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Sensorial Comfort/Discomfort of Lingerie Based on Hand Assessment and Objective Evaluation

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Abstract: The purpose of this study was to determine the relationship between subjective assessments of overall sensorial comfort and bipolar hand attributes, and to predict subjective values with mechanical, surface and thermal characteristic values of lingerie fabrics. The tactile sensation of test samples was evaluated by consumers using the bipolar word pairs. A strong dependence of overall sensorial comfort on fabric soft/hard, smooth/rough and rigid/drapable was observed. Distribution of mechanical properties for these lingerie fabrics was rather smaller than that of women's thin dress fabrics. Therefore, heat, water, and air transmission properties, and surface characteristics of fabrics were important parameters for the prediction of sensorial comfort of lingerie fabrics.

1. Introduction

Comfort or discomfort is important in the acceptance or rejection of clothing by the consumer. There are various stimuli that cause a person to feel discomfort. Thus, the perception of comfort is a complex phenomenon. The concept of comfort includes thermal comfort and tactile comfort, which may be related to the mechanical property of fabrics, heat, moisture and air transmission through fabrics, and garment construction. Psychological and physiological factors also affect the total assessment of whether clothing is judged comfortable or uncomfortable.

Physiological comfort has been studied in terms of skin and core temperature changes and perspiration rate, in the controlled limited environment [1,2]. Perceived comfort has been also studied extensively by the subjective wearing test [3,4] and related physical measurements. Demartino et al. [5,6] extensively studied the perceived comfort of polyester fabrics from both objective and subjective tests. They concluded that objective tests were useful to predict general comfort trends, but that, they could never be used as a replacement for well planned and well executed subjective wearer trials.

Fairly limited works reported the relationship be-

tween physiological comfort and fabric property. Hoscheke [7] considered two aspects which related to clothing comfort, they were prickliness and warmth. Garnsworthy et al. [8] studied mechanisms in cutaneous sensations of prickle and itch evoked by wool fabrics from the skin comfort point of view. They indicated that the major irritant features of wool fabrics were protruding fiber ends capable of bearing loads of approximately 100 mg or more.

Kawabata [9] developed an objective measurement of fabric hand which evaluates mechanical and tactile comfort. In his research, hand assessments are based on tactile sensations caused by a fabric's mechanical and surface properties.

In this paper, we only focussed on tactile sensation of comfort/discomfort of lingerie fabrics. We assume that the final judgment of tactile comfort is based on the suitability of the mechanical and surface properties for the use in a particular season. In that sense, the objective evaluation of fabric hand [9] can be applied to the evaluation of sensorial comfort of lingerie.

The objective of this work was to determine the relationship between the results of the judgment of tactile tests by using bipolar word pairs most highly correlated with bipolar comfort/discomfort assess-

ment and mechanical, surface and thermal characteristic values of selected lingerie fabrics.

2. Experimental

2.1 Samples

The samples used for this study were thirty six

Table 1 Samples

	Fibers	Structure	Wales		Weight (mg/cm ²)	Thickness (mm)
			(cm ⁻¹)	Course (cm ⁻¹)		
T1	polyester	tricot jersey	26	22	8.83	0.367
T2	polyester	tricot jersey	22	26	9.43	0.364
T3	polyester	tricot jersey	21	25	14.76	0.404
T4	polyester	tricot jersey	21	26	9.13	0.319
T5	polyester	double tricot	20	19	8.95	0.322
T6	polyester	tricot	24	19	8.51	0.693
T7	polyester	tricot crepe	17	28	9.82	0.895
T8	polyester	tricot crepe	18	24	9.64	0.983
T9	polyester	tricot crepe	19	20	12.68	0.948
T10	polyester	tricot satin	16	19	9.39	0.388
T11	polyester	tricot matelasse	36	19	7.89	1.062
T12	polyester	tricot jersey	28	24	8.29	0.339
T13	polyester	tricot jersey	22	30	9.70	0.583
T14	polyester	tricot jersey	25	23	8.34	0.425
T15	polyester	tricot crepe	27	20	11.42	0.517
T16	polyester	plain knit	33	27	9.51	0.324
T17	polyester	plain knit	22	18	14.79	0.703
T18	polyester	plain knit	41	25	12.81	0.487
T19	polyester	plain knit	21	24	9.71	0.339
T20	polyester	plain knit	22	24	11.36	0.396
T21	polyester	plain knit	49	22	11.33	0.319
T22	polyester	plain knit	49	31	10.36	0.304
T23	polyester	plain knit	38	27	11.64	0.485
T24	polyester	plain knit	13	11	10.19	0.725
T25	silk	plain knit	25	19	5.66	0.260
T26	acetate 70/ nylon 30	plain knit	41	24	11.10	0.441
T27	polyester 70/ cotton 30	plain knit	25	14	8.98	0.595
T28	cupra	tricot jersey	25	20	10.14	0.351
T29	nylon	tricot jersey	46	23	8.73	0.302
T30	silk	plain knit	16	19	7.74	0.321
T31	cotton	plain knit	15	27	13.28	0.792
T32	polyester 34/ cotton 66	plain knit	11	13	14.03	1.537
			Ends (cm ⁻¹)	Picks (cm ⁻¹)		
T33	polyester	satin woven	42	42	10.08	0.270
T34	polyester	satin woven	130	47	9.79	0.293
T35	silk	satin woven	96	52	8.73	0.264
T36	cotton	lawn woven	40	33	7.00	0.423

Fig. 1 Comparison of the mean ($\bullet$) and standard deviation ($\cdots$) for the 36 lingerie fabrics and women's thin dress fabrics.

commercially produced lingerie fabrics; 26 polyester, 1 nylon, 1 cupra, 3 silk, 2 cotton, 2 cotton/polyester blended fabrics, and 1 acetate/nylon blend. The knitted structure for lingerie is commercially popular, thus thirty-two of the fabrics were knitted and only four fabrics having different fiber type were woven. Details of samples are shown in Table 1.

The Hand Evaluation and Standardization Committee (HESC) in Japan has developed a system of standardization for women's thin dress and underwear fabrics [9,10]. Mechanical and surface properties for fabrics were measured using a KES-F system [9] at 20°C, 65% RH and characteristic values of tensile, bending, shear, compression and surface properties were calculated (see APPENDIX A). In Fig. 1, the mean of 36 samples for the mechanical and surface properties are plotted in the data chart [9] for the women's thin dress woven fabrics (mean weight: 9.17 mg/cm²; standard deviation: 1.50 mg/cm²). Mean ($\bar{x}$) and standard deviation (σ) in the chart are obtained

from 120 commercially produced fabrics in Japan. The broken line indicates the standard deviation for each of the mechanical and surface properties for lingerie fabrics used in this study. It is seen that the mechanical properties of lingerie fabrics are in the same range as those of women's thin dress fabrics with the exception of tensile and bending properties. The difference in tensile and bending properties arises because the lingerie fabrics are mainly knitted.

2.2 Hand Assessment

The survey was conducted in two seasons. The first survey was carried out in the summer from June to August 1989 with 76 women participants and the second survey in the winter from November to December 1989 with 86 women participants who were a different group of people from the previous survey. Three of the fabrics (silk; T30, cotton; T31, polyester/cotton blend; T32) were used only for the winter survey. The subjects were in the 18-30 age range, and included University students aged 18 to 23 making up 61% of all subjects.

Assessments were carried out in the laboratory. Temperature and RH in the room was 25 ± 1.6°C, 62 ± 4.7% RH in the summer and 20 ± 2.4°C, 45 ± 4.4% RH in the winter time.

The semantic differential grid was made according to the following procedure. We first used 15 pairs of adjectives to assess the tactile characteristics of underslip fabrics [11] (viz. soft-hard, smooth-rough, cool-hot, light-heavy, fine-coarse, crisp-limp, clammy-absorbent, natural-synthetic, sheer-bulky, clingy-flowing, crushable-resilient, lacy-plain, drapable-rigid, scratchy-silky, stiff-soft). A preliminary experiment was carried out to present the grids to 28 female students. We selected 10 bipolar descriptors out of 15 which were understood most commonly by the students. We also added such two more (thin-thick, discomfort-comfort) for the following reasons. Fabric thickness is the important fundamental characteristic which can be easily judged by hand. "Comfort-Discomfort" is the overall judgment of a fabric. The twelve bipolar descriptors were again presented to a different group of students. When a subject could not understand the meaning of descriptor, we explained the meaning. For example, "lacy" means a fancy, irregular or puckered surface fabric and "plain"

indicates a fabric with little or no embellishments. "Clingy" means that a fabric clings to the body by electrostatic energy or fabric softness and the opposite meaning represents a fabric which flows or is away from the body. This property is also important to consider the wearing comfort of lingerie. Some words were changed to be more easily understandable. The final 12 bipolar fabric descriptors were soft-hard, smooth-rough, cool-warm, light-heavy, clammy-absorbent, natural-synthetic, thin-thick, clingy-flowing, crushable-resilient, lacy-plain, drapable-rigid and discomfort-comfort.

Subjects were given printed copies of the semantic differential grid as shown in Fig. 2. We then asked them to evaluate test samples (25 cm × 25 cm) by hands and also put a cross (×) on the position of each scale that best described the attributes as a lingerie used in the summer when the survey was carried out in summer. It is essential that the subject has a clear idea of the purpose and season for which the fabric is intended. Firstly, they were allowed to handle all fabric samples before evaluating each sample individually. Fabrics were presented in random order for judging to forestall time error [12] and to prevent judgment fatigue error. They were not told the fiber type and asked to ignore the effect of the fabric color. Actually, the color for 80% of the samples were white, light salmon pink or pale yellow.

2.3 Heat and Moisture Transmission Measurement

Heat and moisture transmission and the transient heat flow were investigated using a KES themolabo II [13]. Heat loss was measured for four cases as follows. 1) a specimen is placed on the hot plate and the rate of heat loss of the hot plate measured (Q_{DC}). 2) A wet paper is placed on the hot plate and the fabric specimen is placed on top of this, then the rate of heat loss of the hot plate Q_{WC} is measured. 3) a 5 mm space is maintained between the specimen and the plate and the rate of heat loss (Q_{DS}) is measured. 4) the wet paper is placed on the hot plate. A space between the specimen and the wet paper is maintained then the ratio of heat loss (Q_{WS}) is measured. Effective thermal conductivity of a fabric λ , and heat conductance K' are also measured. These values are considered to be important to predict the wearing comfort and may be reflected in the evaluation of clammy

feeling. A measure of the warmth or coolness of a fabric surface was obtained by using the finger robot [14] and the characteristic value C which represents the transient heat flow was calculated (see APPENDIX B). Measuring condition for these parameters are listed in APPENDIX B.

2.4 Data Analysis

2.4.1 Subjective Values

We numbered from one to seven on each bipolar scale from left to right and counted extremely soft as one on the left and extremely hard as seven on the right. For each fabric sample, mean and standard deviation values of all judgments were calculated.

2.4.2 Stepwise Block Regression Analysis

In order to investigate the relative influence of objective properties on the subjective values, the stepwise block regression analysis was used. This technique has been developed and successfully used to translate mechanical data into hand values [9].

The parameters were grouped in the following seven blocks; 1) tensile, 2) shear, 3) bending, 4) compression, 5) surface, 6) mass per unit area, thickness and 7) heat, water and air transmission properties.

The average of each subjective value, Y_s (for example softness, smoothness etc.) and the 16 mechanical data and heat, moisture and air transmission data X_i ($i = 1 \cdots 24$) were correlated to give the linear equation as follows:

$$Y_s = C_0 + \sum_{i=1}^{24} C_i X_i \quad (1)$$

where C_0 and C_i are constants and X_i is the deviation of the mechanical parameter from the population mean, normalized by the standard deviation, namely:

$$X_i = \frac{x_i - M_i}{\sigma} \quad (2)$$

where x_i = values of the parameter,

M_i = mean value of x_i for the population of 36 fabrics and

σ = standard deviation of x_i

Mean and standard deviation of mechanical and surface parameters are listed in Table 2. Some values were converted to the logarithmic values in order to obtain the symmetric distribution against the population mean.

Constants C_i in equation (1) represents the contribution of parameters X_i to subjective value Y_s .

The prediction of overall comfort by mechanical, surface and thermal parameters was carried out using the technique developed for the objective total hand value [9]. The regression equation to obtain the value of overall comfort Y_c consists of linear and squared terms of mechanical, surface and thermal variables.

Table 2 Mean, M_i and Standard Deviation σ_i of Mechanical, Surface, Heat and Air Transmission Properties

	Summer (n=33)		Winter (n=36)	
	M_i	σ_i	M_i	σ_i
Tensile				
LT	0.633	0.0901	0.640	0.0901
log WT	0.107	0.2896	0.152	0.3190
RT	51.511	8.3728	50.547	8.7080
Shear				
log G	-0.179	0.2587	-0.194	0.2527
log 2HG	0.155	0.3099	0.153	0.2974
log 2HG3	0.155	0.3099	0.153	0.2974
Bending				
log B	-2.117	0.2501	-2.115	0.2524
log 2HB	-2.253	0.2434	-2.239	0.2641
Surface				
MIU	0.211	0.0352	0.212	0.0358
log MMD	-1.569	0.1609	-1.571	0.1565
log SMD	0.512	0.3018	0.547	0.3131
Compression				
LC	0.690	0.0889	0.684	0.0902
log WC	-1.676	0.3648	-1.651	0.3849
RC	41.455	3.7438	41.556	4.7020
log T	-0.354	0.1720	-0.336	0.1929
Weight				
log W	0.991	0.0825	0.996	0.0876
Heat transmission				
Q_{DC}	10.23	0.6196	10.14	0.6905
Q_{WC}	40.91	0.2031	40.52	2.4676
Q_{DS}	5.845	0.1281	5.839	0.1496
Q_{WS}	19.97	0.4421	19.944	0.4884
$\lambda (\times 10^{-2})$	4.43	0.496	4.46	0.544
K'	123.2	38.02	119.9	38.927
log C	-1.522	0.0808	-1.529	0.0805
Air transmission				
log R	-1.522	0.3362	-1.521	0.3261

Description and unit of a parameter is explained in APPENDIX A.

The contribution of these variables to Y_c was also obtained.

3. Results and Discussion

3.1 Hand Assessment

Table 3 shows the Pearson correlation coefficients of the 12 bipolar descriptors. A strong dependence of overall comfort on fabric soft/hard, smooth/rough and rigid/drapable is observed for both the summer and winter surveys. These three descriptors were also highly correlated with each other. Low negative correlations found between clammy/absorbent, clingy/flowing, crushable/resilient, natural/synthetic, lacy/plain and overall comfort. Pearson correlation coefficients between natural/synthetic and crushable/resilient are 0.809 for the summer and 0.723 for the winter. It seems that consumers thought that fabrics made from synthetic fibers were more resilient than those from natural fibers. It was also seen that the correlation coefficient between natural/synthetic and clingy/flowing are -0.847 for summer and -0.843 for winter. This result may reflect consumer's understanding that synthetic fiber produces more electrostatic property than natural fiber during wearing.

It has been reported that the overall comfort of the lining used for ladies' garments is mostly related to thermal properties [15]. In this trial, the correlation coefficients between cool/warm and comfort/discomfort were -0.762 for summer and -0.622 for winter.

Low Pearson correlation coefficients were obtained between overall sensorial comfort rating and some descriptors which related to the wearing performance viz. clammy/absorbent, clingy/flowing, crushable/resilient. These results showed the limitation of hand assessment to evaluate overall comfort and these properties can be evaluated only by the actual wearing test.

Principal factor analysis was applied to understand the common concept of sensorial overall comfort for subjects based on the hand assessment. The rotation varimax method was then applied to the four factors those eigenvalues were more than 1.0. The results are shown in Table 4-a for the summer and Table 4-b for the winter survey. In the summer survey, the first factor was mainly concerned with the mechanical and surface properties. The second factor was related to

Table 3 The Correlation Coefficients of the 12 Bipolar Descriptors

ITEM		1	2	3	4	5	6	7	8	9	10	11	12
		Soft	Smooth	Cool	Light	Clammy	Natural	Thin	Clingy	Crushable	Lacy	Drapable	Discomfort
		Hard	Rough	Warm	Heavy	Absorbent	Synthetic	Thick	Flowing	Resilient	Plain	Rigid	Comfort
ITEM 1S	1S	1.000	.935	.621	.664	.547	-.635	.510	.727	-.683	.433	.910	-.772
	W	1.000	.927	.430	.418	.438	-.455	.217	.706	-.679	.430	.832	-.883
ITEM 2S	2S		1.000	.668	.598	.599	-.599	.413	.785	-.544	.425	.880	-.762
	W		1.000	.519	.357	.499	-.420	.170	.667	-.526	.389	.783	-.916
ITEM 3S	3S			1.000	.691	.353	-.474	.566	.613	-.410	.406	.766	-.762
	W			1.000	.629	.590	-.690	.553	.662	-.381	.515	.795	-.622
ITEM 4S	4S				1.000	.034	-.137	.945	.325	-.311	.217	.622	-.828
	W				1.000	.049	-.281	.948	.410	-.158	.260	.628	-.585
ITEM 5S	5S					1.000	-.826	-.190	.895	-.523	.582	.656	-.171
	W					1.000	-.874	-.092	.809	-.636	.689	.609	-.390
ITEM 6S	6S						1.000	.059	-.847	.809	-.689	-.749	.268
	W						1.000	-.145	-.843	.723	-.802	-.719	.398
ITEM 7S	7S							1.000	.104	-.162	.017	.432	-.742
	W							1.000	.248	.027	.113	.459	-.431
ITEM 8S	8S								1.000	-.606	.611	.834	-.438
	W								1.000	-.728	.656	.818	-.671
ITEM 9S	9S									1.000	-.594	-.763	.414
	W									1.000	-.687	-.733	.490
ITEM 10S	10S										1.000	.586	-.177
	W										1.000	.611	-.331
ITEM 11S	11S											1.000	-.782
	W											1.000	-.855
ITEM 12S	12S												1.000
	W												1.000

S: summer W: winter

the fabric thickness and weight. The third factor included such items as natural/synthetic, crushable/resilient and lacy/plain. In the winter survey, the first factor includes natural/synthetic, clammy/absorbent, clingy/flowing, crushable/resilient, lacy/plain which were mainly concerned with the performance during wearing. The second factor was related to mechanical properties and the third factor was thickness and weight.

For the evaluation of sensorial overall comfort, our hypothesis was that comfort might be evaluated from two groups of properties. One related to the fabric mechanical, surface and thermal properties which could be detected directly by hands. Others such as

clingy, absorbent, crushable properties were considered to be related to wearing performance. Both properties can be predicted from the mechanical, surface and thermal properties obtained from hands and also from the subject's experience. The results obtained by the winter survey seemed to agree to our hypothesis. However, it was seen in the summer survey that some descriptors related to the wearing performance (clammy/absorbent, clingy/flowing) were included with fabric mechanical and surface properties in the first factor. This results showed some interaction between these two group of properties.

The three fabrics that scored highest (T20, T21, T33) and the lowest (T12, T14, T31) in overall com-

Table 4-a Rotated Factor Pattern (Summer)

	Factor 1	Factor 2	Factor 3
1 Soft-Hard	0.70 *	0.56	0.32
2 Smooth-Rough	0.81 *	0.47	0.21
3 Cool-Warm	0.40	0.63 *	0.30
4 Light-Heavy	0.17	0.95 *	0.10
5 Clammy-Absorbent	0.75 *	-0.20	0.51
6 Natural-Synthetic	-0.57	0.02	-0.77 *
7 Thin-Thick	-0.01	0.96 *	-0.06
8 Clingy-Flowing	0.79 *	0.11	0.51
9 Crushable-Resilient	-0.33	-0.25	-0.78 *
10 Lacy-Plain	0.23	0.07	-0.77 *
11 Drapable-Rigid	0.66 *	0.51	0.51
Eigenvalue	3.441	3.130	2.846
Contribution ratio (%)	60.9	22.4	8.0

Final communality estimates: Total = 9.417

Note: Items that define factors are flagged by an "*".

Table 4-b Rotated Factor Pattern (Winter)

	Factor 1	Factor 2	Factor 3
1 Soft-Hard	0.29	0.92 *	0.18
2 Smooth-Rough	0.25	0.92 *	0.13
3 Cool-Warm	0.57	0.25	0.57
4 Light-Heavy	0.11	0.23	0.95 *
5 Clammy-Absorbent	0.87 *	0.26	-0.11
6 Natural-Synthetic	-0.95 *	-0.17	-0.15
7 Thin-Thick	-0.01	0.05	0.97 *
8 Clingy-Flowing	0.75 *	0.49	0.22
9 Crushable-Resilient	-0.71 *	-0.48	0.02
10 Lacy-Plain	0.80 *	0.17	0.12
11 Drapable-Rigid	0.58	0.64 *	0.46
Eigenvalue	4.177	2.822	2.522
Contribution ratio (%)	61.4	18.4	11.6

Final communality estimates: Total = 9.521

Note: Items that define factors are flagged by an "*".

fort were in both the summer and winter surveys and were selected for further analysis. Average values of 12 bipolar attributes for each of the six fabrics are plotted in Fig. 2. Effective differences between most comfortable and least comfortable fabrics occurs for bipolar descriptors soft/hard, smooth/rough, light/heavy, thin/thick and drapable/rigid. It has been found that consumers regarded very soft and smooth, relatively light weight more resilient and much more drapable fabrics as more comfortable for lingerie.

Fig. 2 Subjective ratings for the fabrics having the three highest scores (●) and the lowest (△) in overall comfort.

3.2 The Relationship between Subjective Judgment and Mechanical, Surface and Thermal Properties

The multiple correlation coefficients R_c from the stepwise block regression analysis for eleven items are shown in Table 5-a and Table 5-b. The accuracy of the prediction increases with an increasing number of blocks but the accuracy almost saturates after three or four steps. The compression property (LC, WC, RC) enters as the first block in the regression equation for the following items of both summer and winter surveys: smooth/rough, clammy/absorbent, natural/synthetic, clingy/flowing, crushable/resilient, lacy/plain, drapable/rigid. The water, heat, air transmission properties and the surface characteristics represent the important parameter for the prediction of soft/hard feeling in the summer survey.

Constants C_i in equation (1) represent the contribution of parameters X_i to subjective value Y_s . Constants C_i , and the multiple correlation coefficients, R_c for items which were highly correlated with overall comfort are shown in Table 6-a and 6-b. In these Tables, positive values indicate that each parameter contributes to the quality becoming more hard, rough, warm or rigid. The most contributed parameter in compression to such items as viz. smooth/rough and drapable/rigid was found to be WC (energy in compressing fabric) in this Table. For soft/hard feeling in the summer survey, the increase of Q_{wc} , K' , C , and the

Table 5-a Multiple Correlation Coefficients R_c from the Stepwise Block Regression Analysis for the Summer Survey

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Item 1	Q_{WC}, K', C, R 0.69	MIU, MMD, SMD 0.76	LT, WT, RT 0.80	LC, WC, RC 0.85	G, 2HG 0.86	T, W 0.87	B, 2HB 0.87
Item 2	LC, WC, RC 0.76	LT, WT, RT 0.80	Q_{WC}, K', C, R 0.83	MIU, MMD, SMD 0.84	G, 2HG 0.84	T, W 0.85	B, 2HB 0.85
Item 3	Q_{WC}, K', C, R 0.85	LC, WC, RC 0.90	B, 2HB 0.91	LT, WT, RT 0.91	MIU, MMD, SMD 0.91	G, 2HG 0.91	T, W 0.91
Item 4	Q_{WC}, K', C, R 0.75	LT, WT, RT 0.81	T, W 0.85	LC, WC, RC 0.86	MIU, MMD, SMD 0.88	G, 2HG 0.89	B, 2HB 0.89
Item 5	LC, WC, RC 0.75	MIU, MMD, SMD 0.82	LT, WT, RT 0.84	Q_{WC}, K', C, R 0.86	B, 2HB 0.87	T, W 0.88	G, 2HG 0.88
Item 6	LC, WC, RC 0.71	MIU, MMD, SMD 0.83	Q_{WC}, K', C, R 0.85	LT, WT, RT 0.86	T, W 0.87	G, 2HG 0.88	B, 2HB 0.89
Item 7	Q_{WC}, K', C, R 0.74	MIU, MMD, SMD 0.81	LC, WC, RC 0.84	G, 2HG 0.86	B, 2HB 0.87	T, W 0.88	LT, WT, RT 0.88
Item 8	LC, WC, RC 0.84	LT, WT, RT 0.89	MIU, MMD, SMD 0.90	Q_{WC}, K', C, R 0.91	T, W 0.91	B, 2HB 0.92	G, 2HG 0.92
Item 9	LC, WC, RC 0.55	LT, WT, RT 0.74	B, 2HB 0.83	Q_{WC}, K', C, R 0.85	LT, WT, RT 0.86	T, W 0.87	G, 2HG 0.87
Item 10	LC, WC, RC 0.55	MIU, MMD, SMD 0.74	T, W 0.79	Q_{WC}, K', C, R 0.81	LT, WT, RT 0.82	B, 2HB 0.82	G, 2HG 0.82
Item 11	LC, WC, RC 0.82	LT, WT, RT 0.88	Q_{WC}, K', C, R 0.89	MIU, MMD, SMD 0.92	G, 2HG 0.93	B, 2HB 0.93	T, W 0.93

Table 5-b Multiple Correlation Coefficients R_c from the Stepwise Block Regression Analysis for the Winter Survey

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Item 1	LC, WC, RC 0.60	LT, WT, RT 0.73	MIU, MMD, SMD 0.78	G, 2HG 0.80	Q_{WC}, K', C, R 0.81	T, W 0.81	B, 2HB 0.81
Item 2	LC, WC, RC 0.67	LT, WT, RT 0.73	MIU, MMD, SMD 0.83	Q_{WC}, K', C, R 0.78	B, 2HB 0.79	G, 2HG 0.79	T, W 0.79
Item 3	Q_{WC}, K', C, R 0.91	B, 2HB 0.93	MIU, MMD, SMD 0.94	LC, WC, RC 0.95	G, 2HG 0.95	LT, WT, RT 0.95	T, W 0.95
Item 4	Q_{WC}, K', C, R 0.74	T, W 0.80	LT, WT, RT 0.84	B, 2HB 0.86	G, 2HG 0.88	MIU, MMD, SMD 0.88	LC, WC, RC 0.88
Item 5	LC, WC, RC 0.76	B, 2HB 0.81	Q_{WC}, K', C, R 0.82	MIU, MMD, SMD 0.83	LT, WT, RT 0.83	G, 2HG 0.83	T, W 0.83
Item 6	LC, WC, RC 0.77	Q_{WC}, K', C, R 0.83	MIU, MMD, SMD 0.86	LT, WT, RT 0.86	T, W 0.87	B, 2HB 0.87	G, 2HG 0.87
Item 7	Q_{WC}, K', C, R 0.72	MIU, MMD, SMD 0.79	T, W 0.81	B, 2HB 0.83	G, 2HG 0.84	LT, WT, RT 0.84	LC, WC, RC 0.84
Item 8	LC, WC, RC 0.80	LT, WT, RT 0.85	MIU, MMD, SMD 0.86	Q_{WC}, K', C, R 0.87	T, W 0.87	B, 2HB 0.87	G, 2HG 0.87
Item 9	LC, WC, RC 0.60	MIU, MMD, SMD 0.78	LT, WT, RT 0.81	Q_{WC}, K', C, R 0.82	T, W 0.83	G, 2HG 0.83	B, 2HB 0.83
Item 10	LC, WC, RC 0.60	MIU, MMD, SMD 0.77	T, W 0.83	LT, WT, RT 0.84	Q_{WC}, K', C, R 0.85	B, 2HB 0.85	G, 2HG 0.85
Item 11	LC, WC, RC 0.82	LT, WT, RT 0.87	Q_{WC}, K', C, R 0.89	MIU, MMD, SMD 0.91	G, 2HG 0.92	B, 2HB 0.93	T, W 0.93

Table 6-a Constants, C_i and the Multiple Correlation, R_c To Explain the Soft/Hard and Smooth/Rough Feeling

Step	Summer		Winter	
	C_i	R_c	C_i	R_c
<i>SOFT-HARD</i>		$C_o=3.367$	$C_o=3.387$	
1	Q_{wc}	-0.269	LC	-0.449
	K'	-0.220	log WC	0.240
	log C	-0.414	RC	-0.035
	log R	0.538		
		(RMS=0.777)		(RMS=0.863)
2	MIU	-0.354	LT	0.248
	log MMD	0.150	log WT	-0.354
	log SMD	0.243	RT	0.249
		(RMS=0.699)		(RMS=0.752)
3	LT	0.081	MIU	-0.086
	log WT	-0.209	log MMD	0.097
	RT	0.160	log SMD	0.278
		(RMS=0.660)		(RMS=0.692)
<i>SMOOTH-ROUGH</i>		$C_o=3.4993$	$C_o=3.5847$	
1	LC	-0.195	LC	-0.272
	log WC	0.629	log WC	0.505
	RC	-0.139	RC	0.015
		(RMS=0.671)		(RMS=0.811)
2	LT	0.147	LT	0.186
	log WT	-0.144	log WT	-0.109
	RT	0.204	RT	0.252
		(RMS=0.621)		(RMS=0.750)
3	Q_{wc}	-0.108	MIU	-0.026
	K'	-0.182	log MMD	0.083
	log C	0.014	log SMD	0.247
	log R	0.118		
		(RMS=0.580)		(RMS=0.698)

RMS: root mean square of regression error.

Table 6-b Constants, C_i and the Multiple Correlation Coefficients, R_c To Explain the Cool/Warm and Drapable/Rigid Feeling

Step	Summer		Winter	
	C_i	R_c	C_i	R_c
<i>COOL-WARM</i>		$C_o=4.2342$	$C_o=4.1455$	
1	Q_{wc}	-0.220	Q_{wc}	-0.306
	K'	-0.168	K'	-0.171
	log C	-0.166	log C	-0.202
	log R	0.146	log R	0.063
		(RMS=0.278)		(RMS=0.263)
2	LC	-0.222	log B	0.116
	log WC	-0.121	log 2HB	-0.004
	RC	0.009		
		(RMS=0.231)		(RMS=0.237)
3	log B	-0.038	MIU	-0.096
	log 2HB	0.081	log MMD	0.037
		(RMS=0.223)	log SMD	0.096
				(RMS=0.210)
<i>DRAPABLE-RIGID</i>		$C_o=3.7395$	$C_o=3.8565$	
1	LC	-0.196	LC	-0.286
	log WC	0.593	log WC	0.574
	RC	-0.161	RC	-0.044
		(RMS=0.529)		(RMS=0.567)
2	LT	0.158	LT	0.199
	log WT	-0.295	log WT	-0.287
	RT	0.054	RT	0.021
		(RMS=0.453)		(RMS=0.50)
3	Q_{wc}	-0.130	Q_{wc}	-0.162
	K'	-0.031	K'	0.055
	log C	-0.071	log C	-0.115
	log R	0.104	log R	0.090
		(RMS=0.408)		(RMS=0.457)

RMS: root mean square of regression error.

Table 7 The Prediction of Sensorial Comfort

Step	Summer			Winter		
	parameter	R_c	RMS	parameter	R_c	RMS
1	Q_{wc}, K', C, R	0.75	0.354	Q_{wc}, K', C, R	0.78	0.363
2	MIU, MMD, SMD	0.84	0.290	MIU, MMD, SMD	0.84	0.313
3	LT, WT, RT	0.88	0.261	G, 2HG	0.89	0.271
4	LC, WC, RC	0.90	0.236	LC, WC, RC	0.90	0.250
5	G, 2HG	0.91	0.220	LT, WT, RT	0.91	0.236
6	B, 2HB	0.92	0.214	T, W	0.93	0.219
7	T, W	0.92	0.207	B, 2HB	0.93	0.211

Fig. 3-a The contribution of heat, water and air transmission and surface characteristics to the comfort of lingerie fabrics for summer survey. **Fig. 3-b** The contribution of heat, water and air transmission and surface characteristics to the comfort of lingerie fabrics for winter survey.

decrease of R_c produced the increase of soft feeling.

Predicted sensorial comfort results are shown in Table 7. It was found that heat, water and air transmission characteristics and the surface characteristics represent the two most important properties for the prediction of overall fabric sensorial comfort. The contribution values, Z , are calculated by and plotted against X_i for each water, air and thermal parameters in Fig. 3-a and also surface parameters in Fig. 3-b. It

can be seen in Fig. 3-a that the smaller values of air resistance R represent a more comfortable feeling. This trend is easily observed in the summer survey results. The larger values of C , which means these fabrics felt cooler, represents a more comfortable feeling. For the winter results, values of Q_{wc} , K' show the optimum values to give a more comfortable feeling. We are not confident to say that properties such as Q_{wc} , R can be evaluated by hands only. It might be

considered that fabrics selected as more comfortable have higher values of heat conductance K' , C and lower value of R than less comfortable fabrics. In Fig. 3-b, the smaller values of MMD give more comfort for both the summer and winter judgments. It is noted that the values of MIU represent the optimum range to contribute to the more comfortable feeling.

5. Conclusion

Sensorial overall comfort of lingerie fabrics was investigated on the basis of hand assessment by consumers. Hand assessment revealed that consumers regarded fabrics, which were very soft and smooth, relatively light weight, more resilient and more drapable as more sensorially comfortable for lingerie than those that are judged hard, rough, heavy, crushable and rigid. Items which were highly correlated with sensorial overall comfort rating were soft/hard, smooth/rough, cool/warm and drapable/rigid. These characteristics were interpreted in terms of mechanical properties and heat and water transmission properties. Compression properties (LC, WC, RC) enters as the first block for the prediction of smooth/rough and drapable/rigid and the compression characteristic, WC, is one of the most important parameters.

Results of the stepwise regression analysis for the comfort/discomfort of fabrics, indicates that heat, water, air transmission properties and also surface characteristics of fabrics are important parameters for the prediction of fabric comfort/discomfort.

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APPENDIX A: Characteristic Values of Basic Mechanical Properties (13)

Parameter symbol	Description	Unit
Tensile		
EM	Fabric extension at 5 N/cm width	%

LT	Linearity of load extension curve	—
WT	Energy in extending fabric to 5 N/cm width	J/m ²
RT	Tensile resilience	%
Shear		
G	Shear rigidity	N/m
2HG	Hysteresis of shear force at 8.7 mrad	N/m
2HG3	Hysteresis of shear force at 52.2 mrad	N/m
Bending		
B	Bending rigidity	μNm
2HB	Hysteresis of bending moment	mN
Surface		
MIU	Coefficient of friction	—
MMD	Mean deviation of MIU	—
SMD	Geometrical roughness	μm
Compression		
LC	Linearity of compression-thickness curve	—
WC	Energy in compressing fabric under 5 kPa	J/m ²
RC	Compressional resilience	%
T	Fabric thickness at 50 Pa pressure	mm
Weight	Mass per unit area	mg/m ²

APPENDIX B: Measurement Conditions of Heat, Water and Air Transport Properties

Heat transport		Unit
QD _c	20 °C, 65% RH	W/(m ² K)
QD _s	Air velocity: 0.3 m/s	W/(m ² K)
Q _{wc}	Temperature difference, 10 °C	W/(m ² K)
Q _{ws}		W/(m ² K)
λ	contact pressure: 490 Pa	W/(m ² K)
K'		W/(m ² K)
C	C = U _{tm} /U _r	
	U _{tm} : peak value of the rate of the temperature change at the receptor	°C/s
	Temperature difference, U _r = 10 °C	s ⁻¹
	contact pressure , 1.47 kPa	
	contact speed , 1 cm/s	
Air transport		
R	Differential pressure method under a constant rate of 0.04 m/s.	kPa.s/m