35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Fundamental Study on Formulation Design of Skin Care Products by Modeling of Tactile Sensation

Yoko Akiyama, Fumihito Mishima, and Shigehiro Nishijima

Abstract— **The objective of this study is to construct a method to quantify and formulate the human tactile sensation. We have tried to indicate the sensory scores of tactile sensation as a combination of the physical values of skin care products. Consequently, the extracted principle factors of the sensory properties could be related to the physical values by multiple regression analysis. For the next step, we investigated the physical mechanism of tactile sensation, and proposed a method to formulate the sensory properties. A method to formulate the sensory properties of skin care products was constructed based on the relation between sensory values, principal factors, physical values and composition. The method was verified by sensory evaluation.**

I. INTRODUCTION

Medicines such as endermic liniments, adhesive skin patches and skin care cosmetics are the products which are repeatedly applied or attached to human skin. Since the effect of these products usually appears only after continued use, it is important for the patients or the consumers that the products are comfortable and easy to use [1]. Moreover, in the patients, a psychological stress due to skin illness often worsens a condition, and a repetitive comfortable tactile sensation may improve a patient's QOL (quality of life). Thus, the composition of skin care products is required to have enough usability and comfort in order to bring out its function or efficacy enough.

The component that makes up the biggest proportion of the ingredients of medicines or cosmetics is called the base. The base mainly controls the transdermal absorption of the main ingredient, which decides the effect or the functionality [2]. At the same time, it also has a large effect on tactile sensation. In this study, we aimed to formulate the tactile sensation of skin care products based on the physical mechanism. Here we analyzed the tactile sensations of lotion products based on a model which focuses on the physical properties of the ingredients. Lotion is one of the common bases for both medical ointments and cosmetics. In the previous study, we tried to quantify the tactile sensation with the physical values [3]. For the next step, we investigated the correlation between the physical properties and the composition of the lotion products. A formula that produces specific tactile sensations was created based on the physical mechanism of tactile sensation.

*This study was supported in part by an MEXT Grant-in-Aid for Young Scientists (B-24700207 "Design of microstructure of sensibility-conscious material focusing on the behavior of water molecules").

Yoko Akiyama, Fumihito Mishima and Shigehiro Nishijima are with Osaka University, A1 Bldg. 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan (phone: +81-6-6879-7897: fax: +81-6-6879-7889:
e-mail: yoko-ak@see.eng.osaka-u.ac.jp).

II. EXPERIMENTAL METHOD

A. Experimental Procedure

A brief overview of this study is shown in Fig.1. Among the tactile sensations of the lotion products, we focused attention on "moistness" and "freshness", because the "moist-type" and "fresh-type" skin care products had been empirically created in Japan. In our previous study [3], the physical properties of lotion products and the principle factors, which determine their sensory values, were correlated. The study clarified the internal structure of each sensory value. In this study, the correlation between the physical properties, which contribute to the principle factors, and the composition of the products was investigated. Finally, a material design method to produce a target tactile sensation was proposed.

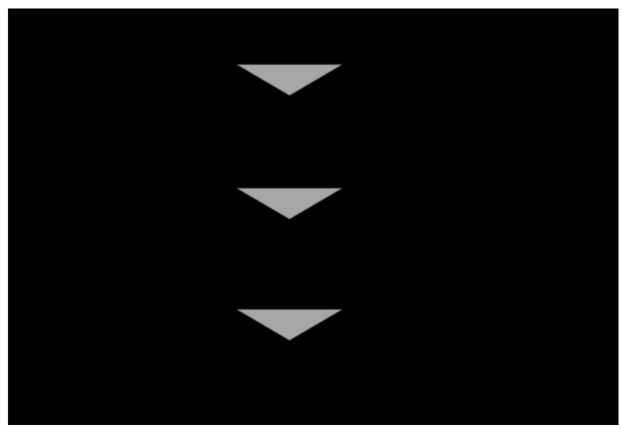

Figure 1. A brief overview of this study

B. Sensory Evaluation

Six lotion samples commercially available under three brands were used, which were divided into two types; moist type (Type M) and fresh type (Type F). The sensory evaluation of tactile sensation was performed during the application of 0.2 mL of each sample using the 5-level SD (Semantic Differential) method. The sensory evaluation was performed using 17 categories that are characteristics of skin care products; for example, "spreadability," "stickiness," "oiliness," "moistness" and "freshness". Five males and five females aged from 20 to 40 participated in the sensory evaluation. The total number of the samples used for statistical analysis was 60. The participants were sufficiently informed about the objective, the method and the ethics of the experiment. They were also informed that they could leave the experiment at any time if they felt discomfort. Informed consent was obtained in writing.

C. Measurement of Physical Properties

Thermal properties, viscosity, contact angle and the frictional properties of each sample were measured. These four properties are supposed to have an influence on the principle factors of sensory properties which were extracted by factor analysis.

The DTA8020 (Rigaku Co., Ltd.) was used to test thermogravimetory (TG), with the temperature increasing up to 473 K at a speed of 5 K/min. The values for calculation was the temperature when 98% of the sample was evaporated. The evaporation of the lotion on the human forearm at skin temperature was also checked with TEWL (Transepidermal water loss) measured by Tewameter (Courage - Khazaka Electronic), and it correlated with the weight loss by heating measured by thermogravimeter. The shear viscosity was measured by a rheometer AR-1000 (TA Instruments) using a 40 mm diameter cone plate, with a 1 degree angle between the surface of the cone and the plate. The values for calculation was the viscosity at shear speed of 1000 s^{-1}. The sample was put in a temperature condition of 37 degrees C and 10 µm gap. A PTFE (polytetrafluoroethylene) plate, which had a contact angle for water similar to that of human skin in the preparatory experiment, was also used as the basal plate of the rheometer, in order to imitate the skin surface. The contact angle was measured by dropping the sample on the PTFE plate, and was calculated using θ/2 method. The coefficients of friction against the medial side of the forearm after the application of the samples were measured by KES-SE (Kato Tec. Co., Ltd.) with 50 g in load and 1 mm/sec in probe speed.

III. RESULTS AND DISCUSSION

A. Physical Phenomena Inducing the Tactile Sensation

The principle factors were extracted by factor analysis for the results of the sensory evaluation during application of the samples. The accumulated contribution rate for the first three factors was around 60 %. The first factor was interpreted as "viscous feeling," the second as "transpiration feeling" and the third as "frictional feeling." Multiple regression analysis was applied by setting principal factors or physical values as the explanatory variables, and sensory scores or principal factors as the objective variable. The results including *p*-values for statistics were shown in Table I.

In Table I, the evaluation term, "sticky" was used for the calculation described in subchapter B. Here, the physical phenomena which respectively lead "moistness" and "freshness" were examined. Firstly, the relation between sensory values and principle factors were discussed. Table I (a) shows that both "moistness" and "freshness" can mainly be explained by first factor of viscous feeling and second factor of transpiration feeling. The coefficients calculated by multiple regression analysis indicate that "moistness" is induced by large viscous feeling and small transpiration feeling, whereas "freshness" is induced under inverse condition.

Next, the relation between the physical values and principle factors relating to above two sensory items were discussed. The standardized partial regression coefficient in Table I (b) indicates that viscous feeling mainly depends on the viscosity and contact angle on PTFE. It means that the viscous feeling is induced when the wettability of the human skin by the lotion sample is low and the viscosity of the sample is high. On the other hand, transpiration feeling mainly depends on the contact angle on PTFE. Hence the transpiration feeling is induced under the condition that the wettability of the human skin by the lotion sample is low. These explanations indicate that the physical phenomena which cause "moistness" and "freshness" were presumed, and it also show that the coexistence of two principle tactile sensations during application is possible.

We focused the attention on the tactile sensation during application of the lotions in this study. As shown in our previous study [3], it was shown that the considerably different result of factor analysis and multiple regression analysis were obtained for the sensory evaluation immediately after application and 30 minutes after application. The haptic mechanisms of the sensory properties after application are to be investigated.

In this way, each sensory value was represented by a linear combination of maximum 3 principle factors, and each factor was also represented by a linear combination of maximum 4 physical values. The sensory values are generally expressed by exponential functions in the field of haptic perception such as distinction of the type or size the object substances [4,5],

TABLE I. THE RESULTS OF REGRESSION ANALYSIS

(a)

Sensory evaluation terms	*Principal factors*	*Partial regression coefficients*	*Standardized partial regression coefficient*	*p-value*
"Moistureness"	1st Factor Viscous feeling	0.66	1.83	0.05
	2nd Factor Transpiration feeling	-0.12	-2.03	0.17
	3rd Factor Frictional feeling	-0.06	-0.22	0.79
	constant term	2.12		0.01
"Freshness"	1st Factor Viscous feeling	-0.36	-1.21	0.24
	2nd Factor Transpiration feeling	0.06	1.19	0.25
	constant term	2.73		0.003
"Sticky"	1st Factor Viscous feeling	0.96	1.54	1.1E-04
	2nd Factor Transpiration feeling	-0.19	-1.97	0.002
	3rd Factor Frictional feeling	-0.28	-0.66	0.16
	constant term	2.17		1.7E-08

(b)

Principal factors	*Physical values*	*Partial regression coefficients*	*Standardized partial regression coefficient*	*p-value*
1st Factor Viscous feeling	Weight loss by heating	0.06	0.86	0.07
	Contact angle on PTFE	0.74	1.77	0.10
	Viscosity on PTFE	665.90	1.17	0.13
	Friction coefficient	-12.46	-0.48	0.21
	constant term	-51.43		0.08
2nd Factor Transpiration feeling	Contact angle on PTFE	3.86	1.51	0.03
	Weight loss by heating	0.28	0.61	0.05
	Viscosity on PTFE	2875.49	0.83	0.08
	constant term	-288.18		0.02
3rd Factor Frictional feeling	Friction coefficient	-20.23	-0.64	0.17
	constant term	9.15		0.18

(a) is data for sensory evaluation terms and (b) is for principle factors.

but it could be expressed by linear combination in this study, because the difference of tactile sensation among lotion products are considerably small compared with above examples.

B. Formulation Design of Lotions

For the next step, a formula which produces specific tactile sensations was prepared based on the results. It is necessary to correlate each physical quantity with the ingredient ratio in order to determine the tactile feeling. Here, we focused attention on the refreshing and moisturizing elements in the lotion base. Firstly, the correlations among the component fractions, the sensory values, the principle factors and the physical values were investigated. The results are shown in Table II.

The typical tactile feelings of the lotion products, "moistness" and "freshness," are shown in this table among the 17 evaluation categories. The sensory values did not show clear correlation with the component fractions, except for negative correlation between refreshing ingredients and moistness. Currently many lotion products commercially available are divided into “moist type” and “fresh type” due to the difference in refreshing and moisturizing elements used in the ingredients. However, it turned out that “moistness” is not always induced by large amount of moisture elements and “freshness” is not simply induced by using large amounts of refreshing elements.

TABLE II CORRELATION AMONG THE RATIOS OF THE COMPONENTS, PRINCIPLE FACTORS, PHYSICAL AND SENSORY VALUES

		Refreshing element	***Moisture element***
Principal factors	1st Factor Viscous feeling	-0.83	0.42
	2nd Factor Transpiration feeling	-0.51	0.02
	3rd Factor Frictional feeling	-0.06	0.27
Physical values	Contact angle on PTFE	0.26	-0.70
	Viscosity on PTFE	-0.38	0.80
	Friction coefficient	0.06	-0.27
	Weight loss by heating	-0.94	0.68
Sensory values	"Moistureness"	-0.60	0.06
	"Freshness"	0.46	0.18

Many of the principle factors and physical quantities, on the other hand, had good correlations with the component fractions. It is notable that three of four physical amounts that contribute to the principle factors were in high correlation with the ratio of either the moisturizing element, or the refreshing element.

On the basis of this result, we tried to estimate the composition which induces a target tactile sensation, and prepared a lotion sample based on the result. In addition to “freshness” and “moistness,” we focused our attentions on the “sticky” sensation, which is one of the typical negative feelings when applying lotion. A series of methods to calculate the composition in order to achieve the target sensory value is shown in Fig. 2. The regression formulas (1) and (2) in Fig. 2 respectively correspond to the values in Table I (a) and (b).

At first, ideal factor scores of the three principle factors

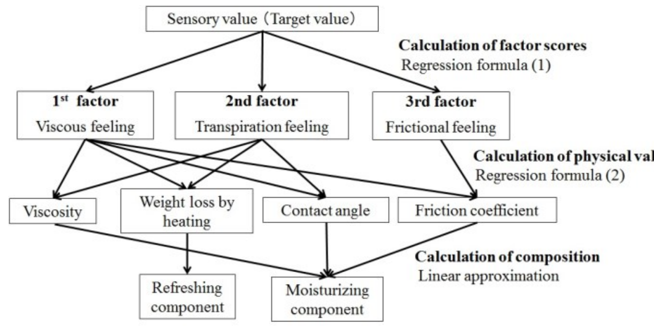

Figure 2. Method of calculating composition from the target sensory value.

were determined so as to fulfill each target sensory value by linear programming. Next, the physical quantities that satisfy the factor scores above were calculated by solving the simultaneous equation under limiting condition. Finally, the ratios of refreshing and moisturizing elements which satisfy these physical quantities were determined by linear approximation between the refreshing or moisturizing elements and physical quantities. All these parameters were optimized in the limiting condition so that the ratios of the components and physical properties are within the applicable condition for a lotion product.

The compositions which satisfy the target sensory values were determined by solving the simultaneous equations by the method above. The calculated compositions of the refreshing and moisturizing elements are shown in Table III, which was determined by the relational expressions between sensory values, physical quantities and the ratio of components. Two types of the samples were targeted. Sample A was given a target level of 3.5 in the “sticky” sensation in the 5 level SD method, with the sensory value of “moistness” being higher than that of “freshness”. On the other hand, Sample B´s target was 1.0 in the “sticky” sensation category, with the sensory value of “freshness” being comparatively higher than that of “moistness.” The target values of sensory evaluation was

TABLE III. THE TARGET VALUES OF SENSORY SCORE AND THE CALCULATED PARAMETERS

		Sample A	***Sample B***
Target Sensory Value	**"Sticky"**	**3.5**	**1.0**
	"Moistureness"	**3.5**	**1.5**
	"Freshness"	**2.0**	**3.0**
Factor Score	1st Factor	2.26	-0.77
	2nd Factor	-0.14	0.21
	3rd Factor	0.23	-0.02
Physical values	Weight loss by heating (°C)	220	120
	Contact angle on PTFE (°)	47	66
	Viscosity on PTFE (Pa・s)	0.016	0.0001
	Friction coefficient (-)	0.4	0.5
Refleshing Element (wt.%)		2	16
Moisture Element (wt.%)		18	7

determined so as to avoid the extreme values which is expected to easy to formulate, and the number of target sensory values were set in order to obtain a unique composition by the simultaneous equations shown in Table I and Figure 2.

C. Validation of Tactile Formula

To validate the tactile formula using the above method, the lotion samples A and B were prepared according to the results of Table III. Ethanol and glycerin, which are the typical ingredients as refreshing and moisturizing elements, were used as the model constituents. Purified water was used as residual base ingredient. The ingredients were stirred for 10 minutes and then left to stand for 12 hours.

The tactile sensation was confirmed by the sensory evaluation of these two samples by five male and five female subjects. The results are shown in Fig. 3. It was confirmed that the observed sensory values of “moistness,” “freshness” and “stickiness” were almost the same as the target values within the standard deviation in both samples A and B. From the results, the use of the proposed method to calculate the formula of ingredients in regard to tactile sensation was shown to be valid.

An issue of above method is that some steps are needed to predict the sensory scores which includes errors introduced in earlier prediction. Thus we are currently investigating the physical model which can describe each tactile feeling to enable tactile design of various materials in more simple method. The formulation of tactile sensation is required not only in the field of medicines and cosmetics [6,7], but also in a wide range of fields, such as those relating to fabrics [8], leathers [9] and woods [10]. We are planning to improve upon the proposed way of utilizing this versatile method for the advancement of the living environment.

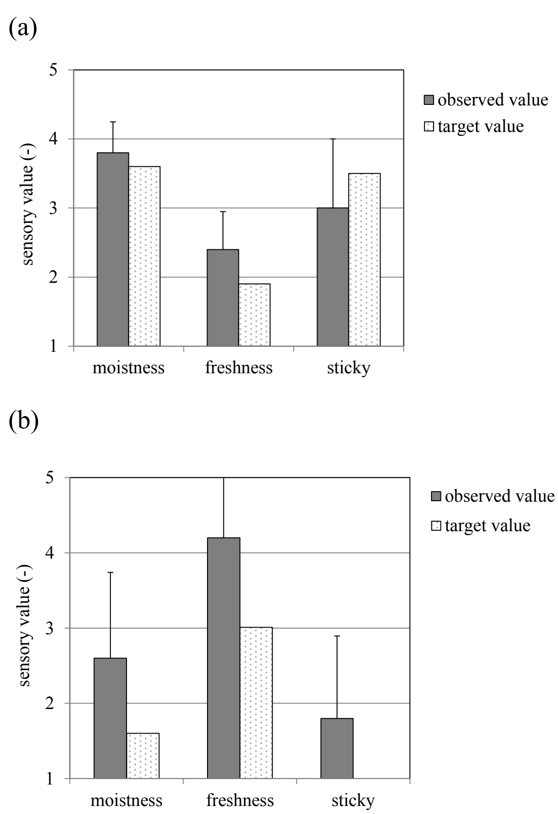

Figure 3. Observed and target values of sensory scores of “sticky” sensation for (a) Sample A and (b) Sample B.

IV. CONCLUSION

We tried to correlate the tactile sensation, the physical values and the ratio of components so as to formulate the tactile sensation of skin care products. Based on the principle factors extracted from the sensory evaluation, each sensory value was successfully represented as a mathematical formula that consists of physical values. From the result, the physical phenomena inducing “moistness” and “freshness” were examined. For the next step, the composition of the lotion product which induces a target tactile sensation was determined by further statistical calculation. As a result, the composition of a lotion with the desired tactile sensation could be formulated, and its validity had few errors compared with the actual sensory scores.

In a future study, we will investigate the applicability of this technique for other materials, and will develop the system to optimize the material composition or structure to induce the desired tactile sensations.

REFERENCES

[1] Y. Shibata, H. Ikeda, Y. Kondo, K. Kihira, “Comparison of pharmaceutical properties of topical non-steroidal anti-inflammatory drug preparations on quality of life,” Yakugaku Zassi, vol. 125, no. 5, pp. 397-404, May 2005.

[2] M. Ohtani, M. Matsumoto, Y. Yamamura, M. Sugiura, K. Uchino, T. Etoh, “Evaluation of the influence of bases, formulations and skin conditions of two preparations of commercially available drugs on permeability and adverse effects in hairless rat skin,” The Japanese journal of dermatology, vol. 120, no. 1, pp. 37-43, January 2010.

[3] Y. Akiyama, F. Mishima, S. Nishijima, “Fundamental study on quantification of tactile sensation,” IEEJ Transactions on Electronics, Information and Systems, vol. 132, no. 1, pp. 166-172, January 2012.

[4] R.S.JOHANSSON, “Tactile sensibility in the human hand: receptive field characteristics of mechanoreceptive units in the glabrous skin area,” Pheyiol, 281, pp.101-123, 1978

[5] M.A.Srinivasan and K.Dandekar, “An Investigation of the Mechanics of Tactile Sense Using Two-Dimensional Models of the Primate Fingertip,” Journal of Biomechanical Engineering, Vol.118, pp.48-55, 1996

[6] Kaoru Suganuma and Masako Niwa, ”Relation between physical property of massage creams and skin surface smoothness,” Journal of SCCJ, Vol. 24, No. 3, pp. 212 -219, 1991

[7] Yuuka Shibata, Hiroaki Ikeda, Yoshihiro Kondou and Kenji Kihira, ”Comparison of phamaceutial properties of topical non-steroidal anti-inflammatory drug preparations on quality of life,” Yakugaku Zassi, Vol. 125, No.5, pp. 405-416, 2005

[8] Mami Tanaka, Fumihiro Wagatsuma, Sonoko Ishimaru and Seiji Chonan, ”Measurement and Valuation of Touch Sensation : Measurement of Texture on Fabrics,” JSME annual meeting Vol. 2, pp. 155-156, 2000

[9] Agnès Giboreau, Séverine Navarroa, Pauline Fayeb and Jacqueline Dumortierc, ”Sensory evaluation of automotive fabrics: the contribution of categorization tasks and non verbal information to set-up a descriptive method of tactile properties,” Food Quality and Preference, Vol. 12, No. 5-7, pp. 311-322, 2001

[10] Takeshi Okano, ”Evaluation of wood surface roughness as related to tactile roughness,” Journal of the Society of Materials Science, Vol. 46, No.9, pp. 1112-1117, 1997