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Effect of Fabric Sound and Touch on Human Subjective Sensation

Gilsoo Cho*, John G. Casali[1], and Eunjou Yi

Department of Clothing and Textiles, Yonsei University, Seoul 120-749, Korea
[1]*Department of Industrial and Systems Engineering, Virginia Tech, Blacksburg, VA*
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Abstract: In order to investigate the relationship between subjective sensation for fabric sound and touch and the objective measurements, eight different apparel fabrics were selected as specimens. Sound parameters of fabrics including level pressure of total sound (LPT), level range (ΔL), and frequency differences (Δf) and mechanical properties by Kawabata Evaluation System (KES) were obtained. For subjective evaluation, seven aspects of the sound (softness, loudness, pleasantness, sharpness, clearness, roughness, and highness) and eight of the touch (hardness, smoothness, fineness, coolness, pliability, crispness, heaviness, and thickness) were rated using semantic differential scale. Polyester ultrasuede was evaluated to sound softer and more pleasant while polyester taffeta to sound louder and rougher than any other fabrics. Wool fabrics such as worsted and woolen showed similar sensation for sound but differed in some touch sensation in that woolen was coarsest, heaviest, and thickest in touch. In the prediction model for sound sensation, LPT affected positively subjective roughness and highness as well as loudness, while ΔL was found as a parameter related positively with softness and pleasantness. Touch sensation was explained by some of mechanical properties such as surface, compressional, shear, and bending properties implying that a touch sensation could be expressed by a variety of properties.

Keywords: Fabric sound, Touch, Subjective sensation, Semantic differential scale, Prediction model

Introduction

The evaluation of fabric hand, quality, and related fabric performance attributes, in terms of objectively measurable properties, has been an important issue during the last decade in the field of textile and apparel industry. It is called Fabric Objective Measurement (FOM). The principal aim of FOM is to identify and assess quantitatively the properties that contribute to the perception of fabric and garment quality in specific end-uses[1].

Although the meaning of FOM is widely understood, this is a potentially misleading abbreviation, especially for those unfamiliar with developments in this area of textile evaluation and specification. The instrumental measurement of selected fabric mechanical and surface properties is only one of the means that is essential to the approach. The successful application of FOM depends as much on establishing reliable methods for quantifying subjective judgments, and on establishing equations that accurately predict such judgments from the chosen objective measurements.

Over the years, the reliability and fitness for purpose of fabrics and garments have been progressively improved. This is undoubtedly due to, in part, the gradual introduction and continual refinement of nationally and internationally recognized performance standards and test methods, as well as to the enactment of legislation designed to protect consumers against the sale of shoddy goods.

It is perhaps surprising that these improvements in the reliability of textile and clothing products have been made in the absence of any framework of subjective or objective criteria relating to the hand of fabrics. It is more surprising since hand is the most fundamental attribute that determines whether or not a particular fabric is suitable for a given end-use, and that it therefore follows that fabric hand often determines the commercial success of textile manufacturing process and products.

The term 'fabric hand' can be defined as the summation of the weighted contributions of stimuli evoked by fabric on the major sensory centers[1]. Fabric sensory properties such as tactility, drape, luster, hairiness, prickle, and odor have been discussed in some publications. A previous study[2] in that mechanical properties in Kawabata Evaluation System were investigated to describe subjective response of fabric texture reported that compressional energy and surface roughness were the most important predictors. It seems that the evaluation of fabric noise could also become a useful addition to the FOM system at some stage. There rarely, however, is to be publications in the sense of hearing in the present FOM context. Only some studies have been found dealt with objective measurement of fabric sound. The waveform patterns of rustling sounds of silk-like polyester and natural silk were compared to imitate silk-scrooping[3]. In other previous works[4,5], it was attempted to quantify physical parameters of fabric sound and relate them with mechanical measurements of fabrics. Actually, the sound parameters such as LPT, ΔL, Δf, and AR coefficients were revealed to be concerned with some mechanical characteristics such as tensile and shear properties. In addition, sound parameters including psychoacoustic characteristics were discussed according to fiber groups and their relationship was analyzed[6]. Based on those results, now, it should be

*Corresponding author: gscho@yonsei.ac.kr

studied how the objective measurements of fabrics affect human subjective sensation for sound to identify quantitatively the physical properties determining the sound sensation of fabrics. In addition, touch sensation of fabrics also needs to be assessed and compared with aural perception for overall consumer satisfaction.

The purpose of this study is to investigate sound and touch sensation of fabrics using a scaling method and to determine the effects of quantified physical sound parameters and mechanical measurements of fabrics on both sensation by establishing prediction models for providing information concerning human subjects' sensation and satisfaction for fabric sounds and touch. It is expected that the results will be utilized as a source to develop textile fabrics that are designed to satisfy consumers in terms of auditory and tactile comfort.

Experimental

Specimens

Eight different apparel fabrics commercially available were used as test specimen. The characteristics of the test specimens were summarized in Table 1.

Sound Recording and FFT Analysis

The sound generator introduced in a previous work[4] was used to generate fabric sounds for the study. Sound was recorded in an anechoic chamber of which loudness of background noise and cutoff frequency were below 10 dB and 63 Hz respectively. A powerful microphone (Type 4145, B & K) was used to pick up the fabric sounds. The sounds were recorded using a DAT data recorder (TEAC Model RD-145T). Recorded sounds were transformed into spectral curves in terms of amplitude and frequency by FFT analyzer (model 35670A, HP).

Objective Measurements

Sound Parameters

To quantify the fabric sound, three parameters were calculated from the spectral curves. Broadband levels over bandwidth 16-20,000 Hz (LPT) were calculated using the equation as follows;

$$LPT(dB) = 10\log 10^{\frac{BL_1}{10} + \cdots + \frac{BL_n}{10}} \quad (1)$$

where, BL: Broadband Level

Level range over broadband level (ΔL) was obtained from $dB_{max} - dB_{min}$. Frequency difference (Δf) was obtained from $f_{max} - f_{min}$.

Mechanical Properties

Mechanical properties of 8 fabrics were measured by using the Kawabata Evaluation System (KES) – FB[7] under the standard condition. The properties included tensile, bending, shearing, compression, surface properties, 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. A total of 30 subjects between 18 and 26 years of age participated in the study.

Screening Procedure

Each participant was screened to determine if he/she is qualified for the study. The screening consisted of a hearing test and several questions to assess the general health and condition of his/her ears. In conducting the audiogram, the experimenter fitted a set of headphones on the participant and then presented very quiet pulsed, pure tones to the participant through the headphones to determine the participant's auditory threshold. For each ear, the hearing threshold at each of the pure-tone frequencies of 500, 1000, 2000, 4000, 6000, and 8,000 Hz were determined by a Houghson-Westlake, or "5 dB up, 10 dB down" procedure [8] (Morill, 1984). The participant answered that he/she heard the tones by pressing a silent push button on a hand-held response switch. The tones presented to the participant during the audiogram were at or below the participant's auditory threshold and posed no risk to the participant's hearing.

Table 1. Characteristics of specimens

Fabrics	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/Beaten	Upholstery

Experimental Procedure

Each of the 8 prerecorded fabric sounds was presented to each participant using laptop computer. Also 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 sound and touch, the participants were asked to answer questions relating to their subjective sensation of the sound and touch. The questions dealt with seven aspects of sensation of the sounds by Semantic Differential Scale (SDS): softness (S1), loudness (S2), pleasantness (S3), sharpness (S4), clearness (S5), roughness (S6), and highness (S7), and eight (8) aspects of sensation of the touch: hardness (T1), smoothness (T2), fineness (T3), coolness (T4), pliability (T5), crispness (T6), heaviness (T7), and thickness (T8). The sounds and the fabric samples were presented and touched twice by the orders previously determined randomly using the random number table for each subject.

Results and Discussion

Sound Parameters and Mechanical Properties

Sound parameters as physical stimuli of fabrics are shown in Table 2. The total sound pressure (LPT) of taffeta (F7) was the highest one as the value of 62.10 dB. This value is equal to the level representing normal conversation. On the contrary, the value of fabric F3 (ultrasuede) was the lowest one (37.41 dB) nearly corresponding to the level of noise in a living room. Level range over broadband level (ΔL) obtained from maximum dB minus minimum dB ranged from 18.56 dB (F4) to 52.37 dB (F5). This indicates that F4 (leno) had the small difference of minimum dB from maximum dB, while F5 (crepe de chine) did the large difference. Frequency differences (Δf) of all fabrics had negative values. This means that shapes of sound curves for all fabrics were the ones that had a left-handed slope.

Table 2. Sound measurements of fabrics

Fabrics	LPT (dB)	ΔL (dB)	Δf (Hz)
F1	54.77	21.42	–4704.00
F2	52.64	22.95	–19872.00
F3	37.41	41.13	–5728.00
F4	51.20	18.56	–560.00
F5	49.27	52.37	–7424.00
F6	59.69	41.41	–19712.00
F7	62.10	21.08	–3920.00
F8	46.81	33.61	–19936.00

Mechanical properties by KES are shown in Table 3. From these data, F5 (crepe de chine) which was thinner and lighter than any other fabrics was the most stretchable fabrics at tensile strength and the most deformable one at shearing. The fabric was also found as be most easily compressed. On the contrary F2 (woolen) which was the thickest and the heaviest one was the least deformable at shearing and the most resistant under compression.

Sensation for Sound

The means of the seven sensations for sound by SDS for the eight fabrics are presented in Table 4. Specimen F3 (ultrasuede) was evaluated to have the highest values for softness and pleasantness, while F7 (taffeta) showed the highest values for loudness. Based on the hypothesis, the two wool fabrics (F1, F2) should produce similar results, and the results for the four polyester fabrics should also have similarity. As predicted, the means of the wool fabrics for each of the seven sensations were almost identical. The resulting means for the polyester fabrics, however, did not show many similarities. The four types of polyester fabrics were ultrasuede (F3), leno (F4), surah (F6), and taffeta (F7). The latter three had a nearly identical degree of softness, between −1.33 and −1.87. On the contrary, the ultrasuede had a higher softness rating of 1.60. Again, the latter three showed similar means for loudness, ranging from 1.13 to 1.87, while the ultrasuede had a smaller loudness rating −1.87. Ultrasuede showed the lowest rating of roughness at –0.50 among the fabrics. For the last sensation of highness, leno and taffeta provided similar means to each other, while ultrasuede reported a lower degree of highness, and woolen a higher one. All of the fabrics were evaluated as sounding less clear in that they were rated negatively. Also, they did not show scores for clearness that were obviously different

Table 3. Mechanical properties of fabrics

Fabrics	EM (%)	LT (–)	WT (gf · cm/cm^2)	G (gf/cm · deg)	2HG5 (gf/cm)	WC (gf · cm/cm^2)	SMD (micron)	T (mm)	W (mg/cm^2)
F1	6.46	0.63	10.07	0.56	1.50	0.20	0.56	0.46	23.24
F2	8.82	0.58	13.13	0.94	3.16	1.82	0.93	0.68	40.52
F3	3.81	0.76	9.11	0.39	1.49	0.12	0.26	0.30	14.28
F4	10.82	0.71	19.11	0.32	0.89	0.24	2.15	0.58	22.34
F5	13.07	0.48	15.61	0.21	0.22	0.08	0.31	0.18	6.51
F6	3.44	0.73	6.25	0.31	1.19	0.11	0.16	0.25	12.91
F7	4.00	0.65	6.45	0.87	2.54	0.07	1.62	0.28	16.35
F8	2.20	0.80	4.34	0.59	2.93	0.18	2.47	0.40	15.95

Table 4. Sound sensations by semantic differential scale

Fabrics	Softness	Loudness	Pleasantness	Sharpness	Clearness	Roughness	Highness
F1	−1.77	1.80	−1.80	0.93	−0.47	1.67	0.97
F2	−1.77	1.80	−1.77	1.03	−0.23	1.87	0.97
F3	1.60	−1.87	0.23	−0.93	−0.30	−0.50	−1.30
F4	−1.80	1.73	−1.57	1.03	−0.13	1.23	0.80
F5	−0.03	−0.47	−0.83	−0.70	−0.90	0.63	−1.03
F6	−1.33	1.13	−1.60	0.23	−0.70	1.60	0.10
F7	−1.87	1.87	−2.07	0.60	−0.60	1.80	0.63
F8	−0.60	0.47	−0.57	0.20	−0.33	1.30	−0.43

Table 5. Touch sensations by semantic differential scale

Fabrics	Hardness	Smoothness	Coarseness	Coolness	Pliability	Crispness	Heaviness	Thickness
F1	−0.50	−0.37	0.33	−0.97	−0.10	−1.20	0.27	0.33
F2	−1.13	−0.80	1.73	−0.63	−0.57	−0.83	1.93	2.17
F3	−2.23	1.67	0.27	−1.93	2.03	−1.83	−1.10	−0.73
F4	0.63	−1.83	−1.30	−0.87	−1.77	−0.83	−1.40	−1.60
F5	−2.00	1.90	−1.23	−2.57	1.83	−2.50	−2.87	−2.60
F6	−2.27	1.53	−0.07	−1.87	2.27	−1.30	−1.23	−1.00
F7	−0.27	0.07	−0.77	−0.53	0.17	0.23	−0.97	−0.50
F8	1.77	−2.27	−0.77	1.70	−2.10	1.53	0.40	0.47

from one another.

Sensation for Touch

Prior to the touch semantic portion of the experiment, one would expect that fewer similarities would result, than resulted in the sound portion. This is because touching the fabrics gives a greater degree of accuracy when differentiating between eight fabrics. Such factors as thickness and weight of the fabrics will now be influential in discriminating between the fabrics. Table 5 gives the means for the eight touch sensations. Each sensation for touch showed significant differences among the fabrics. Specimen F2 (woolen) was evaluated as coarsest, heaviest, and thickest in touch, while F5 (crepe de chine) was rated as being smoother, more pliable, less heavier, and less thicker in touch than any other fabrics. Touch sensation for hardness, coolness, and crispness was highest for F8 (beaten). This proves the hypothesis that flax is the most abrasive of all of the fabrics used in the experiment. The two wool fabrics (F1, F2) that were evaluated as having similar characteristics in sound differed in some touch sensation such as thickness and weight. Especially the woolen (F2) had a much higher means for heaviness and thickness than any other fabrics. The ultrasuede, surah, and taffeta were fairly similar to one another in thickness and in weight, so means for these fabrics should somewhat coincide. The leno, however, was substantially thicker and heavier, so its similarities with the other three should be limited. Silk, having such a different feel than the others, as would be expected, had extremely high means in such categories as smoothness, pliability, and a much lower means for thickness, crispness, and heaviness. Flax, due to its rougher feel, showed a much higher mean for both coolness and crispness.

Fabric four, the leno polyester, had the least in common as far as means with the three other polyester fabrics. It had the most negative means for coarseness and heaviness in both semantic portion, implying that this fabric was the finest and the most light among the four polyesters. The leno was actually the thickest of the polyesters from the KES measurements, so the rating as the thinnest of four polyester fabrics was a bit surprising. Taffeta (F7), the plain polyester, which was rated as having sound louder, sharper, and rougher showed no strong sensation for touch that was associated with it.

Sound Sensation Predicted by Sound Parameters and Mechanical Properties

To provide information on fabric sound, stepwise regression was performed in which sound sensation was predicted by sound parameters and mechanical properties. First, all of sound sensation except clearness were described by some sound parameters. For softness, the equation meant that fabrics with higher ΔL and lower LPT were evaluated as sounding softer ($Y = 0.045\,\boldsymbol{\Delta L} - 0.106\,\mathbf{LPT} + 3.092$, $R^2 = 0.847$). Broadband level pressure (LPT) and ΔL were also found as related negatively and positively with pleasantness ($Y=0.021\,\boldsymbol{\Delta L} - 0.080\,\mathbf{LPT} + 2.228$, $R^2 = 0.912$), respectively. As given in Figure 1 and Figure 2, this result is supported by the fact that ultrasuede (F3) with the lowest values for LPT was rated as generating sound more pleasant as well as softer

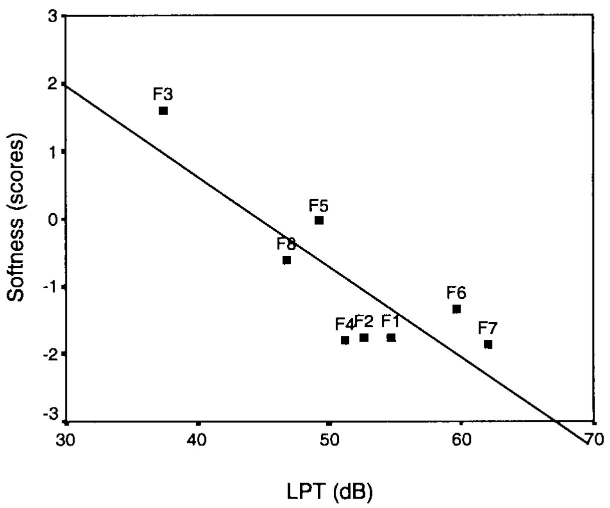

Figure 1. Relationship between LPT and softness for sound.

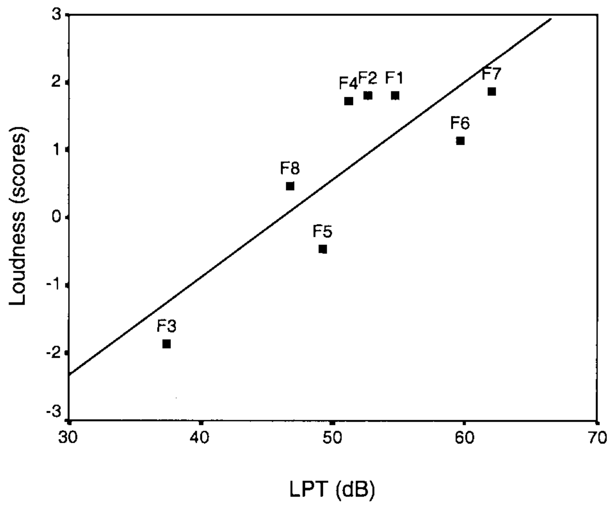

Figure 3. Relationship between LPT and loudness for sound.

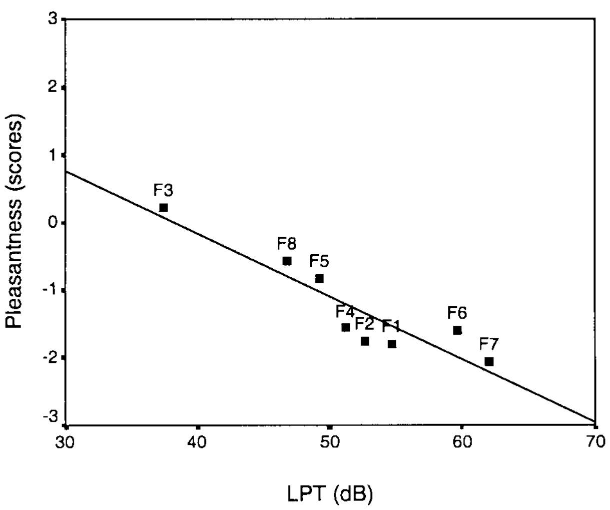

Figure 2. Relationship between LPT and pleasantness for sound.

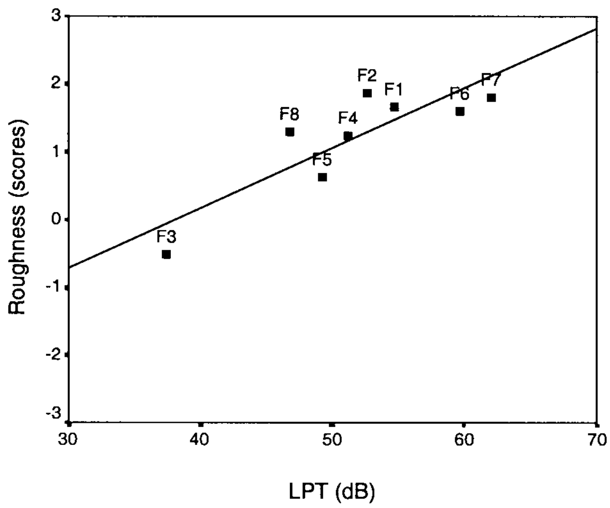

Figure 4. Relationship between LPT and roughness for sound.

than any other fabrics. On the contrary to that, taffeta (F7) having the highest LPT showed the lowest means for softness and pleasantness. These fabrics could be examples for proofing that LPT affected positively loudness ($Y = -0.059\ \boldsymbol{\Delta L} + 0.108\ \mathbf{LPT} - 2.919$, $R^2 = 0.879$), roughness ($Y = 0.088\ \mathbf{LPT} - 3.356$, $R^2 = 0.687$), and highness ($Y = 0.049\ \mathbf{LPT} - 0.052\ \boldsymbol{\Delta L} - 0.815$, $R^2 = 0.868$).

In Figure 3 and Figure 4, taffeta (F7) was rated as sounding louder and rougher than any other fabrics while ultrasuede (F3) perceived as less louder and less rougher. A sound parameter developed to quantify fabric sounds, ΔL was revealed to be a variable determining softness and pleasantness positively, while for the other sound sensation such as loudness, sharpness ($Y = -0.054\ \boldsymbol{\Delta L} + 2.014$, $R^2 = 0.747$), and roughness it acted as a negative predictor.

As shown in Figure 5, leno (F4) of which ΔL was calculated as the lowest among the fabrics was evaluated as the sharpest in sound. Among the sensation, no prediction model was established for clearness by sound parameters. This sensation seemed not to be explained by the sound parameters in this study. As mentioned above equations, the regression equation for each sensation showed relatively higher values for adjusted R^2, which leads to conclusions that the sound parameters for this study are sufficiently available for explaining the sound sensation. Another quantified sound parameter, Δf did not enter any prediction model for sound sensation. Comparing ΔL with Δf, fabric sound sensation seemed to be affected more by ΔL.

To explain sound sensation better, regression equations were obtained which predict sound sensation with both of sound parameters and mechanical properties. All of sensation were described by some of sound parameters and

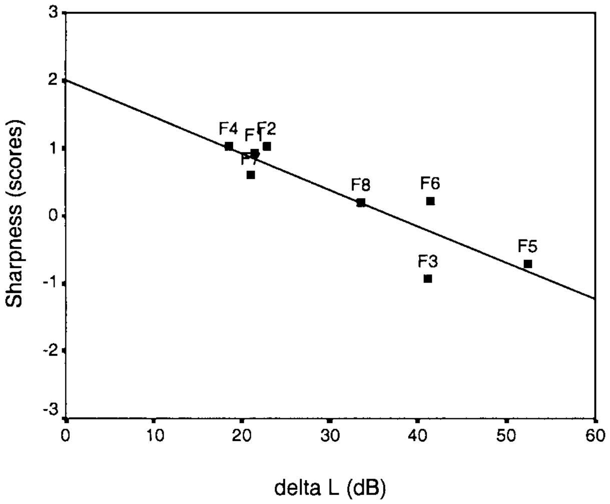

Figure 5. Relationship between delta L and sharpness for sound.

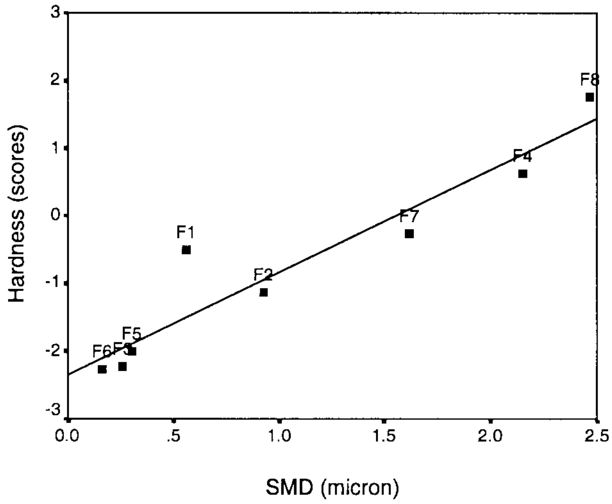

Figure 6. Relationship between SMD and hardness for touch.

mechanical properties including clearness that did not have a regression model only by sound parameters. The LPT seemed to be the most important sound parameters for explaining fabric sound in that the parameter entered most of equations such as softness ($Y = -0.137$ **LPT** $- 4.458$ **T** $+ 7.795$, $R^2 = 0.966$), loudness ($Y = 0.140$ **LPT** $+ 5.269$ **T** $- 1.482$ **MIU** $+ 8.547$ **MMD** $- 7.887$, $R^2 = 1.000$), pleasantness ($Y = -0.0863$ **LPT** $- 2.290$ **T** $+ 1.416$ **LT** $- 0.0097$ **RT** $+ 3.652$, $R^2 = 0.998$), roughness ($Y = 0.0865$ **LPT** $- 3.364$, $R^2 = 0.758$), and highness ($Y = -0.0574$ $\boldsymbol{\Delta L}$ $+ 0.0572$ **LPT** $- 0.586$ **2HG** $- 0.729$, $R^2 = 0.981$). The Equations provided ΔL as a negative predictor for sharpness ($Y = -0.0517$ $\boldsymbol{\Delta L}$ $+ 1.891$, R^2=0.723) and highness equal to the prediction model for both of two sensation only by sound parameters. Of the mechanical measurements, thickness (T), coefficient of friction (MIU), mean deviation of MIU (MMD), tensile linearity (LT), tensile resilience (RT), and shear hysteresis (2HG5) were found to be significant properties for fabric sounds. Especially, prediction model for clearness not explained only by sound parameters was established showing physical thickness as a positive predictor. Fabrics that were thicker seemed to generate sound more loudly and clearly while those less thicker to sound more softly and pleasantly. As for MMD, fabrics having higher mean deviation of frictional coefficient tended to be rated as sounding louder. Sound sensation was more accurately regressed by both sound parameters and mechanical properties than only by sound parameters of fabrics in that the equations showed higher R^2 values than those in the equations only by sound parameters. These imply that fabric sound could be informed more precisely when considering both of sound parameters and mechanical properties.

Touch Sensation Predicted by Mechanical Properties

All of touch sensation showed significant equations except

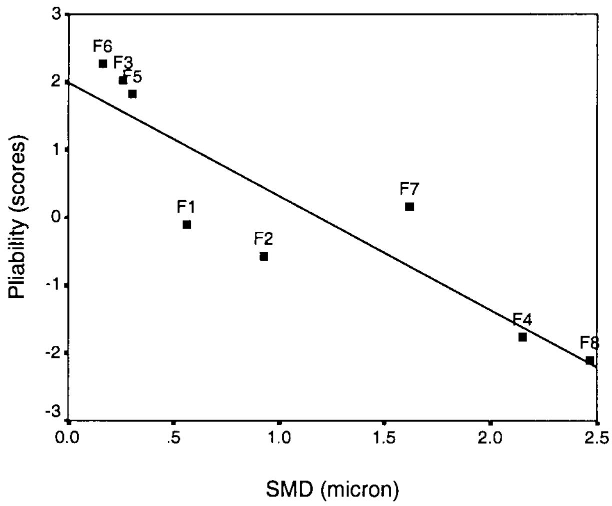

Figure 7. Relationship between SMD and pliability for touch.

coarseness and heaviness by some mechanical measurements. Mechanical property predicting hardness ($Y = 1.509$ **SMD** $- 2.316$, $R^2 = 0.879$) and pliability ($Y = -1.706$ **SMD** $+ 2.166$, $R^2 = 0.836$) was geometrical roughness (SMD). The SMD affected hardness positively while pliability negatively. This result was supported by Figures 6 and 7 in which the fabrics with higher SMD such as beaten (F8) also tended to show higher scores for hardness while lower for pliability. In those figures, on the contrary, fabrics having lower SMD including surah (F6) seemed to be rated as touched less harder while more pliable than any other fabrics. Smoothness ($Y = -5.076$ **T** $- 1.157$ **SMD** $+ 3.120$, $R^2 = 0.917$) was revealed to have two significant predictors, thickness and SMD. Compressional Energy (WC) was the only positive predictor for coolness (Y=0.755 **WC** $- 1.559$, $R^2 = 0.696$). It is because that beaten (F8) with the highest value for WC was rated as being touched more coolly than any other fabrics. For crispness ($Y = 0.629$ **SMD** + 0.905 **2HG5** − 2.883, $R^2 = 0.932$), SMD and shear hysteresis at 5° (2HG5) were the significant predictable properties. Crepe de chine (F5) and beaten (F8) were found as be the most limp and the crispest fabric, respectively. The two fabrics showed the differences in especially the values for SMD and 2HG5. In touch, subjects usually rub and extend the fabric with their fingers. Thus, whether a fabric is crisp or not seemed to be determined mainly by its geometrical roughness and recoverability at shearing. Thickness ($Y = -0.200$ **EM** + 0.427, $R^2 = 0.552$) was regressed negatively by elongation at maximum load (EM). This suggests that thickness as the sensation is a more complex sensation determined by another properties such as tensile properties as well as physical thickness of fabrics. Heaviness was not regressed by any mechanical property. This also implies that subjects may not perceive heaviness of a fabric only by weight of the fabrics. Moreover, other properties but those in this study could be concerned with the sensation.

Conclusions

This study was carried out to inform on human subjective sensation about fabric sound and touch by establishing the equations for predicting them by quantified sound parameters and mechanical properties of fabrics as objective measurements. Two types of wool fabrics including worsted and woolen showed similar sensation for sound but differed in some touch sensation. Polyester fabrics that were varied in fabric types were found as being evaluated differently in sound as well as in touch. In prediction for sound and touch sensation by the physical measurements, most of them were regressed somewhat accurately showing relatively higher R^2. Of the sound parameters, broadband sound level (LPT) affected positively subjective roughness and highness as well as loudness. Among the quantified sound parameters, ΔL was found as a parameter related positively with softness and pleasantness. Therefore this parameter could be useful to expect sound sensation of fabrics. As expected, each of touch sensation was explained significantly by some of mechanical properties of fabrics implying that a touch sensation could be expressed by a variety of properties.

The results could be utilized in providing information that could be used to better develop textile fabrics to satisfy consumers. Further research could also include testing additional fabrics such as cotton or cashmere for the same sensations. Moreover, it should be investigated how the sensation of fabrics is determined according to their end uses such as suit and sports outwear. This would help to encompass a wider range of consumer needs.

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