotton pad	**.644**	.149	.043
	gentle to skin	**.587**	.305	-.136
skin feeling after application	skin feels moisturized	-.129	**.890**	-.059
	skin feels hydrated	.272	**.799**	-.159
	skin feels clingy	-.049	**.750**	.126
	skin feels refreshed	.286	**-.498**	.386
	good sensation on the skin	.114	**.487**	.364
	skin feels springy	.228	**.478**	.164
wiped-off feeling	feels exfoliated	-.184	.116	**.863**
	skin tone has changed	-.008	-.044	**.744**
	feels no residues	.114	.044	**.649**
	skin feels refreshed	-.003	-.048	**.419**

S2)

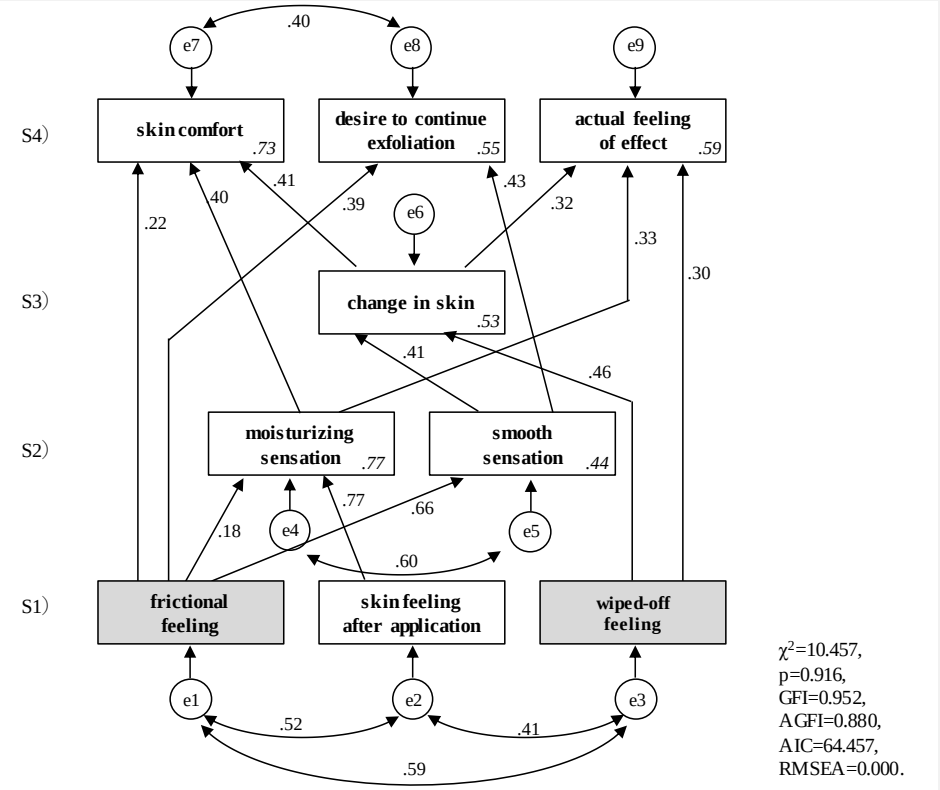
Factor name	Evaluation word	Factor 1	2
moisturizing sensation	increase moisturized feeling	**.991**	-.125
	skin feels moisturized	**.975**	-.205
	skin feels hydrated	**.773**	.018
	skin feels volumed	**.541**	.154
	skin feels compatible for the skin	**.509**	.309
smooth sensation	skin feels smooth	.052	**.887**
	skin feels fresh	.013	**.633**
	silky smooth	-.274	**.628**
	well penetrated	.205	**.585**
	skin feels nice to the touch	.276	**.498**
	skin feels elastics	.256	**.401**

S3)

Factor name	Evaluation word	Factor 1
change in skin	feels translucent	**.876**
	skin feels bright	**.786**
	no dullness	**.740**
	skin condition appears good	**.715**
	smooth feeling	**.714**
	fresh feeling	**.621**
	more effetive penetration	**.608**
	silky smooth	**.603**
	easy to apply makeup to skin	**.520**

S4)

Factor name	Evaluation word	Factor 1	2	3
skin comfort	pleasant	**.901**	.051	-.064
	skin feels nice	**.887**	-.254	.121
	skin feels softer	**.884**	-.269	.207
	good texture when used	**.666**	.454	-.192
	gentle to the skin	**.665**	.150	.021
	good feeling	**.489**	.418	-.069
	good skin condition after use	**.482**	.218	.205
	no burden on the skin	**.465**	.407	-.120
desire to continue exfoliation	exfoliating feels pleasant	-.220	**1.077**	-.037
	skin feels cleansed	-.179	**.563**	.221
	want to use continuously	.280	**.552**	.111
	desire to use continuously	.213	**.509**	.326
actual feeling of effect	active ingredients is contained	.048	.001	**.811**
	skin feels changed	.061	.140	**.686**



Figure−1. Psychological structure of using an exfoliating lotion.

Experiment 2: Determining the relationship between the frictional force and the tactile impression

MATERIALS AND METHODS

Impression evaluation of the texture

We conducted an impression evaluation of the textures of the exfoliating lotions with the informed consent of 30 healthy women (24–56-year old) who did not participate in Experiment 1. The study participants used 12 types of exfoliating lotions with different textures twice a day and were required to assign grades of 1–7 to 18 evaluation words of S1, as in Experiment 1.

Measurement of the dynamic friction coefficient

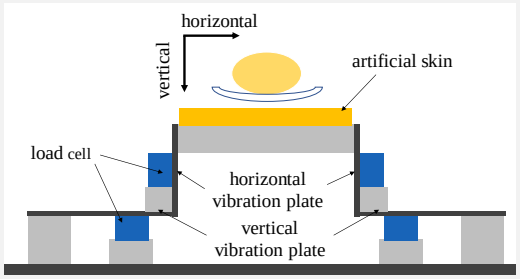
The dynamic friction coefficients of the exfoliating lotions were measured using TYPE-14 (Shinto Scientific Co., Ltd.), a friction tester. Cotton pads were set in a holder simulating the curvature of a finger, and 1.5 ml of the exfoliating lotion was applied. This holder was set on an arm, and a vertical load of 100 gram force (gf) was applied. An artificial skin that reproduced a skin texture pattern created with the aid of a 3D printer was set on a moving table. The outward measurement was performed 10 times at a moving distance of 50 mm and a moving speed of 50 mm/s, and the average dynamic friction coefficients of the 12 types of exfoliating lotions were measured.

Measurement of the time profile of the friction force

The tactile texture obtained when stroking the surface of an object is formed by acquiring a time profile of the

interaction force occurring between the skin and the object surface via tactile receptors. To measure the time profile of this interaction force, we fabricated a dedicated device shown in Figure−2[7]. This device can measure the interaction force generated on the surface when wiping the artificial skin with cotton pads. Herein, we analyzed the frictional force, which is the interaction force in the direction horizontal to the artificial skin surface.

We selected 10 study participants (24–47-year old) from the subjects in the impression evaluation experiment. Using cotton pads with 1.5 ml of the exfoliating lotion, the study participants used their dominant hands to wipe the artificial skin toward the front 10 times at a speed of approximately 50 mm/s with a pushing force of approximately 100 gf. The time profiles of the frictional forces of the 12 types of exfoliating lotions were then measured.



Figure−2. Schematic of the device used for performing measurements.

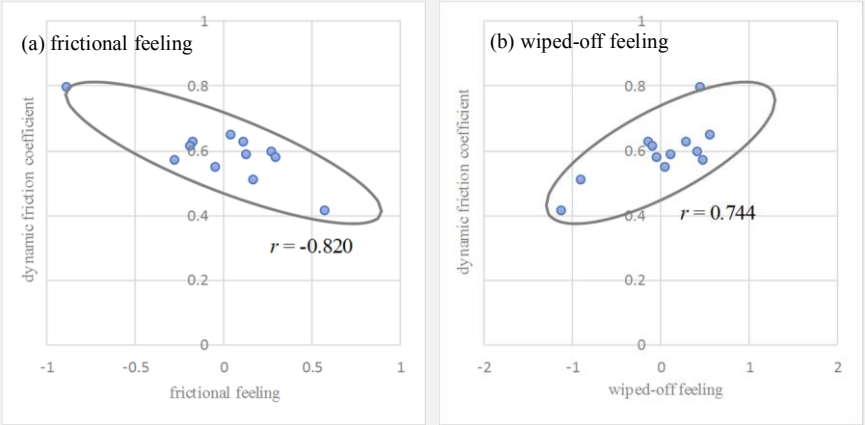
RESULTS AND DISCUSSION

Impression evaluation of the texture

A factor analysis was performed on the evaluation results under conditions same as those considered in Experiment 1. As a result, three factors having a structure that was nearly same as that in Experiment 1 were extracted. To compare the similarity between these factors and those considered in Experiment 1, Tucker's congruence coefficient was calculated. The factors "frictional feeling," "wiped-off feeling," and "skin feeling after application" had coefficients of 0.889, 0.861, and 0.879, respectively, and were found to be similar. Therefore, it was decided that the "frictional feeling" and the "wiped-off feeling" obtained in this experiment could follow the structural equation modeling of Experiment 1.

Relationship with the dynamic friction coefficient

A correlation analysis was performed on the measured dynamic friction coefficients and the factor scores of the "frictional feeling" and the "wiped-off feeling". The scatter plots of each are shown in Figure−3. The "frictional feeling" and "wiped-off feeling" were negatively and positively correlated with the dynamic friction coefficient, respectively (with correlation coefficients of $r = -0.820$ and 0.744, respectively). This result confirmed that the "frictional feeling" and "wiped-off feeling" cannot be evaluated as independent elements when only using the dynamic friction coefficient.

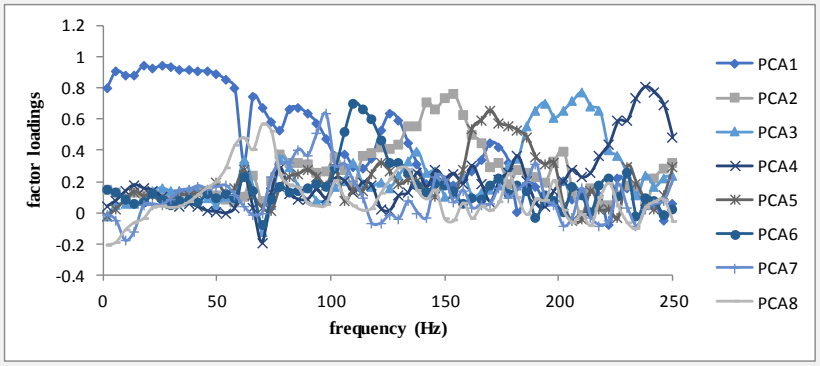


Figure−3. Correlation with the dynamic friction coefficient.

Relationship with the vibrational feature quantities calculated from the time profile

The time profile of the frictional force was evaluated via a frequency analysis using the Welch method (window width: 0.5 s; overlap rate: 0.5) to estimate the power spectral density (hereinafter referred to as power). In this case, considering the sensibility characteristics of the tactile receptors, 0–252 Hz was assumed as the analytical region, which was discretized in 63 pieces at 4-Hz intervals and examined. This power was calculated for all samples for each study participant using the average power of the 10 repeat measurements.

Feature extraction of the vibrational components was performed via a principal component analysis of the 120 power measurements (10 subjects × 12 samples). In total, eight factors were extracted under the condition that the eigenvalue was 1.0 or greater; the cumulative contribution ratio was 76.62%. Figure−4 shows the basis functions of the extracted factors. Consequently, it was confirmed that each factor represents a different frequency domain. The principal component scores of each factor were calculated as the vibrational feature quantities.



Figure−4. Basis function of the vibrational properties.

Next, multiple regression analysis was performed with the factor scores of the "frictional feeling" and "wiped-off feeling" as the objective variables and the vibrational feature quantities as the explanatory variables. The results are summarized in Table−2. The "frictional feeling" and "wiped-off feeling" were estimated with high accuracy (r^2 = 0.672 and 0.722, respectively) using the vibrational feature quantities. On comparing these two factors, PCA 1 was found to exhibit a negative (−0.569) correlation for the "frictional feeling" and an opposite positive tendency (0.421) for the "wiped-off feeling." This is similar to the correlation with the dynamic friction coefficient. This result shows the validity of the vibrational feature quantities calculated in this experiment; it also shows that PCA1, having the low-frequency region of 0–104 Hz as its main component, shows a behavior similar to that of the dynamic friction coefficient, which is a quantitative physical

Table−2. Results of the multiple regression analysis.

explanatory variable	main frequency region	standardised partial regression coefficient	
		frictional feeling	wiped-off feeling
PCA1	**0 - 104 Hz**	-0.569 *	0.421 *
PCA2	132 - 160 Hz	—	—
PCA3	**184 - 220 Hz**	0.631 *	—
PCA4	**220 - 252 Hz**	—	0.621 **
PCA5	**160 - 184 Hz**	0.530	—
PCA6	104 - 120 Hz	—	—
PCA7	96 - 100 Hz	—	—
PCA8	60 - 64 Hz	—	—
coefficient of determination		0.672	0.722
adjusted coefficient of determination		0.549	0.661
p value		0.024	0.003

** : $p < 0.01$, * : $p < 0.05$

quantity. Conversely, in the high-frequency regions, each factor corresponds to a different vibrational feature, e.g., “frictional feeling” correlated with PCA 3 (184–220 Hz) and PCA 5 (160–184 Hz) and “wiped-off feeling” correlated with PCA 4 (220–252 Hz). Therefore, each factor is physically independent. This result suggests that both factors can be simultaneously increased by controlling the frictional force.

Based on this result, in Experiment 3, we designed an exfoliating lotion that enhances the vibrational features and consequently intensifies each factor.

Experiment 3: Development of an exfoliating lotion with superior tactile impressions during wiping motions

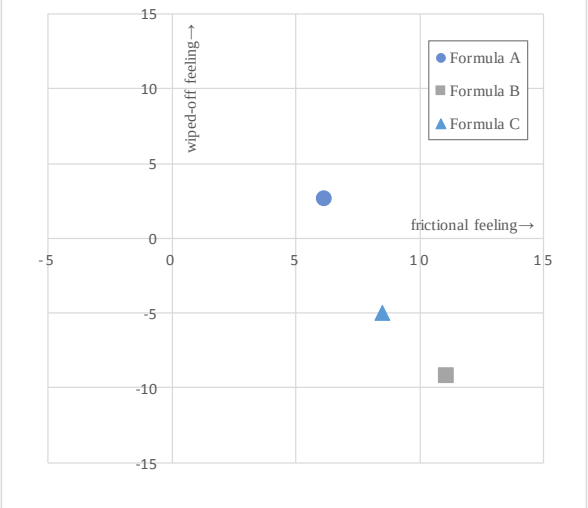
MATERIALS AND METHODS

Each exfoliating lotion was prepared by blending alcaligenes polysaccharides (Formula A), sodium hyaluronate (Formula B), and hydroxypropyl methylcellulose stearoxy ether (Formula C), which are polymer ingredients, to obtain the same viscosities. In addition, a standard lotion was used, i.e., the lotion that showed the best “frictional feeling” and “wiped-off feeling” in the impression evaluation of Experiment 2. One study participant measured the time profile using a method same as that used in Experiment 2.

RESULTS AND DISCUSSION

The power was estimated from the time profile using a same as that used in Experiment 2. Next, the deviation was calculated based on the power of the standard lotion. With respect to this deviation, based on the analytical results of Experiment 2, the integrated value of the power was calculated for the frequency regions corresponding to the “frictional feeling” at 160–220 Hz and the “wiped-off feeling” at 220–252 Hz.

In Figure−5, the integrated values of the power for each factor are taken as the two axes and a scatter diagram is plotted for each sample. It was found that Formula A is superior in both its “frictional feeling” and its “wiped-off feeling” to the conventional exfoliating lotion [origin (0, 0)] used as the standard lotion. Conventional polymer ingredients, such as sodium hyaluronate and hydroxypropyl methylcellulose stearoxy ether, improve the “frictional feeling” but degrade the “wiped-off feeling”. Conversely, a unique thickening behavior has been reported for alcaligenes polysaccharides[8]. It is thought that this contributed toward improving the "wiping feeling" without impairing the “frictional feeling”.



Figure−5. Evaluation results for each sample using a predictive index of the tactile impression.

CONCLUSIONS

By visualizing the “sensibility,” we were able to understand the factors that users subconsciously regard as important and predict them by correlating them with physical quantities. First, as a consequence of modeling the psychological structure of a user, it was suggested that the two factors derived from the texture of an exfoliating

lotion, particularly the tactile impression during the wiping motions, were potentially important. Next, we examined the relationship of the frictional force during the wiping motion with respect to the tactile impression. Using the dynamic friction coefficient, the two factors could not be individually evaluated; however, we found that they could be independently predicted using vibrational feature quantities calculated from the friction force. Using this as a predictive index of the tactile impression, it was possible to design an exfoliating lotion that had a superior texture at the time of wiping; this could not be achieved in the past.

This method will be extremely useful for developing exfoliating lotions and other cosmetics that appeal to users' sensibility.

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