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Sensory Evaluation of Fabric Touch by Free Modulus Magnitude Estimation

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Abstract: Fabric touch was evaluated psychophysically in order to determine the relationship between mechanical properties and subjective sensation. For subjective touch sensation, eight aspects such as hardness, smoothness, coarseness, coolness, pliability, crispness, heaviness and thickness were evaluated using free modulus magnitude estimation (FMME) technique. KES-FB was used to measure the mechanical properties of fabrics. Woolen fabric with the highest values of WC and weight was evaluated as the coarsest, heaviest and thickest. While silk crepe de chine with the lowest LT, G, 2HG, thickness and weight was rated as smoother and more pliable than any other fabrics. And flax with the highest values of LT and SMD was evaluated as hard, cool and crisp. Fabric touch and satisfaction were predicted well from the mechanical properties, especially from SMD, by regression analysis. Satisfaction for touch increased as smoothness increased.

Keywords: Free modulus magnitude estimation, Fabric touch, Prediction model, Sensation, Mechanical properties

Introduction

When consumers purchase a textile product, they usually touch and rub the surface of the fabric so as to feel the tactility, and to assess the quality and prospective performance of the product in a specific end use. The tactile sensation is, therefore, one of the most important characteristics of textile products to satisfy them. But discrepancy between textile products' quality and consumers' demand in fabric touch is occurred frequently because linguistic expression for the sensation is ambiguous and diverse according to human being. To develop textile products for satisfying tactile sensation require fabric objective measurement (FOM). FOM attempts to find the relationship between fabric touch sensation and some physical or mechanical properties of fabric, and to identify and assess the sensation from the measured mechanical properties quantitatively. It contributes to the perception of fabric and garment quality in specific end-uses[1]. In the long run, it describes fabric hand by using translated results from some measured values of relevant attributes of a fabric.

The assessment of fabric hand can be accomplished subjectively and/or objectively. Subjective assessment treats fabric hand as a psychological reaction obtained from sense of touch. Apparently it is a valuable method that has traditionally been used by textile researchers. In order to describe hand, adjectives such as 'soft', 'harsh', 'limp', and 'crisp' are used. Human sensation can be psychophysically evaluated using semantic differential scaling (SDS), magnitude estimation, and etc[2]. The SDS has been widely used in the past, and is easy to administer, but it provides only qualitative information about subjective sensation and feelings. On the other hand, magnitude estimation has an advantage that it produces quantitative data with characteristics of the ratio scale, which can be subject to various statistical analyses and generally is less sensitive to end effects and range-frequency effects than most other rating scales[3].

Magnitude estimation is a method to evaluate sensation against stimuli by giving any number corresponding to the magnitude of perceived attribute[2]. Free Modulus magnitude estimation (FMME) which is one of the magnitude estimation methods, is considered as a more advanced technique because FMME is free enough to estimate the magnitude of each sensation by giving any number considering the intervals. The observers use their own standards without any modulus for comparison, since a standard stimulus causes the potential bias effects for the response. According to Gescheider[4], it is better to permit the observers to choose their own modulus rather than to designate one for them.

Therefore, the objectives of this study were to provide information concerning human subjects' sensation and satisfaction for fabric touch by FMME, and to establish the models for fabric touch predicted from mechanical properties of fabrics.

Experimental

Specimens

Eight different fabrics were selected statistically among 65 commercial apparel fabrics by classifying their fabric sounds according to cluster analysis. Table 1 shows the characteristics of the test specimens.

Measurement of Mechanical Properties of Fabrics

Mechanical properties of specimen were measured by using the Kawabata Evaluation System (KES)-FB[5]. The

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Table 1. Characteristics of fabrics

Fabric number	Fiber content	Yarn type	Fabric construction/Name	End-use
F1	Wool	Staple	Plain/Worsted	Suit
F2	Wool	Staple	Plain/Woolen	Suit
F3	Polyester	Staple	Twill/Ultrasuede	Suit
F4	Polyester	Staple	Leno/Leno	Suit
F5	Silk	Filament	Plain/Crepe de chine	Blouse
F6	Polyester	Filament	Twill/Surah	Sportswear
F7	Polyester	Filament	Plain/Taffeta	Sportswear
F8	Flax	Staple	Plain/Burlap	Upholstery

properties included tensile, shearing, compression properties, geometrical roughness, thickness and weight.

Subjective Evaluation

Subjects

Participants for this study were recruited from the Virginia Tech student population by means of posted fliers and postings to the local VT newsgroups. Thirty subjects between 18 and 26 years of age participated in the study. The proportion of male and female students was 14 and 16, respectively.

Questionnaire and Sensory Evaluation

The questionnaire dealt with eight aspects of fabric touch: hardness(T1), smoothness (T2), fineness(T3), coolness(T4), pliability(T5), crispness(T6), heaviness(T7), thickness (T8) and added satisfaction. It was composed of the forms of free modulus magnitude estimation (FMME)[6,7]. Before main test, line length estimation was carried out for pretest.

Each of 8 fabric samples, sized 30×30 cm^2 and placed separately in pillory boxes, was presented and touched by each participant. For each sensation, each participant assigned a number to each sensation and satisfaction so that high number represented high sensation and satisfaction and low number, represented low sensation and satisfaction[8].

Sensory evaluations were repeated twice so that two responses were obtained for each participant and sensation. The fabric samples were presented to each participant in different orders using the random number table.

Calculation of the Geometric Mean of FMME

To compare magnitude estimation judgments among participants who responded using varied number ranges, every score for each participant required correction. The subjective FMME data were transformed[7] to eliminate inter-participant variance and intra-participant variability by the following steps:

① Each response value was converted to its logarithm. ② The arithmetic mean of the logarithms of the responses made by each participant to each stimulus was calculated. This value is equal to the logarithm of the geometric mean of the participants responses to each sensation. ③ The means were plotted in a table, in which participants are listed by row and specimens are listed by column. ④ The arithmetic mean of the logarithmic responses in each row was obtained. This is equal to the logarithm of the geometric mean of each observer's responses to all the sensation. ⑤ The arithmetic mean of all the values determined in step 4 was obtained. This is equal to the logarithmic value of the grand mean of all the responses for all participants to all stimuli in the original data matrix. ⑥ The value obtained in step 5, the grand mean log response, was subtracted from each of the arithmetic individual mean log responses determined in step 4. ⑦ The value obtained in step 6 from the row of values obtained for each observer in step 2 was subtracted. ⑧ The antilog of every value obtained in step 7 was obtained.

Results and Discussion

Mechanical Properties of Fabrics

Mechanical properties by KES are shown in Table 2. Silk crepe de chine(F5) which was thinner and lighter than any other fabrics showed the lowest values of LT (tensile linearity), G (shear stiffness), and 2HG (shear hysteresis). It means that the fabric was more stretchable and easily deformable than any other fabrics. The thick and heavy woolen fabric (F2) was found to be the bulkiest and the least deformable at shearing and most resistant under compression because of the highest values for WC (compression energy) and weight. Polyester leno (F4) was the most stretchable in tensile strain because the fabric showed the highest value of WT (tensile energy). Flax fabric (F8) was the least stretchable and the roughest due to the highest values for LT (tensile linearity) and SMD (geometrical roughness).

The FMME Results for Touch of Fabrics

The means of sensation of fabrics evaluated by free modulus magnitude estimation are shown in Figure 1. The one-way analysis of variance (ANOVA) was performed for each of seven sensations in order to test whether sensation effects of eight fabrics are the same or not. All of fabric

Table 2. Mechanical properties of fabrics

Fabrics	EM (%)	LT (-)	WT (gf.cm/cm^2)	RT (%)	G (gf/cm.deg)	2HG (gf/cm)	2HG5 (gf/cm)	WC (gf.cm/cm^2)	SMD (micron)	T (mm)	W (mg/cm^2)
F1	6.46	0.63	10.07	60.06	0.56	0.81	1.50	0.20	0.56	0.46	23.24
F2	8.82	0.58	13.13	56.07	0.94	2.19	3.16	1.82	0.93	0.68	40.52
F3	3.81	0.76	9.11	58.29	0.39	0.73	1.49	0.12	0.26	0.30	14.28
F4	10.82	0.71	19.11	45.43	0.32	0.45	0.89	0.24	2.15	0.58	22.34
F5	13.07	0.48	15.61	50.65	0.21	0.05	0.22	0.08	0.31	0.18	6.51
F6	3.44	0.73	6.25	55.90	0.31	0.51	1.19	0.11	0.16	0.25	12.91
F7	4.00	0.65	6.45	64.52	0.87	1.59	2.54	0.07	1.62	0.28	16.35
F8	2.20	0.80	4.34	43.50	0.59	0.65	2.93	0.18	2.43	0.40	15.95

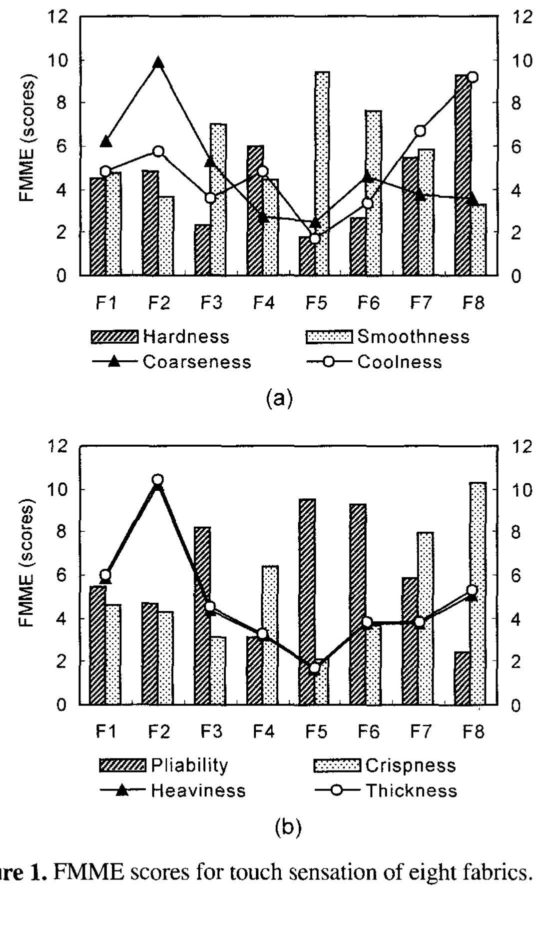

Figure 1. FMME scores for touch sensation of eight fabrics.

touches were significantly different among eight fabrics ($p<0.001$).

Hardness, smoothness, coarseness, and coolness are shown Figure 1(a), and pliability, crispness, heaviness, and thickness are presented in Figure 1(b). Hardness and coolness were the highest for F8 (flax) and the lowest for F5 (silk crepe de chine). And F8 (flax fabric) was harder and cooler than F1(worsted) and F2 (woolen). Smoothness was the highest for F5 (silk crepe de chine) with the lowest SMD and was the lowest for F8 (flax) with the highest SMD. This means that F5 for blouse silk fabric was felt smooth but flax fabric for upholstery was felt rough. So smoothness by FMME was shown good relationship with mechanical properties. Coarseness was the highest for F2 (Woolen) while it was the lowest for F5 (silk crepe de shine).

Pliability was the highest for F5 (silk crepe de chine) with lowest G and 2HG and the heaviness was highest for F2 (woolen fabric), the thickest and heaviest fabric. Crispness was the highest for F8 (flax) due to its rougher feel. And heaviness and thickness showed similar tendency for all fabrics. These were the highest for F2 (woolen) with the highest T and W and were the lowest for F5 (silk crepe de chine) with the lowest T and W. F3 (ultrasuede), F6 (surah), and F7 (taffeta) were fairly similar to one another in thickness and weight, so means for these fabrics somewhat coincide. Thickness and weight among mechanical properties should a high correlation each other.

Therefore F2 (woolen) was evaluated as coarsest, heaviest, and thickest in touch, while F5 (crepe de chine) was rated as being smoother and more pliable in touch than any other fabrics. As predicted, silk fabric, having such a different feel than the other seven fabrics, had extremely high means in such categories as smoothness, pliability, and a much lower mean for thickness. Flax, due to its rougher feel, showed a much higher mean for hardness, coolness and crispness.

Relationship between Fabric Touch and Mechanical Properties

The correlation between fabric touch and mechanical properties is shown in Table 3. Hardness was positively correlated with 2HG5 and SMD. This means that the stiffer and rougher the fabric, the higher the hardness. Smoothness was negatively correlated with the shear properties (G, 2HG, 2HG5), SMD, T and W. Therefore, smoothness decreased with increasing stiffness, roughness, thickness and weight. On the contrary, coarseness showed a positive correlation with shear properties (G, 2HG, 2HG5), WC and W. That is, coarseness increased with increasing stiffness, bulkiness and

Table 3. Correlation coefficients between mechanical property and fabric touch by FMME

	EM	LT	WT	RT	G	2HG	2HG5	WC	SMD	T	W
Hardness	−0.33	0.47	−0.26	−0.45	0.44	0.22	**0.64****	0.09	**0.92****	0.45	0.29
Smoothness	0.25	−0.39	0.10	0.23	**−0.63****	**−0.53***	**−0.74****	−0.47	**−0.70****	**−0.82****	**−0.72****
Coarseness	−0.08	−0.15	−0.06	0.40	**0.64****	**0.77****	**0.57***	**0.85****	−0.29	0.60	**0.84****
Coolness	**−0.54***	**0.50***	−0.49	−0.19	**0.65****	0.45	**0.84****	0.17	**0.80****	0.39	0.34
Pliability	0.09	−0.36	−0.05	0.43	−0.47	−0.32	**−0.58***	−0.28	**−0.88****	**−0.73****	**0.54***
Crispness	−0.48	**0.54***	−0.42	−0.30	0.44	0.20	**0.62***	−0.12	**0.91****	0.22	0.09
Heaviness	−0.13	−0.23	−0.09	0.19	**0.74****	**0.81****	**0.75****	**0.89****	0.03	**0.75****	**0.91****
Thickness	−0.14	−0.12	0.15	0.18	**0.74****	**0.81****	**0.75****	**0.88****	0.04	**0.75****	**0.91****

*: $p< 0.05$; **: $p< 0.01$.

weight. Coolness was positively correlated with shear properties (G, 2HG5) and SMD, and negatively with EM. The participants felt cool as fabrics got stiff and rough. And pliability was negatively correlated with 2HG5, SMD and T, and positively with W. So rough and thick fabric was felt more pliable than others. Crispness was positively correlated with LT, 2HG5 and SMD. Therefore stretchy and rough fabric was felt crispier than any other fabrics. Heaviness and Thickness was positively related with W, WC, T and shear properties (G, 2HG, 2HG5). Especially heaviness among touch sensation by FMME showed a positive correlation weight with weight.

Regression Models Predicting Fabric Touch

Fabric touch was predicted from mechanical properties of fabrics by stepwise regression and the equations were shown in Table 4. The goodness of fit for each model was high above 0.82. From the previous study[9], two different equations for each sensation predicted with both FMME and SDS can be compared. Touch sensation by FMME was better predicted than that by SDS showing higher values of R^2. Furthermore, coarseness and crispness, which were not predicted by SDS, were highly predicted by FMME. Their R^2 values were 0.857 and 0.925, respectively. This suggests that psychophysical scaling by FMME could contribute more to establish the relationship between touch sensation as a psychological response and mechanical properties as physical stimuli.

Table 4. Regression equations for fabric touch predicted by the mechanical property measurements

Touch sensation	Regression model	R^2 (R^2 of SDS *)
Hardness	Y = 1.191 + 2.149 * **SMD** + 0.662 * **2HG5**	0.911 (0.897)
Smoothness	Y = 8.826 − 10.287 * **T** + 0.176 * **WC** − 0.854 * **SMD**	0.978 (0.917)
Coarseness	Y = −2.792 + 3.374 * **WC** + 0.118 * **RT**	0.857 (−)
Coolness	Y = 1.270 + 1.313 * **2HG5** + 1.367 * **SMD**	0.930 (0.696)
Pliability	Y = 10.985 2.109 * **SMD** − 6.898 * **T**	0.945 (0.836)
Crispness	Y = 2.388 + 2.766 * **SMD**	0.826 (0.932)
Heaviness	Y = 1.676 + 0.246 * **W** − 0.155 * **WT**	0.925 (−)
Thickness	Y = 1.794 + 0.252 * **W** − 0.164 * **WT**	0.928 (0.552)

*: quoted from reference 9.

Hardness, smoothness, coolness, pliability and crispness could be predicted with SMD, which makes it the most important factor in deciding touch sensation of fabrics. And heaviness and thickness increased with W and decreased with WT. Heaviness and thickness had a positive relationship with weight of fabric and a negative relationship with WT. Comparing the regression models for coolness and thickness, the independent variables in the model by FMME were 2HG5, SMD for coolness and W and WT for thickness, whereas, those by SDS were WC for coolness and EM for thickness. Considering the sensation it was more valid to have the independent variables in the models by FMME than to have them in the models by SDS.

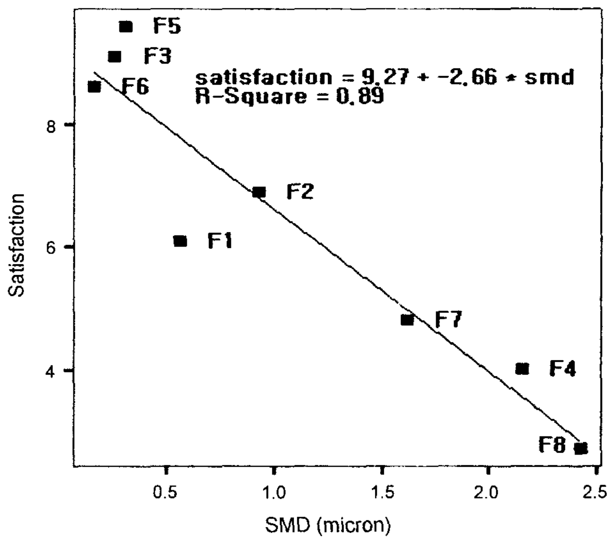

Figure 2. Relationship between subjective satisfaction and SMD.

Satisfaction of Touch Sensation

Subjective satisfaction of fabric touch was predicted form mechanical properties by stepwise regression. It was found that satisfaction was negatively related with SMD (Y = 9.27 − 2.66 * SMD, R^2 = 0.89).

Figure 2 showed the relationship between SMD and subjective satisfaction of fabric touch by FMME. F5 (silk crepe de chine) and F3 (ultrasuede) with low value of SMD were perceived more satisfactory touch. On the contrary, F8 (flax) with the highest value of SMD was felt to be unsatisfactory touch. Therefore satisfaction of fabric touch increased with decreasing surface roughness.

Conclusions

We have investigated the human subjective sensation and satisfaction of apparel fabrics by FMME and have established the equations for predicting them by mechanical properties of fabrics. The fabrics showed significant differences in sensation for fabric touch measured by FMME. In prediction for touch sensation and perceived satisfaction by the physical measurements, they were regressed somewhat accurately showing R^2 above 0.82.

The thick and bulk woolen fabric showing the highest values for WC and weight was evaluated as coarsest, heaviest, and thickest in touch, while a thin and light silk fabric with the lowest LT, G, and 2HG values was rated as being smoother and more pliable in touch than any other fabrics. And Flax with the highest value for LT and SMD, due to its rougher feel, showed a much higher mean for hardness, coolness, and crispness.

As expected, each of fabric touch estimated by FMME was explained significantly by some of mechanical properties of fabrics implying that a subjective sense of touch could be expressed by a variety of properties. Heaviness and thickness was showed the corresponding relation with weight of mechanical properties. Satisfaction and most of the touch such as hardness, smoothness, coolness, pliability, and crispness could be predicted with SMD, which makes SMD an important factor in deciding the most touch sensation of fabrics. The fabrics that were smoother and more pliable seemed to satisfy the participants.

Most of the mechanical properties were found to significantly affect the touch sensation. The FMME could be confirmed as a good subjective estimation method. Therefore, the touch sensation can be designed by changing mechanical properties of fabrics. This type of work may be extended to other complex constructions such as that of a knit as well as fabric to produce a touch database in various textile fabrics. This informative database can be used not only in the manufacturing process but also in marketing to satisfy consumer's emotion by touch sensation.

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