〔보 문〕

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Sound Sensation and Its Related Objective Parameters of Nylon Fabrics for Sports Outerwear

스포츠 아우터웨어용 나일론 직물의 소리 감각과 이와 관련된 객관적 파라미터들

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Abstract

본 연구는 스포츠 아우터웨어용 나일론 직물의 소리에 대한 주관적 감각과 이에 관련된 객관적 측정치를 규명하기 위하여, 서로 다른 8종의 나일론 직물의 소리의 스펙트럼 파형을 고찰하였으며, 소리 파라미터로 총음압(level pressure of total sound, LPT), 세 가지 AR (autoregressive) 계수, Zwicker의 심리음향학적 모델에 따른 크기(Z)와 날카로움(Z)를 계산하였고, Kawabata Evaluation System (KES)으로 직물의 물리적 성질을 측정하였다. 주관적 감각 평가를 위하여 피험자에게 녹음된 각 직물소리를 들려주어 7개 소리 감각 (부드러움, 시끄러움, 날카로움, 맑음, 거칠, 높음, 유쾌함)을 의미분별척도로 답하게 한 후, 단계적 선형 회귀식을 이용하여 직물 소리의 주관적 감각에 대한 예측 모델을 제시하였다. 울트라스웨이드를 제외한 태피터 나일론 직물들은 스펙트럼 파형에서 다른 조성 섬유의 직물들보다 음압 값이 높고, 총음압이 60dB 안팎의 값을 보여, 착용자에게 불쾌감을 줄 것으로 예상되었으며, 주관적 감각 평가에서도 소리의 부드러움과 맑음, 유쾌함에서 음의 점수를, 시끄러움과 날카로움, 거칠, 높음에서 양의 점수를 얻었다. 주관적 감각의 예측 모델에서 총음압은 시끄러움과 거칠에 정적 영향을, 유쾌함에 부적 영향을 미쳐서 나일론 직물 소리의 총음압이 50dB 이하일 때 주관적으로 유쾌하게 느껴지는 것으로 나타났다.

Key words: fabric sound, nylon fabrics for sports outerwear, physical properties, subjective sensation, prediction model; 직물 소리, 스포츠 아우터웨어용 나일론 직물, 물리적 성질, 주관적 감각, 예측 모델

I. Introduction

There has been a growing interest for fibers and textiles to have auditory sensorial effects. Sound attributes of apparel fabrics are nowadays concerned as important qualities in wear comfort of garments as well as tactile and vision performance. The sensory perceptions towards clothing are related to physical characteristics of the material constituents[1]. Fabric sound was also found as concerned with some measurable properties of fabrics[2], and the effects of such properties on fabric sound are significant in developing sensible textile products.

Some sounds from fabrics may be desirable for aesthetic qualities, whereas others are uncomfortable due to their noise levels which should be lowered. The swish and scrooping of silk are desired in some styles of ladies' dresses. However, aural comfort, as applied to textile use, is usually concerned with the noise a material makes when it rubs against another surface such as skin or another fabric, and the degree of comfort registered depends on the situation[3]. Also, sound effect may be important quality attributes depending on the fabric end uses[1]. For example, the rustle of a soldiers anorak during night maneuvers can be a target for enemy fire[1]. Denim Jean pants also make some noise when a wearer walks. Coated fabrics, used for such applications as water-repellent and wind-proofing jackets, tend to make a lot of noise, which in some cases bothers both the wearers and others. Therefore, auditory comfort of these coated fabrics need to be improved for grading up total performance of the jackets made from these fabrics. Nevertheless, there has not been yet any systematic research on noise reduction from apparel fabrics and their related measurements for the application to manufacturing process.

As mentioned above, aural perception of fabrics may be dependant mainly on situation and end uses. Therefore, it is significant to figure out sound characteristics of fabrics according to both fiber content group and end uses. In a previous study[4], sound parameters of fabrics including silk and silk-like polyester and their primary hand values were investigated to establish prediction model for sound sensation of blouse fabrics. Another study[5] reported that sound pressure of wool suiting fabrics was affected by tensile and surface properties. Some of nylon fabrics for outdoor sports have been observed in terms of sound parameters and the related mechanical properties[2]. However, in order to predict consumers' perception, subjective sensation for sound of nylon fabrics should be now evaluated, furthermore, its related parameters that can be measured need to be identified.

The purpose of this study was to investigate sound characteristics and physical properties of nylon fabrics for sports outerwear, to evaluate subjective human sensation for sound of the fabrics, and finally to identify the related objective parameters with subjective sensation by establishing the prediction models for providing information on developing sensible textile materials with improved aural comfort.

II. Experimental

1. Specimens

Eight different nylon fabrics commercially available for outdoor sportswear were selected as specimens for this study. Characteristics of specimens were summarized in Table 1. All of them were taffeta fabrics except N8, ultrasuede of twill weave. Some of taffeta with asterisk were those of which surfaces of back side were coated with polyurethane films for water proof/repellency.

2. Upgrading sound generator

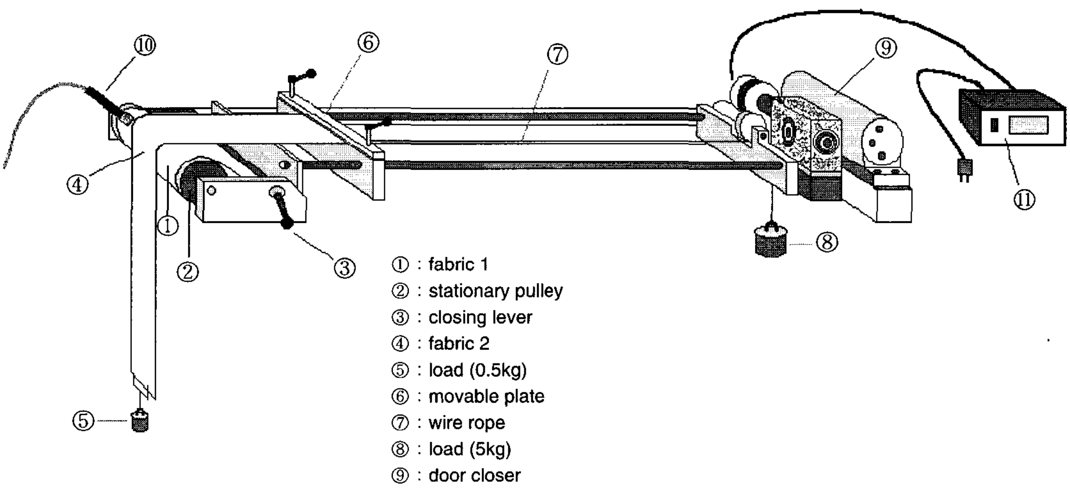
Fabric sound was generated by use of measuring apparatus for fabric noise (MAFN) completed by upgrading the sound generator used in previous works[2,4,5]. The MAFN was patented as a utility model in Korea with the application number of 0212605, in 2000. Fig. 1 is a diagram of the side view of the MAFN. The MAFN operates by the same principle as the previous generator in that two pieces of fabrics in a belt-pulley system

Table 1. Characteristics of Specimens

Specimen	Fiber Component	Yarn Type	Construction	Thickness (mm)	Weight (g/m²)	Fabric Name
N1*	nylon 100%	filament	plain	0.31	188.9	taffeta
N2	〃	〃	〃	0.10	65.5	taffeta
N3*	〃	〃	〃	0.18	102.9	taffeta
N4	〃	〃	〃	0.29	120.8	taffeta
N5	〃	〃	〃	0.20	101.8	taffeta
N6	〃	〃	〃	0.13	80.5	cotton-like taffeta
N7*	〃	〃	〃	0.14	106.1	taffeta
N8	〃	〃	twill	0.23	131.3	ultra-suede

* polyurethane coated

rub against each other to generate sound and any extra power source such as a electric motor which might cause noises is not applied but making the upper fabrics connected to a load falling down by gravity move along on the lower fabric. In a pilot study, a fabric on the MAFN was found as making equivalent sound to that on the previous sound generator when the same load and rubbing speed were introduced. Nevertheless, the MAFN has several advantages over the previous version as follows; First of all, a door closer replaced the oil cylinder in the previous generator which should be supplied with oil, and moreover, the rubbing velocity can be controlled by operating the door closer. Another advantage is that the speed meter included in the MAFN is able to indicate the rubbing velocity exactly. Finally the MAFN can vary the degree of compression between the two fabrics by selecting an acceptable load which will be connected to the upper fabric for each experiment.



① : fabric 1
② : stationary pulley
③ : closing lever
④ : fabric 2
⑤ : load (0.5kg)
⑥ : movable plate
⑦ : wire rope
⑧ : load (5kg)
⑨ : door closer
⑩ : microphone
⑪ : speed meter

Fig. 1. Diagram of MAFN

Sound of each fabric was recorded by a DAT (Digital Audio Tape) recorder (TEAC RD-145T) in an anechoic chamber in which the loudness of the background noise and the cutoff frequency were below 10dB and 63Hz, respectively, and picked up by a microphone (Type 4145, B&K)

3. Sound characteristics

As sound characteristics, sound spectrum of each fabric, first of all, was investigated by Fast Fourier Transform (FFT) to figure out shapes of spectral curves. For objective measurements, sound parameters of fabrics were obtained as follows; The level pressure of total sound (LPT) and three autoregressive (AR) coefficients (ARC, ARF, ARE) were calculated as introduced in the previous study2) on the basis of FFT spectrum, while loudness(Z) and sharpness(Z)6) were obtained considering Zwicker' s psychoacoustic models[7].

4. Physical properties

Physical properties by use of KES-FB[8] were measured under the standard condition. These included tensile, bending, shearing, compression, surface properties, thickness, and weight.

5. Subjective evaluation

For evaluating subjective sensation, volunteers were recruited among male and female students in Yonsei University aged from 18 to 26. After screening tests a total of 30 students participated in this study. They were screened for normal hearing by a Houghson-Westlake, or "5dB up, 10dB down" procedure[9] using an audiometer (GSI 17, Grason-Stadler, Inc.). Each of prerecorded sound of fabrics was presented to each participant wearing a powerful headphone (Philips, SBC HP 110) connected to a computer with the wave files for the fabric sounds. After each presentation the participants were asked to answer the questionaire relating to their subjective sensation of the sound using semantic differential scales for rating each sound. The questions consisted of seven different bipolar descriptors dealing with sensation of the sounds as presented in Table 2.

Table 2. Descriptors for sound sensation

Sound Sensation	Descriptors	
	−3 ssssssssssssssssss	+3
S_1	Hard ssssssssssssssssss	Soft
S_2	Quiet ssssssssssssssssss	Loud
S_3	Dull ssssssssssssssssss	Sharp
S_4	Obscure ssssssssssssss	Clear
S_5	Smooth ssssssssssssss	Rough
S_6	Low ssssssssssssssssss	High
S_7	Unpleasant ssssssssss	Pleasant

6. Experimental design and statistical analysis

A balanced incomplete block design was used for the subjective experiment. By the design each subject rated 6 different fabric sound stimuli including nylon and other fabrics such as wool and silk in random order and each stimulus was scored repeatedly by 3 different subjects.

In order to establish prediction model for nylon fabrics, stepwise linear regression was used with sound parameters and physical properties as independent variables and with each of subjective sensation as a dependent variable.

III. Results and Discussion

1. Sound characteristics and physical properties of nylon fabrics

1) Sound characteristics

Through FFT transform, spectral curves of nylon fabrics were investigated as given in Fig. 2. Sound spectra of nylon fabrics for sports outerwear had flatter shapes than those of other fibers such as wool and silk in the previous study[2]. In addition, most of nylon fabrics except N2 and N8 showed higher values for amplitudes. This result means that they are expected to make sound louder than others. Especially, amplitude values in most ranges of frequency were much higher for N1 and N6 than for any other nylon fabrics, which implies that the two fabrics are supposed to have higher LPT as physical loudness of sound. As described above, amplitude values were lower for N2 and N8, however, they were higher for N2 in frequency ranges lower than 10,000Hz and higher than about 17,500Hz, respectively. This indicates that LPT obtained by summing up individual values for amplitude may be much higher for N2 than for N8.

Table 3 presents sound parameter values of nylon fabrics. Sound pressure (LPT) ranged from 49.62dB (N8) to 63.84dB (N6). However, most of the fabrics showed LPT values near to 60dB corresponding to sound level of normal human conversation. This result indicates that sound from nylon taffeta could disturb both wearers and others, and furthermore have an influence on their aural comfort. The values for ARC ranging from 35.10 to 51.56 and for loudness(Z) from 1.47 to 3.90 sone seemed to be generally proportional to those for LPT as discussed in the previous study. The only ultrasuede, N8 also showed the lowest values for the two parameters. Sharpness (Z) values were from 2.92 to 4.60 acum. They were higher than those for woodwinds reported as 0.5~2.0 acum[10] as well as than those for other fibers in the previous study[9], which implies that wearers may perceive sounds of nylon fabrics as sharper than those of woodwinds and other fiber-composed fabrics There were just a little differences among the values for ARF and ARE, however, ultrasuede (N8) showed the highest values for ARF (-0.0020) and the lowest for ARE (0.9976), while taffeta (N4) did the lowest for ARF (-0.0027) and the highest for ARE (0.9989), respectively. This was supported by the fact that shape of spectral curve for N8 was flatter in most ranges of frequencies than those for others considering that ARF determines mainly the

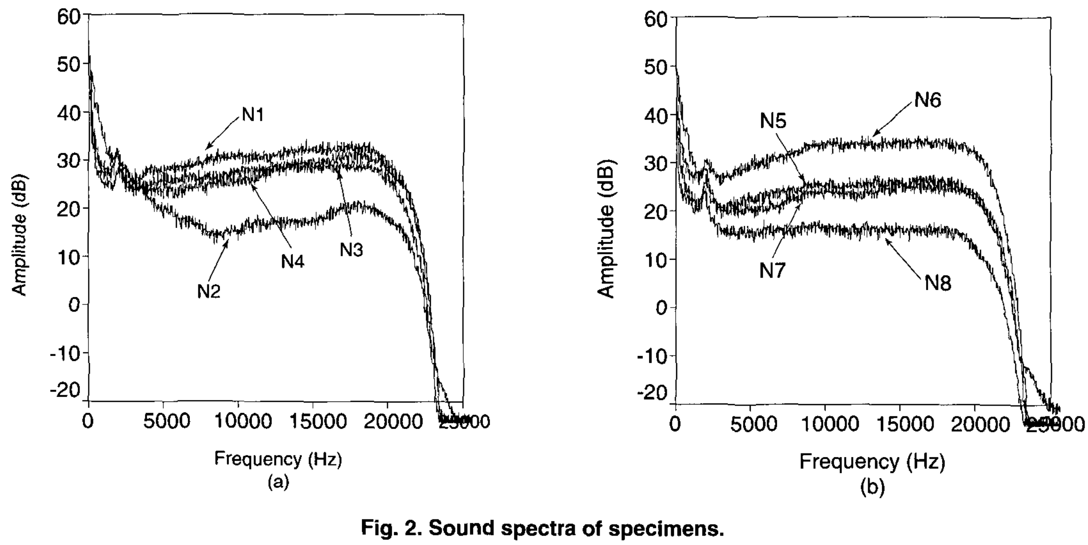


Fig. 2. Sound spectra of specimens.

Table 3. Sound Characteristic Values of Specimens

Specimen	LPT (dB)	AR coefficients			Psychoacoustic factors	
		ARC	ARF	ARE	Loudness(Z) (sone)	Sharpness(Z) (acum)
N1	61.91	47.77	-0.0024	0.9986	3.43	4.42
N2	61.43	43.16	-0.0024	0.9980	2.65	2.92
N3	59.80	49.45	-0.0026	0.9987	2.74	4.56
N4	61.20	51.56	-0.0027	0.9989	2.98	4.06
N5	56.39	39.56	-0.0021	0.9985	2.40	4.52
N6	63.84	45.02	-0.0023	0.9988	3.90	4.60
N7	60.56	48.68	-0.0025	0.9986	2.54	3.60
N8	49.62	35.10	-0.0020	0.9976	1.47	4.11

Table 4. Physical Properties of Specimens

Specimen	Physical Properties																
	Tensile Properties				Bending Properties		Shear Properties			Compressional Properties			Surface Properties			Thickness Weight	
	EM	LT	WT	RT	B	2HB	G	2HG	2HG5	LC	WC	RC	MIU	MMD	SMD	T	W
N1	2.86	0.81	5.86	60.86	0.14	0.07	6.06	7.58	9.96	0.43	0.10	49.50	0.32	0.006	1.28	0.31	18.89
N2	4.35	0.75	7.99	61.72	0.02	0.03	0.56	3.47	4.02	0.30	0.03	46.15	0.27	0.002	0.39	0.10	6.55
N3	4.01	0.86	8.63	52.27	0.05	0.04	3.57	8.98	8.18	0.39	0.12	50.79	0.34	0.003	0.91	0.18	10.29
N4	5.80	0.83	12.02	44.86	0.04	0.03	1.12	1.22	4.78	0.50	0.20	42.00	0.36	0.003	0.64	0.29	12.08
N5	2.89	0.92	6.67	59.00	0.08	0.05	5.13	10.49	10.06	0.50	0.17	44.25	0.31	0.003	0.95	0.20	10.18
N6	5.91	0.78	11.32	62.89	0.04	0.02	2.50	4.00	5.21	0.37	0.08	60.98	0.28	0.003	0.46	0.13	8.05
N7	3.20	0.98	7.72	59.99	0.07	0.04	4.89	9.01	9.85	0.30	0.02	58.33	0.21	0.003	0.35	0.14	10.61
N8	3.65	0.73	6.62	56.36	0.13	0.07	1.27	3.25	5.13	0.47	0.11	44.44	0.43	0.002	0.18	0.23	13.13

slopes of sound curves because it is the coefficient of x (frequency) term.

2) Physical properties

By KES measurements, seventeen properties of nylon fabrics were obtained as given in Table 4. In terms of tensile properties, nylon fabrics were found as less deformable at early stage of strain and less recoverable showing the range for tensile linearity (LT) from 0.73 (N8) to 0.98 (N7) and for tensile resilience (RT) from 44.86 (N4) to 62.89 % (N6) comparing with men's winter suiting fabrics having the values around to 0.60 for LT and 60% forRT, respectively8). In addition, some of nylon fabrics were also revealed to be less deformable at shearing, for example, showing 6.06 gf/cm · degree for N1 and 5.13 gf/cm · degree for N5 in shear stiffness (G) than other fabrics for suits or dress. These features might make sound of the fabrics louder and sharper in terms of sound parameters.

2. Subjective sensation for sound of nylon fabrics

Sounds of nylon fabrics were evaluated in terms of seven aspects of sound sensation including softness, loudness, sharpness, clearness, roughness, highness, and pleasantness, as given in Fig. 3. Among the sensation, softness, clearness,

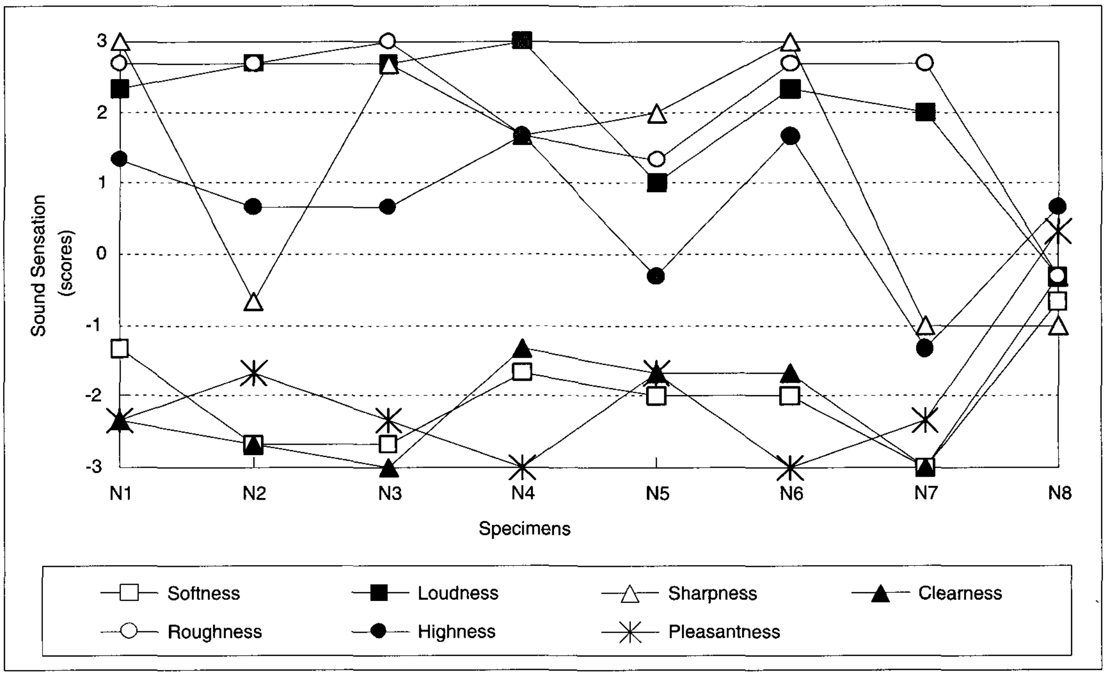


Fig. 3. Sound Sensation of Nylon Fabrics

and pleasantness were rated as negatively for most of nylon fabrics except N8, ultrasuede. This indicates that sound from most of nylon fabrics for sports outerwear were perceived as hard, obscure, and unpleasant rather than soft, clear, and pleasant. The other hand, loudness, sharpness, roughness, and highness showed positive scores for most of nylon fabrics. Moreover, loudness and roughness scores were 2 points and over for most fabrics including N1, N2, N3, and N6, which implies that they make sound loud and rough like a noise. Pleasantness, as described above, gave negative scores for all of fabrics except the ultrasuede. The ultrasuede showed the positive scores for pleasantness of 0.33, which means that it was evaluated as sounding pleasant slightly. From this result, sports garments made of ultrasuede very closely woven with micrfibric technology using ultrafine fibers may be expected to give aural pleasantness to consumers. However, the fabric had the negative scores for softness and clearness of -0.67 and -0.33, respectively, meaning slightly hard and obscure. Therefore, this suggests that ultrasuede for sportswear need to be improved increasingly for appealing to human sensitivity in hearing.

3. Prediction model for sound sensation with its related parameters of nylon fabrics

To establish prediction model for sound sensation of nylon fabrics, stepwise linear regression was used. In the models, the relationship between subjective sensation as a dependent variable and objective measurements including sound parameters and physical properties as independent variables can be expressed as follows;

$$Y = C_0 + \text{sum} \sum_{i=1}^{n} C_i X_i$$

Y : dependent variables

C_0 : constant of stepwise regression equation

n : number of independent variables in stepwise regression equation

X_i : ith independent variable

C_i : coefficient of X_i

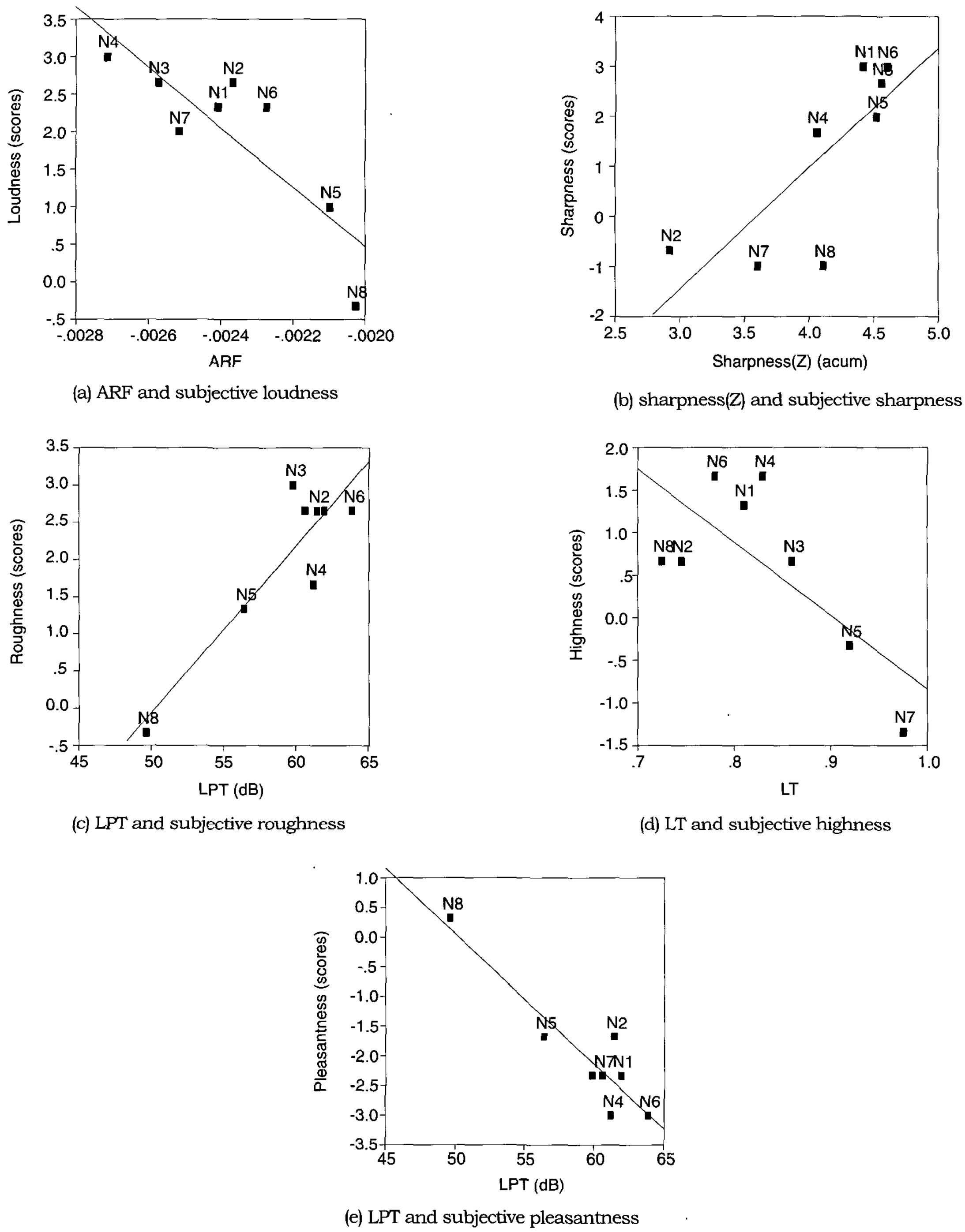
Table 5 presents the parameters in the regression equations showing R^2 higher than 0.8 for sound sensation by its related objective measurements for nylon fabrics. Among the sensation, loudness, sharpness, roughness, highness, and pleasantness were predicted by some of sound parameters and physical properties. In the models, subjective loudness was revealed to be significantly explained with both LPT and ARF. Of the two parameters, LPT affected loudness positively while ARF did negatively. Fig. 4 (a) shows the relationship between ARF and subjective loudness. Ultrasuede (N8) with the highest value for ARF which had a little bit flatter shape of spectral curve than other fabrics was rated as sounding slightly quiet rather than loud. In addition, the ultrasuede showed the lowest values for LPT among the fabrics. On the other hand, subjective sharpness was found as related positively with both sharpness(Z) and LPT. Fabrics with higher values for sharpness(Z) seemed to be perceived as sounding sharper subjectively as given in Fig. 4 (b). The model described subjective roughness significantly with LPT. According to Fig. 4 (c), as sounds of fabrics showed higher values for LPT, they seemed to be evaluated as rougher. In terms of subjective highness, some of parameters including tensile linearity (LT), ARE, and compressional linearity were related with the sensation. Among them, LT described highness negatively as presented in Fig. 4 (d), which means that fabrics less deformable to tensile strain at early stage had a tendency to make sound more lowly rather than highly. Finally, subjective pleasantness was found as negatively affected by ARE, LPT, and shear stiffness (G). In Fig 4 (e), ultrasuede (N8) with the lowest LPT value showed the highest score for pleasantness while a taffeta (N6) with the highest LPT was perceived as sounding very unpleasant showing the score of -3.0. As discussed above, ultrasuede was the only one with the value less than 50dB for LPT. This result indicates that nylon fabrics with LPT values lower than 50dB could provide pleasantness to human ears. Therefore, this relationship should be utilized to manufacturing process for reducing noise of nylon fabrics.

Table 5. Parameters of Prediction Models for Nylon Fabrics

Y	i	X_i	C_i	C_0	R^2
Loudness	1	LPT	0.16	-12.21	0.95
	2	ARF	-2078.87		
Sharpness	1	sharpness(Z)	2.52	-21.76	0.89
	2	LPT	0.21		
Roughness	1	LPT	0.23	-11.31	0.81
Highness	1	LT	-13.53	-1786.56	0.99
	2	ARE	1800.00		
	3	LC	3.03		
Pleasantness	1	ARE	-1605.88	1607.37	1.00
	2	LPT	-0.10		
	3	G	-0.05		

IV. Conclusions

In this study, we investigated sound characteristics, mechanical properties, and subjective sensation for sound of nylon fabrics for sports outerwear in order to establish the prediction model for sound



(a) ARF and subjective loudness

(b) sharpness(Z) and subjective sharpness

(c) LPT and subjective roughness

(d) LT and subjective highness

(e) LPT and subjective pleasantness

Fig. 4. Relationship between Objective Measurements and Sound Sensation

sensation. Nylon fabrics stiffer and less deformable than fabrics with other end uses showed higher amplitude values as well as flatter shapes than other fibers in spectral curves. Among the sound parameters, LPT values were near to 60dB corresponding to normal conversation for all of nylon taffeta fabrics, which indicates sound from them may disturb wearers. In subjective evaluation, most of nylon taffeta fabrics were revealed to sound louder, sharper, rougher, and higher rather than softer, clearer, and more pleasant, while ultrasuede to have positive scores for pleasantness. This implies that consumers may perceive sound from nylon fabrics as uncomfortable like a noise. Some of sound sensation were predicted with both sound parameters and physical properties. As sound characteristics, LPT explained subjective loudness, sharpness and roughness positively while subjective pleasantness negatively. Especially, sound of fabrics were rated as pleasant if their LPT values were lower than 50dB, which leads to the conclusion that noise of nylon fabrics for sports outerwear should be reduced for aural comfort. These relationships between the objective parameters and sensation could be utilized to manufacturing process for reducing noise of outer wear nylon fabrics.

This study was the first attempt for obtaining data on the relationship between the sound characteristics and physical properties to establish prediction model for sound sensation of sports outerwear nylon fabrics. The results have strong implications for developing textile materials for sportswear with auditory sensorial comfort and function. Further study needs to investigate sounds from a variety of fabrics produced by new technology today of fiber spinning, fabrication, and finishing in sport application.

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