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Psychological and Physiological Responses to the Rustling Sounds of Korean Traditional Silk Fabrics

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Abstract: The objectives of this study were to investigate physiological and psychological responses to the rustling sound of Korean traditional silk fabrics and to figure out objective measurements such as sound parameters and mechanical properties determining the human responses. Five different traditional silk fabrics were selected by cluster analysis and their sound characteristics were observed in terms of FFT spectra and some calculated sound parameters including level pressure of total sound (LPT), Zwicker's psychoacoustic parameters – loudness(Z), sharpness(Z), roughness(Z), and fluctuation strength(Z), and sound color factors such as ΔL and Δf. As physiological signals, the ratio of low frequency to high frequency (LF/HF) from the power spectrum of heart rate variability, pulse volume (PV), heart rate (HR), and skin conductance level (SCL) evoked by the fabric sounds were measured from thirty participants. Also, seven aspects of psychological state including softness, loudness, sharpness, roughness, clearness, highness, and pleasantness were evaluated when each sound was presented. The traditional silk fabric sounds were likely to be felt as soft and pleasant rather than clear and high, which seemed to evoke less change of both LF/HF and SCL indicating a negative sensation than other fabrics previously reported. As fluctuation strength(Z) were higher and bending rigidity (B) values lower, the fabrics tended to be perceived as sounding softer, which resulted in increase of PV changes. The higher LPT was concerned with higher rating for subjective loudness so that HR was more increased. Also, compression linearity (LC) affected subjective pleasantness positively, which caused less changes of HR. Therefore, we concluded that such objective measurements as LPT, fluctuation strength(Z), bending rigidity (B), and compression linearity (LC) were significant factors affecting physiological and psychological responses to the sounds of Korean traditional silk fabrics.

Keywords: Korean traditional silk fabric, Sound parameter, Mechanical property, Physiological response, Psychological response

Introduction

Nowadays consumers are becoming more sophisticated in their choice for the textile goods as well as demanding better qualities with a variety of desirable features in them. This also caused growing interests in sensory aspects for textile material such as visual, tactile, and auditory attributes in the interaction between textile products and human beings. Sounds from fabrics recognized recently as a significant factor by both manufacturers and researchers have been investigated in a few years on the purpose of giving quantitative correlations between physical measurements and psychological assessments. Precisely, researchers have conducted a series of studies to quantify the characteristics of rubbing sounds from various woven fabrics [1,2], to analyze the sounds according to mechanical properties and geometric features such as cross sectional shapes, weaving structures and etc. [3], and to figure out human subjective sensation for them [4-6].

Although subjective evaluation has been increasingly employed for application to practical condition recently, there may be individual idiosyncrasies that can influence a response to stimuli when the descriptors might be understood differently by each person or by psychological state of a person [7]. Accordingly, physiological signals have adopted even in psychological fields as a new way to determine human subjective sensation owing to the advantage that the physiological responses are generally consistent regardless of a human's intention. As a result of this drawback, physiological signals were also investigated in a few works [7-9] dealing with fabric sounds so that we have found some of physiological indices to predict human sensation for sounds from some woven and knitted fabrics. However, successive efforts should be made to detect psycho-physiological aspects of sounds from fabrics with a variety of fabric types and end-uses in order to provide auditory database for fabrics.

As a congenial sound not an annoying noise, scrooping sound by Asian traditional silk fabrics has been well known so that a synthetic fiber has been introduced to imitate it in textile market [10]. Its aural aesthetics have been usually thought as being arisen from triangular cross section of silk. In addition, some of traditional silk fabrics in Asia have gotten a different manufacturing process from those in western in yarn preparation and weaving. As Asian silk fabrics, Korean traditional silk has been also considered as making sound delicate and congenial. Actually, through a few works [11,12], it was reported that Korean traditional silk fabrics sounded less loudly than other western silk ones but their auditory pleasantness in subjective assessment was not easily predicted by a single objective parameters such as physical loudness. Thus, it needs to employ physiological signal analysis for

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the Korean traditional silk fabric sound for more accurate and consistent results in human sensation. In this study, we performed both physiological and psychological evaluation and related them to objective parameters such as acoustic and mechanical properties in order to quantify the human responses to sounds from Korean traditional silk fabrics.

The purpose of this study is to investigate physiological signal and psychological responses for sounds from Korean traditional silk fabrics, to relate physiological indices with psychological feeling, and finally to obtain both sound and mechanical properties correlated with psycho-physiological responses. This study will be helpful to design and produce more appealing Korean traditional silk fabrics in auditory comfort.

Experimental

Preparation of Specimens

For the specimens in this study, 38 different Korean traditional silk fabrics were collected first. Rustling sound of each fabric generated by MAFN (Measuring Apparatus for Fabric Noise, patent no. 2001-0073360) was analyzed by a Sound Quality System (Type 7698, B&K) in order to calculate its objective sound parameters such as LPT (level pressure of total sound), ΔL (the level of rage), Δf (the frequency difference), and Zwicker's psychoacoustic parameters [13] including loudness(Z), sharpness(Z), roughness(Z), and fluctuation strength(Z). The fabrics were classified into five groups by hierarchical clustering using their sound parameters. The final selected specimens from each group were Gapsa, Nobangju, Shantung, Myoungju, and Gongdan (Table 1). They were also investigated in terms of mechanical properties by using Kawabata Evaluation System (KES-FB, Kato Tech, LTD. Co.) [14].

Measurement of Physiological and Psychological Responses

Participants

A total of 30 college students (15 male, 15 female) between 20-25 years of age, and right-handed, participated in both physiological measurements and psychological evaluations after a screening test for normal hearing according to 5 dB up and 10 dB down procedure [15] by use of an audiometer (Grason-Stadler, Inc.).

Experimental Protocol

Participants were instructed to sit on a reclining chair in an anechoic chamber and experienced an adaptation period for 10 minutes. After recording a baseline for 60 seconds, sound of each specimen was presented for 60 seconds and physiological signals were recorded simultaneously. After 90 seconds rests, the same experimental procedure was repeated for the next stimulus.

Psychological Response Evaluation

After recording of physiological signals, each participant was asked to fill out a questionnaire using a SDS (Semantic Differential Scale) dealing with seven aspects of sound sensation (softness, loudness, sharpness, clearness, roughness, highness, pleasantness) developed in previous study [5]. The sound of each fabric was presented in a random order.

Physiological Signal Data Acquisition

The ANS (Autonomic Nervous System) was acquired by and MP100WS (Biopac systems, Inc.) in an anechoic chamber. Low frequency (LF, 0.04~0.15 Hz) and high frequency (HF, 0.15~0.4 Hz) were obtained from the power spectra of heart rate variability (HRV), and the ratio of LF/HF was then calculated and used as a parameter to determine changes in ANS activities. For measuring of pulse volume (PV), photoplenthysmograms (PPG) were obtained by placing the sensors on a thumb of one or both hands for assessing peripheral microcirculation caused by periodic pulsation of arterial blood. Skin conductance levels (SCL) were acquired as a way to measure electrothermal activity (EDA) detected by placing the electrodes on the middle section of the second and the third fingers of one or both hands.

Results and Discussion

Sound Spectra and Sound Parameters of Korean Traditional Silk Fabrics

The FFT spectra of the specimens are shown in Figure 1. Their amplitudes ranged between −30 dB~60 dB over a full range of frequencies. By and large, each curve showed similar shape of the fluent curve from 0 kHz to 13 kHz with its exponential that decreased after about 13 kHz. All of specimens seemed to have peak amplitudes below 500 Hz in their curves. Among the specimens, Shantung (ST) had the

Table 1. Characteristics of specimens

Specimens	Fiber content	Yarn type	Weave structure	Weight (mg/cm^2)	Thickness (mm)	Korean traditional fabric name
GS	Silk 100 %	Filament	Leno variation	3.69	0.09	Gapsa
NB			Plain	5.23	0.15	Nobangju
MJ				4.48	0.08	Myoungju
ST			Satin	11.99	0.21	Shantung
GD				9.38	0.18	Gongdan

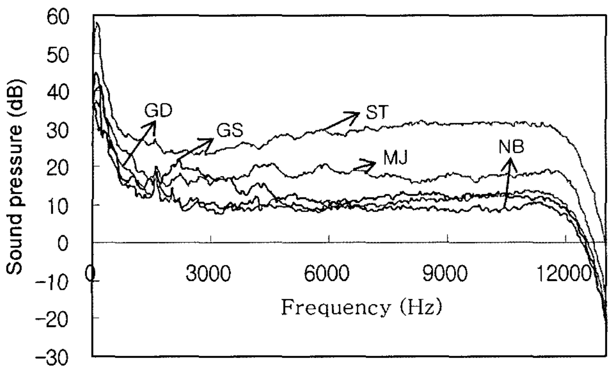


Figure 1. FFT spectra of Korean traditional silk fabrics' sounds.

highest amplitudes over frequencies. Especially it showed the amplitudes above 4000 Hz that is almost three times as high as those of both Gapsa (GS) and Myoungju (MJ).

Table 2 presents the values for sound parameters of each Korean traditional silk fabric. As for LPT, the values ranged from 42.3 dB (Gapsa) to 60.6 dB (Shantung). As reported in a previous work [11], Korean traditional silk fabrics were found as having lower LPT values than other woven fabrics such as wool gabardine and nylon taffeta. In terms of loudness(Z) among Zwicker's psychoacoustic characteristics, loudness(Z) ranged between about 2.52 sone (Nobangju) ~8.69 sone (Shantung), of which ranges are higher than those of some polyester knitted fabrics in previous studies [7,9]. Sharpness(Z), similar to loudness(Z), had the lowest value for Nobangju (2 acum), while the highest for Shantung (2.6 acum). Considering roughness(Z), Gongdan generated the least roughest sound (1.7 asper) while Gapsa did the roughest (2.0 asper) among specimens. Fluctuation strength(Z) ranged between 0.49 vacil (Nobangju) and 1.56 vacil (Gongdan). The values for both roughness(Z) and fluctuation strength(Z) were lower than those for both other woven and knitted fabrics [7-9]. On the other hand, ΔL values ranged from 25.7 dB (Myoungju)~38.24 dB (Nobangju). The higher the values, the more bent the spectra. Therefore, it can be said that Nobangju had the most bent spectral curve among the specimens. Delta f(Δf) values were negative for all specimens, which means that the specimens had the highest amplitudes at lower frequencies while the lowest at higher ones. Gapsa

Table 2. Sound parameters of Korean traditional silk fabrics

Specimens	LPT (dB)	ΔL(dB)	Δf(Hz)	Loudness (Z) (sone)	Sharpness (Z) (acum)	Roughness (Z) (asper)	Fluctuation strength(Z) (vacil)
GS	42.3	25.77	−11929.40	2.87	2.34	2.10	1.06
NB	47.8	38.24	−11929.40	2.52	2.06	1.81	0.49
MJ	46.4	25.06	−2196.39	4.25	2.41	2.03	1.55
ST	60.6	35.05	−2756.25	8.69	2.58	1.93	1.33
GD	53.8	33.96	−3057.71	7.28	2.38	1.7	1.56

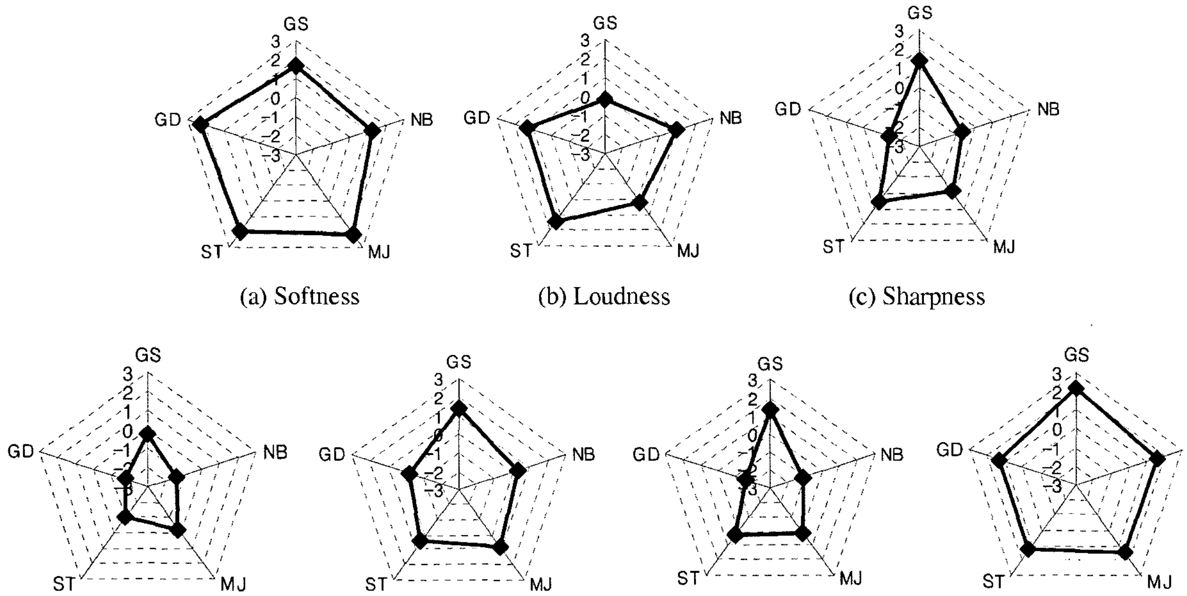


Figure 2. Psychological responses to sounds of Korean traditional silk fabrics.

and Nobangju had the lowest Δf values (-11929.40 Hz) among specimens.

Psychological Estimates to Korean Traditional Silk Fabrics' Sounds

In Figure 2, psychological responses for each sound were given by semantic differential scale. All of sounds from Korean traditional silk fabrics were estimated as soft and pleasant rather than hard and unpleasant. On the contrary, the perceived values for sharpness, clearness, and highness were lower than those for sensation mentioned above. This result is supported by the findings in a previous study [11] for the fabrics. Therefore, it can be said that Korean traditional silk fabrics seemed to be perceived as sounding comfortably in terms of their subjective evaluation for softness and pleasantness, compared to other woven fabrics [5,6]. Among the fabrics, the sound of Gapsa was the roughest, the sharpest, the highest, and the most pleasant. On the other hand, Shantung and Gongdan were felt as sounding louder but softer than other fabrics. These results indicate that auditory pleasantness of Korean traditional silk fabrics didn't tend to be reverse to loudness, roughness, and sharpness unlikely to that of other woven fabrics reported in some previous works [5,6]. Furthermore, it can be thought that delicate sounds of Korean traditional silk fabrics may evoke more complicate sensation than other fabrics.

Physiological Responses to Korean Traditional Silk Fabrics' Sounds

Table 3 shows the changes of physiological responses to the five different Korean traditional silk fabrics' sounds. As for ANS signals, heart rate (HR) responses, the estimates of stress and tension, increased to all of the fabric sounds with the range from 2.287 bpm (Gapsa) to 12.538 bpm (Shantung). The pulse volume (PV) reflecting a positive sensation decreased for Gapsa and Nobangju, but increased for Myoungju, Shantung, and Gongdan. Especially the increment for Gongdan (0.663 %) was the largest, which means Gongdan's sound gave a positive sensation to humans. Both skin conductance level (SCL) and LF/HF, the physiological indices for a negative sensation or activation of the sympathetic nervous system, had a tendency to show little change for all of sounds from Korean traditional silk fabrics. The values of LF/HF change were much lower for the silk fabrics than for other woven and knitted ones [7-9], which means that sounds from Korean traditional silk fabrics were likely to arouse less negative sensation of humans. On the other hand, SCL values decreased in Myoungju, Shantung, and Gongdan. This result implies that sounds from those fabrics may be perceived as comfortable rather than annoying.

Table 3. Changes of physiological responses to sounds of Korean traditional silk fabrics

Specimens	HR (bpm)	LF/HF(–)	PV (%)	SCL (μS)
GS	2.287	0.081	–0.009	0.006
NB	6.959	0.052	–0.377	0.000
MJ	7.312	0.035	0.637	–0.001
ST	12.538	0.034	0.377	–0.002
GD	7.511	0.023	0.663	–0.065

Table 4. Correlation coefficients between psychological and physiological responses

	HR	LF/HF	PV	SCL
Softness	0.291	–0.655	0.996**	–0.578
Loudness	0.786	–0.713	0.173	–0.543
Sharpness	–0.277	0.740	–0.264	0.736
Clearness	–0.438	0.567	0.017	0.694
Roughness	–0.576	0.803	–0.257	0.758
Highness	–0.304	0.681	–0.118	0.711
Pleasantness	–0.895*	0.950*	–0.496	0.456

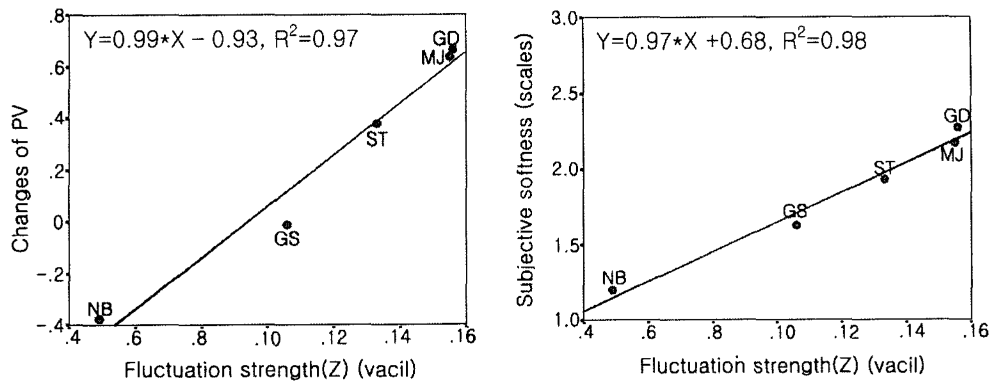
*$p<0.05$, **$p<0.01$.

Relationship between Psychological and Physiological Responses

Psychological responses were found as significantly correlated with physiological responses as given in Table 4. The 'softness' was positively correlated with the pulse volume (PV), which means the PV seemed to increase when humans felt the fabric sounds as softer. Actually, human subjects showed the largest changes of PV when they heard the sound of Gongdan which was perceived as softer than any other fabrics. The 'pleasantness' was negatively correlated to the heart rate (HR) while positively to LF/HF. It could be thought that as human felt the fabric sounds as pleasant they provided the more decrease for the heart rate (HR). As mentioned above, Gongdan evaluated as sounding the most pleasant also showed the least increase for the heart rate (HR). On the other hand, we couldn't find any significant correlations to physiological signals for other psychological estimates including loudness, sharpness, clearness, and highness, which was attributable to the absence of noticeable differences for psychological responses among the silk fabrics.

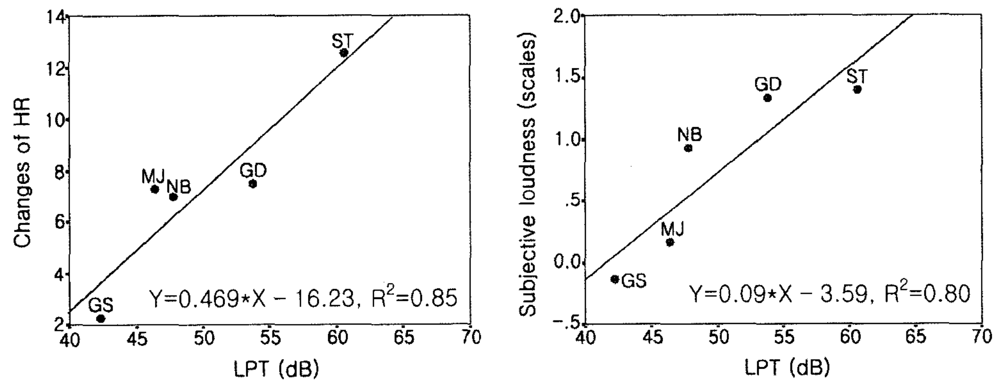
Effect of Sound Parameters on Psychological and Physiological Responses

We tried to determine objective measurements such as sound parameters and mechanical properties of the Korean traditional silk fabrics significantly affecting physiological and psychological responses in order to find out an indication of how to manage the objective features for aural comfort. First, multiple stepwise regression was employed to predict human responses with sound parameters. Among the sound parameters, fluctuation strength(Z) first appeared to be a significant predictor for both changes of pulse volume (PV) and subjective softness. The relationship between fluctuation strength(Z) and the both of two human responses is given in Figure 3(a) and (b). The figures describe that fluctuation strength(Z) was positively correlated with both changes of PV and subjective softness. As mentioned above, subjective softness showed significant correlation coefficient with changes of PV. Furthermore, from the Figure 3, we can infer that both of them are likely to be explained by fluctuation strength(Z). Although all sounds of the Korean traditional silk fabrics were felt as soft, positive physiological signals of PV were arisen from Shantung, Myoungju, and Gongdan among them as shown in Figure 3(a). From this result, it could be concluded that threshold of fluctuation strength(Z) for positive responses of PV from sounds of Korean traditional silk fabrics may be



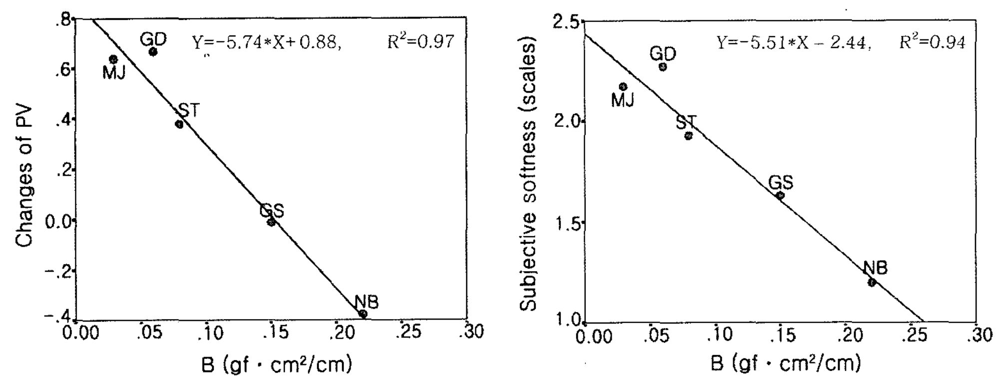
(a) Changes of PV (b) Subjective softness

Figure 3. Effects of fluctuation strength(Z) on psychological and physiological responses.



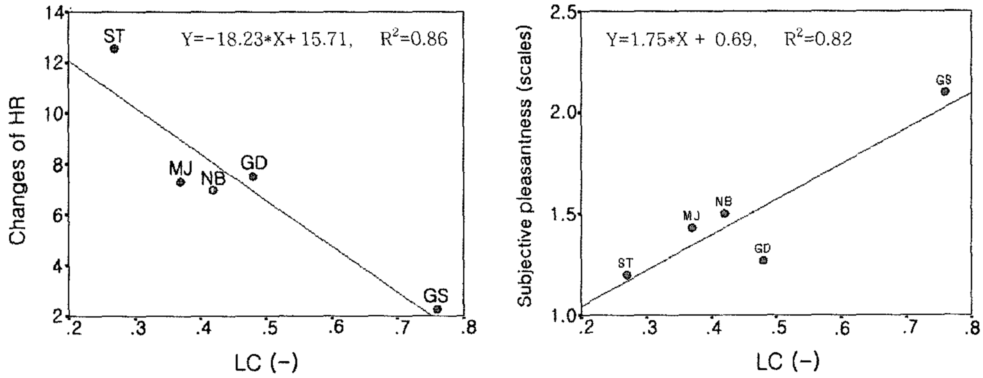
(a) Changes of HR (b) Subjective loudness

Figure 4. Effects of LPT on psychological and physiological responses.



(a) Changes of PV (b) Subjective softness

Figure 5. Effects of bending rigidity (B) on psychological and physiological responses.



(a) Changes of HR (b) Subjective pleasantness

Figure 6. Effects of compression linearity (LC) on psychological and physiological responses.

about 1.1 vacil.

Another predictable sound parameter for physiological and psychological responses was LPT, a physical loudness. Figure 4(a) and (b) explains that both changes of heart rate (HR) and subjective loudness tended to increase as the fabrics have louder sound. Human subjects felt all of sounds from the fabrics as loud except Gapsa and their HR values indicated their negative sensory state.

Effect of Mechanical Properties on Psychological and Physiological Responses

Among mechanical properties, bending rigidity (B) entered each of regression models for changes of pulse volume (PV) and subjective softness. As given in Figure 5(a) and (b), as the fabrics were more resistant against bending, they seemed to be evaluated as sounding less soft, which evoked the decrease of changes of PV. The threshold of bending rigidity (B) for positive PV responses may be about 1.4 gf·cm^2/cm. As mentioned in the results for the relationship between changes of PV and fluctuation strength(Z) in Figure 3(a), the silk fabrics without degumming such as Gapsa and Nobangju made sounds evoking the decrease of PV. On the contrary, those under scouring including Myoungju and Gongdan presented the increase nevertheless they were thicker and denser in their structural aspect.

Compression linearity (LC) was revealed as other significant mechanical properties having an effect on human responses for Korean traditional silk fabric sounds. The Figure 6(a) and (b) shows the effects of compression linearity (LC) on changes of heart rate (HR) and subjective pleasantness, respectively. As the fabrics were less bulk, their sounds seemed to cause stronger perception of pleasantness and less increase for changes of HR.

Conclusion

In this study, we examined acoustic characteristics of Korean traditional silk fabrics selected using clustering 38 Korean traditional silk fabrics by their sound parameters and investigate physiological and psychological responses of human beings to the sound of them. In addition, we tried to identify the objective factors including sound parameters and mechanical properties affecting the responses.

Among the fabrics, Gapsa structured by plain weave with gummed yarn showed the lowest LPT, and loudness(Z) values as expected in its FFT spectrum with lower levels over the range of frequencies, while it had the highest one for roughness(Z). On the other hand, Gongdan having dense satin weave that underwent sericin removal was found as giving the lowest values for roughness(Z) but the highest for fluctuation strength(Z). All of the Korean traditional silk fabrics tended to be perceived as sounding soft and pleasant so that Gongdan and Myoungju as the softest while Gapsa the most pleasant. On the contrary, most of sounds from the fabrics got the values for both clearness and highness lower than zero. As for physiological signals, indicators for a negative sensation such as LF/HF and skin conductance levels (SCL) changed less when the Korean traditional silk fabric sounds were presented than when other woven and knitted fabric sounds were. These results imply that Korean traditional silk fabrics seemed to make sounds comfortable rather than disturbing. We figured out sound parameters and mechanical properties that were significantly related with both physiological and psychological responses and thus were able to be utilized in order to control the sound quality of Korean traditional silk fabrics. Both Changes of pulse volume (PV) and subjective softness were affected positively by fluctuation strength(Z) and negatively by bending rigidity (B), respectively. Although sounds of the fabrics were evaluated as soft, the threshold values for positive responses of PV signal were about 1.1 vacil in fluctuation strength(Z) and 1.4 gf·cm^2/cm in the bending property, respectively. Other significant objective measurements for human responses were LPT and compression linearity (LC). Changes of heart rate (HR) were affected by both LPT and compression linearity (LC) in that the fabric sounds evoked larger changes of HR as they had higher LPT and also lower compression linearity (LC). Therefore it can be suggested that by controlling such sound parameters and mechanical properties above it will be possible to design more comfortable sound of Korean traditional silk fabrics.

This study has a strong implication in that characteristics of physiological responses were analyzed for Korean traditional silk fabrics for the first time and significant objective measurements such as mechanical properties as well as sound parameters were identified to apply them for designing more sensation specific Korean traditional silk fabrics to meet the requirements of the global textile market. It is worthwhile to further investigate such human responses to sounds of Korean traditional silk fabrics according to their weave structures and their traditional name categories because the silk fabrics' end-uses have been usually assigned by them. Moreover, additional feasible mechanical properties need to be searched so that their relationship with physiological and psychological responses can be used for providing more auditory sensible textile goods to consumers.

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