Transmission of Acoustic Information of Percussion Instruments through Tactile Sensation Using Air-Jet Stimulation for Hearing Impaired Person

Tomokazu Furuya[1], Yuki Yanagisawa[1], Takahiro Tamesue[2], and Kazunori Itoh[2]

[1] Graduate School of Science and Technology, Shinshu University,
4-17-1 Wakasato, Nagano-shi, Nagano 380-8553, Japan
tomo_f@cd5.so-net.ne.jp, t08a568@shinshu-u.ac.jp
[2] Faculty of Engineering, Shinshu University,
4-17-1 Wakasato, Nagano-shi, Nagano 380-8553, Japan
{tamesue,itoh}@cs.shinshu-u.ac.jp

Abstract. We are trying to transfer acoustic information to hearing impaired persons through tactile sensation using air-jet stimuli. We focused on psychological tonal impressions given when hearing various sounds, and examined whether these impressions could be given by air-jet stimuli. In order to replace percussion sounds with air-jets, we connected the acoustic characteristics to the parameters of the air-jet stimuli. Relationships between the acoustic characteristics of percussion instruments and the physical characteristics of air-jets have been found by analysis of psychological impressions given when hearing percussion instrument sounds and perceiving air-jet stimuli. As a result, transmitting musical information was possible.

Keywords: Acoustic information, Percussion sound, Tactile sensation, Air-jet stimulation, Hearing impaired person, Psychological impression.

1 Introduction

People can enjoy listening to music whenever and wherever thanks to the spread of portable music players. However, hearing impaired persons may have little or no access to them, because it is difficult for them to enjoy listening to music. It is necessary to develop a new interface device so they can enjoy listening to music. Accordingly, we are trying to transfer acoustic information to hearing impaired persons using tactile stimuli.

Vibratory stimuli or electric stimuli were used for transmitting rhythm in previous work[1], [2], [3], [4]. We thought that the transmission of timbre and melody were important, and focused on psychological tonal impressions given when hearing music. Transmission of the impressions was tried by tactile stimuli. An air-jet was used for the tactile stimuli. Air-jet stimuli evoke various tactile impressions such as powerfulness and weakness, sharpness and dullness, warmth and coldness, which are similar to psychological impressions induced by natural phenomena such as hurricanes and gentle winds, gusts and constant winds, warm breezes and cold winds. It was thought that

C. Stephanidis (Ed.): Universal Access in HCI, Part I, HCII 2009, LNCS 5614, pp. 48–57, 2009.

an impression similar to the tonal impression can be given by air-jet stimuli. Furthermore, it is possible to control the flow volume, injection time and temperature of an air-jet by a compact lightweight actuator. Air-jets are applied also in the field of virtual reality[5], [6].

In order to examine the transmission of music information by air-jet stimuli, we did a basic experiment[7]. As a result, the minimum perceptible interval is 65ms, the minimum perceptible flow volume is 4*L*/min, and the minimum perceptible differential flow volume is 1*L*/min. It was confirmed that air-jet stimuli are able to transmit rhythm and strength.

In this paper, we examined the psychological impressions of instrument sounds, and examined whether similar impressions were given by air-jet stimuli. It is difficult to examine the psychological impressions of musical instruments such as pianos and violins because these musical instruments have a lot of sounds. Thus, percussion instruments which have no musical scale were examined. Air-jets with various flow volumes, injection times, nozzle diameters and temperatures were used to examine psychological tactile impressions. As a result, transmitting psychological impressions similar to impressions given when hearing percussion instrument sounds by air-jet stimuli was possible.

2 Basic Concept and Procedure

We explain the basic concept and procedure of this research in this chapter. Fig. 1 shows the basic concept and procedure of this research. There are six steps in the procedure as numbered in Fig. 1. The procedure is shown as follows.

1. Psychological impressions given when hearing various percussion instruments are evaluated by adjective pairs. Principal factors on tonal impression are extracted by factor analysis.
2. The acoustic characteristics of the percussion instruments such as intensity and frequency are analyzed, and acoustic characteristics that influence factors are examined.
3. Psychological impressions of air-jet stimuli as well as tonal impressions of percussion instruments are evaluated by adjective pairs, and principal factors for tactile stimuli are extracted by factor analysis.
4. The physical characteristics of the air-jet, such as flow volume and temperature that influence factors are analyzed.
5. Each factor is related by a common adjective.
6. Common adjective scales to represent both tonal impression and tactile impression are estimated. Acoustic information from percussions is converted into control signals for the air-jet actuator.

A psychological tactile impression similar to that given when hearing a percussion sound can be given using an air-jet stimulus by the above-mentioned procedure.

For example, a powerful factor was extracted when a percussion instrument was heard (1). The acoustic characteristic that influenced this factor was the intensity (2). At this moment, a quantity factor was extracted when perceiving the air-jet stimulus (3).

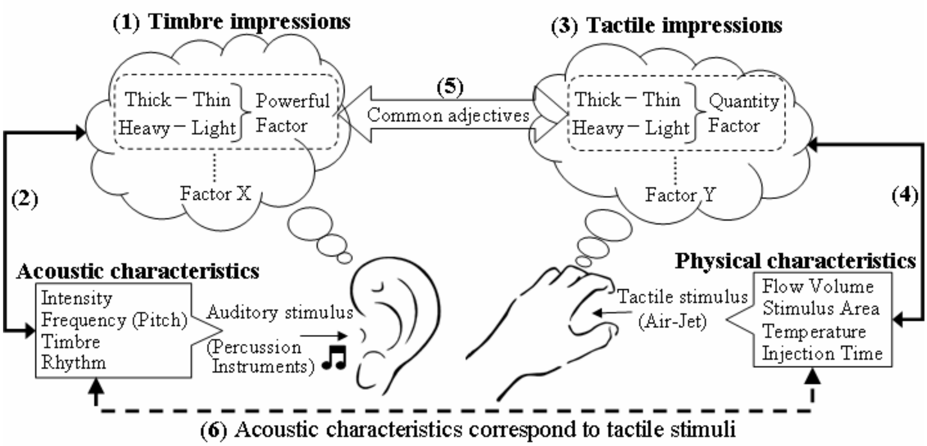


Fig. 1. Basic concept of this research

This factor is related to the flow volume (4). If common adjective pairs are included in both factors, the powerful factor and the quantity factor are similar impressions, and it is possible to relate them (5). In consequence, the intensity corresponds to the flow volume (6), and the air-jet stimulus can give an impression similar to the tonal impression.

3 Relationships between Psychological Impressions of Timbre and Acoustic Characteristics of Percussions

The psychological impression given when hearing a percussion sound was evaluated using the semantic differential (SD) method, and the factors of the psychological impression were investigated.

3.1 Psychology Evaluation Experiment of Percussion Instruments

In this study, 47 percussion instruments, which have been defined as such by the general musical instruments digital interface (MIDI), were classified and 22 percussion instruments were selected from them to be used for the psychological evaluation [8]. Table 1 shows the selected percussion instruments.

As for the adjective pairs used for the psychological evaluation, the eight adjective pairs that were in both the list of 40 Japanese adjective pairs used for the psychological evaluation of music and the list of 20 Japanese adjective pairs used to evaluate materials were selected [9], [10]. In Table 2, the selected adjective pairs are expressed in both English and Japanese [11].

In this study, 20 healthy persons (20–24 years old) were used as the subjects. The subjects wore a headphone in a soundproof chamber, and they heard the percussion sounds shown in Table 1 projected at comfortable volumes. They were asked to grade the sounds on a seven level scale (from –3 to +3) in terms of the eight adjective pairs shown in Table 2.

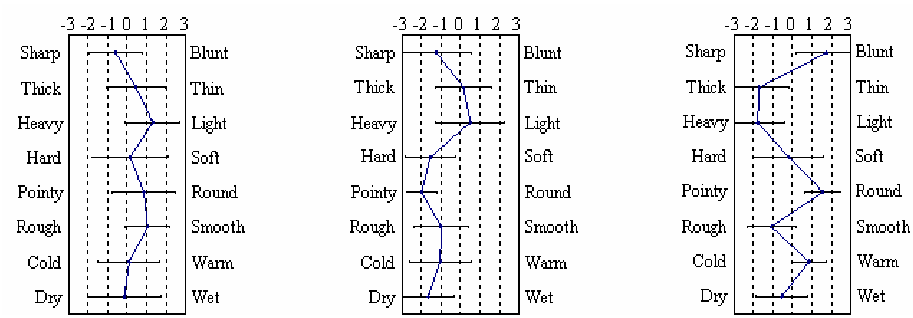
Table 1. Percussion instruments

Classification	Note No.	Instrument
Wooden Idiophone	73	Short Guiro
	75	Claves
	77	Low Wood Block
Metallic Idiophone	42	Closed Hi-hat
	46	Open Hi-hat
	49	Crash Cymbal 1
	53	Ride Bell
	56	Cowbell
	68	Low Agogo
	81	Open Triangle
Other Idiophone	69	Cabasa
	70	Maracas
	39	Hand Clap
	58	Vibra-slap
Membranophone	36	Bass Drum 1
	38	Acoustic Snare
	47	Low-Mid Tom
	54	Tambourine
	61	Low Bongo
	66	Low Timbale
	64	Low Conga
	79	Open Cuica

Table 2. Adjective pairs

No.	Adjective pair		
1	Thick (Atsuminoaru)	–	Thin (Usupperana)
2	Sharp (Surudoi)	–	Blunt (Nibui)
3	Heavy (Omoi)	–	Light (Karui)
4	Hard (Katai)	–	Soft (Yawarakai)
5	Cold (Tsumetai)	–	Warm (Atatakaminoaru)
6	Pointy (Togetogeshii)	–	Round (Maruminoaru)
7	Dry (Kawaita)	–	Wet (Uruoinoaru)
8	Rough (Arai)	–	Smooth (Kimenokomakai)

The levels obtained for each percussion sound were averaged, and the standard deviation was calculated. The results obtained using three typical percussion instruments (Low Wood Block, Crash Cymbal 1, and Bass Drum 1) are shown in Fig. 2. For example, for the adjective pair "sharp–blunt", the values shown in this figure are represented as follows: 0, neither of them; –1, rather sharp; –2, considerably sharp; –3, very sharp; +1, rather blunt; +2, considerably blunt; and +3, very blunt. The Low Wood Block type of wooden idiophone was evaluated highly in terms of light and smooth. Crash Cymbal 1 type of metal idiophone was evaluated highly in terms of pointy and dry. Bass Drum 1 type of membranophone was highly evaluated in terms of thick, heavy, and rough; this result was contrary to that of the Low Wood Block. As shown in Fig. 2, the evaluations changed significantly according to the type of percussion instrument.



(a) Low Wood Block (b) Crash Cymbal 1 (c) Bass Drum 1

Fig. 2. The result of the psychological evaluation of percussion instruments

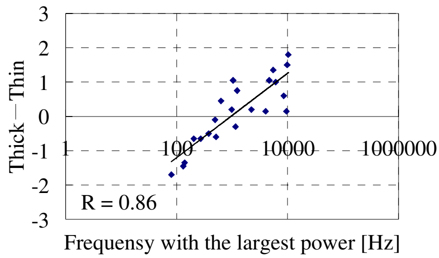
Factor analysis was performed on the data obtained from the psychological evaluation using the principal factor method and varimax rotation, and consequently, two factors (Factors 1 and 2) were extracted. Table 3 shows the factor loading of each. Previous studies have demonstrated that the image of each tone was determined by its powerful, metallic, and aesthetic factors. When the above was taken into consideration, Factors 1 and 2 could be interpreted as powerful and metallic factors, respectively. The reasons why only two factors were extracted were possibly that the number of adjective pairs was insufficient and the subjects hardly received any aesthetic impressions due to the very short sounds of the percussion instruments. In addition, since the difference in the factor loading was small between cold and warm and between rough and smooth, these adjective pairs were not used in the factor analysis.

Table 3. Factor loading for timbre impression of percussion

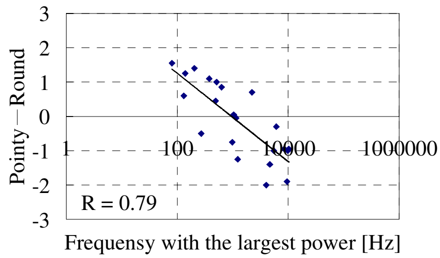
No.	Adjective Pair			Factor1	Factor2
1	Thick (Atsuminoaru)	–	Thin (Usupperana)	-0.656	-0.216
3	Heavy (Omoi)	–	Light (Karui)	-0.639	-0.040
2	Sharp (Surudoi)	–	Blunt (Nibui)	0.521	0.157
6	Pointy (Togetogeshii)	–	Round (Maruminoaru)	0.281	0.729
4	Hard (Katai)	–	Soft (Yawarakai)	0.090	0.535
7	Dry (Kawaita)	–	Wet (Uruoinoaru)	0.025	0.513
5	Cold (Tsumetai)	–	Warm (Atatakaminoaru)	0.421	0.453
8	Rough (Arai)	–	Smooth (Kimenokomakai)	0.471	-0.428

3.2 Acoustic Characteristics of Percussive Instruments

Among the adjective pairs used for the psychological evaluation, those with high factor loadings were considered to represent the factors of the psychological impression. As shown in Table 3, the adjective pair representing the powerful factor is "thick–thin," and that representing the metallic factor is "pointy–round." Then, the relationship between the evaluation results of these adjective pairs and the physical quantities of percussion sounds was investigated. The frequency of the sound pressure waveform was analyzed as a physical quantity, and the frequency with the largest power was obtained. Fig. 3 shows the results. As shown in this figure, the feeling of powerful represented by thick increased as the frequency with the largest power decreased. Moreover, the impression of pointy increased as the frequency with the largest power increased.



(a) Thick–Thin



(b) Pointy–Round

Fig. 3. Relationship between the evaluation result and acoustic characteristics

4 Relationships between Psychological Impressions of Tactile Sensation and Physical Characteristics of Air-Jet Stimuli

The psychological impression given when perceiving an air-jet stimulus was evaluated using parameters and factors involving tactile stimuli were also investigated.

4.1 Psychological Evaluation Experiment of Air-Jet Stimuli

The device shown in Fig.4 was used for the psychological evaluation of air-jet stimuli. The device consists of an air-jet compressor, a PIC microcomputer, an electromagnetic valve, a flow volume sensor, a heater, a nozzle. We can control the nozzle diameter, flow volume, injection time and temperature of the air-jet.

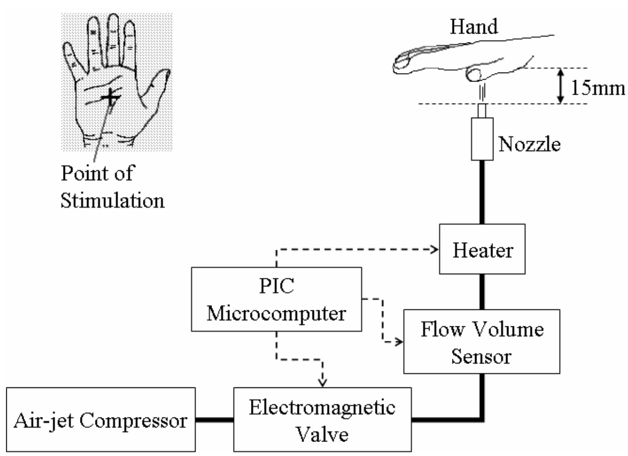


Fig. 4. Block Diagram of Air-jet Device

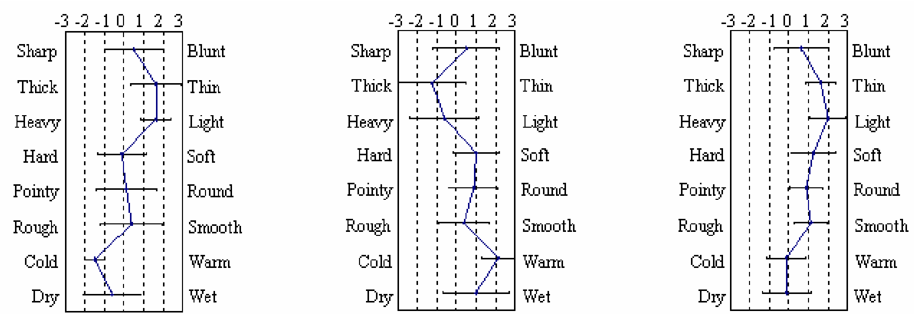
Each subject evaluated the 16 air-jet stimuli shown in Table 4 and graded them on a seven level scale in terms of the eight adjective pairs shown in Table 2. The distance between the palm and the nozzle is 15mm, and the center of palm was stimulated. The subjects were 8 healthy persons (21–32 years old).

Table 4. Parameters of Air-jet stimulations

No.	Nozzle diameter (mm)	Flow Volume (*L*/min)	Injection Time (ms)	Temperature (C)
1	0.5	5.9	940	11
2	0.5	5.9	62	11
3	0.5	3.1	62	11
4	0.5	3.1	940	11
5	1.5	4.7	940	28
6	1.5	4.7	62	28
7	1.5	9,5	62	28
8	1.5	9.5	940	28
9	0.5	5.9	940	28
10	0.5	5.9	62	28
11	0.5	3.1	62	28
12	0.5	3.1	940	28
13	1.5	4.7	940	11
14	1.5	4.7	62	11
15	1.5	9,5	62	11
16	1.5	9.5	940	11

The psychological evaluation results obtained by the air-jet stimuli with various parameters were averaged and the standard deviation was calculated. Fig. 5 shows some typical results. In this figure, No. 3 is an air-jet stimulus with a combination of the parameters' minimum values, and the evaluation results indicate the impressions of thin, light, and cold. No. 8 is an air-jet stimulus with a combination of the parameters' maximum values, and the evaluation results indicate the impressions of thick and warm; this result was contrary to that of No. 3. Therefore, it was demonstrated that when the parameters of an air-jet stimulus changed, the impressions received by the subjects also changed. No. 11 is an air-jet stimulus with parameters in which only the temperature differed from that of No. 3. Since the temperature was high in No. 11, the evaluation level of warm was expected to be high, similar to the results of No. 8. However, that level was almost equivalent to the mean value. Therefore, the impression was considered to change not only because of one parameter but also as a combination of multiple parameters.

Factor analysis was performed on the data obtained from the psychological evaluation using the principal factor method and varimax rotation, and, consequently, two factors (Factors 1 and 2) were extracted. Table 5 shows the factor loading of each. Since Factor 1 was related to the adjective pairs of "pointy–round" and "hard–soft," this factor could be interpreted as representing the feelings of quality. Since Factor 2 was related to the adjective pairs of "thick–thin" and "heavy–light," this factor could be interpreted to represent the feelings of quantity. Therefore, Factors 1 and 2 were defined as quality and quantity factors, respectively. In addition, since the difference in the factor loading was small between cold and warm, this adjective pair was not used in the factor analysis.



(a) No.3 (b) No.8 (c) No.11

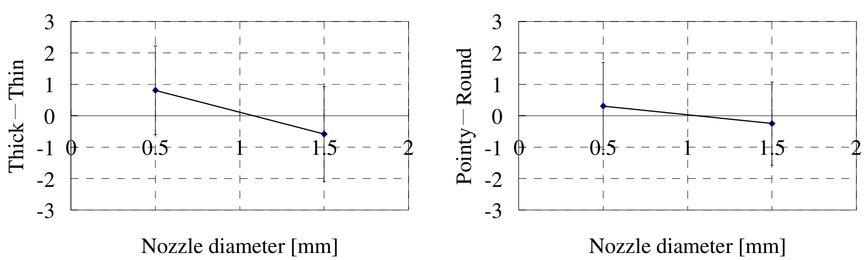
Fig. 5. The result of psychology evaluation of air-jet stimuli

Table 5. Factor loading matrix for tactile impression by air-jet stimulations

No.	Adjective Pair			Factor1	Factor2
6	Pointy (Togetogeshii)	–	Round (Maruminoaru)	0.909	0.022
4	Hard (Katai)	–	Soft (Yawarakai)	0.834	0.125
2	Sharp (Surudoi)	–	Blunt (Nibui)	0.738	0.155
7	Dry (Kawaita)	–	Wet (Uruoinoaru)	0.468	-0.007
8	Rough (Arai)	–	Smooth (Kimenokomakai)	0.450	0.190
1	Thick (Atsuminoaru)	–	Thin (Usupperana)	0.030	0.896
3	Heavy (Omoi)	–	Light (Karui)	0.236	0.777
5	Cold (Tsumetai)	–	Warm (Atatakaminoaru)	0.347	-0.271

4.2 Physical Characteristics of Air-Jet Stimuli

The adjective pair with the highest factor loading was selected as the representative of each factor. As shown in Table 5, the adjective pair representing the quality factor was "pointy–round," and the one representing the quantity factor was "thick–thin." Fig. 6 shows the relationship between the evaluation results of each adjective pair and the parameters of the air-jet stimuli. As shown in this figure, the feelings of quantity and quality increased as the nozzle diameter increased; here, the feeling of quality was expressed as pointy.



(a) Thick–Thin (b) Pointy–Round

Fig. 6. Relationship between the evaluation result and physical characteristics of air-jet stimuli

5 Correlation between the Acoustic Features and the Parameters Used for the Air-Jet Stimuli

The impressions received by percussion sounds were compared with those received by air-jet stimuli. The adjective pair "thick–thin" had the highest factor loading among the adjective pairs related to the powerful factor of a percussion sound. Also, this adjective pair had the highest factor loading among the adjective pairs related to the quantity factor of an air-jet stimulus. Moreover, the adjective pair "pointy–round" had the highest factor loading among the adjective pairs related to the metallic factor of a percussion sound and also had the highest factor loading among the adjective pairs related to the quality factor of an air-jet stimulus. Therefore, it can be said that the powerful factor corresponds to the quantity factor, and the metallic factor corresponds to the quality factor.

The frequency with the largest power of the percussion sound was correlated to the evaluation result of the adjective pair "thick–thin." Moreover, the nozzle diameter used for the air-jet stimuli was also correlated to the adjective pair "thick–thin." Since sounds with a low frequency have the impression of thickness, if the impression of thickness is desirable, the nozzle diameter should be enlarged. By enlarging the nozzle's diameter, an impression similar to that given when a percussion sound was heard can be given by an air-jet stimulus. However, the impression changes according to a combination of multiple parameters, and the interaction between these parameters must be taken into consideration.

6 Conclusion

In this study, adjective pairs to evaluate tones and the tactile sense were selected. By using the selected adjective pairs, psychological evaluations and factor analyses were performed. Moreover, the principal factor of the impression when hearing a percussion sound and that of the impression when receiving an air-jet stimulus were analyzed. Consequently, it was demonstrated that powerful and metallic factors are related to percussion sounds, and quality and quantity factors are related to air-jet stimuli. Moreover, since the correlation between the acoustic features and the parameters used for air-jet stimuli were observed, the physical quantities of a percussion sound could be replaced by the parameters used for an air-jet stimulus. Therefore, an impression similar to that given when a percussion sound was heard can be given by an air-jet stimulus.

In a basic experiment, the rhythm and intensity of a sound were demonstrated to be transmitted. In this study, the different impressions due to different percussion sounds were demonstrated to be given by air-jet stimuli. Therefore, transmission of musical information was possible. In the future, by using MIDI sound sources, we will actually apply air-jet stimuli to the hearing-impaired and investigate the transmission of this musical information.

References

1. Miura, S., Sugimoto, M.: T-RHYTHM: A System for Supporting Rhythm Learning by Using Tactile Devices. In: Proceedings of the IEEE International Workshop on Wireless and Mobile Technologies in Education, pp. 264–268 (2005)
2. Kawashima M.: Transcutaneous Electrical Rhythm Stimulator for Hearing Impaired People, Technical report of IEICE ET2003-83, pp.1–4 (2004) (in Japanese)
3. Schurmann, M., Caetano, G., Hlushchuk, Y., Jousmaki, V., Hari, R.: Touch activates human auditory cortex. NeuroImage 30, 1325–1331 (2006)
4. Gunther, E., Davenport, G., O'Modhrain, S.: Cutaneous Grooves: Composing for the Sense of Touch. In: Proceedings of the 2002 International Conference on New Interfaces for Musical Expression - NIME 2002, pp. 37–42 (2002)
5. Suzuki, Y., Kobayashi, M.: Air Jet Driven Force Feedback in Virtual Reality. IEEE Computer Graphics and Applications, 44–47 (2005)
6. Amemiya, K., Tnaka, Y.: Portable Tactile Feedback Interface Using Air Jet. In: Proceedings of 9th International Conference on Artificial Reality and Tele-Existence (ICAT 1999), pp. 115–122 (1999)
7. Furuya, T., Itoh, K.: Basic study for transmission of music information through tactile sensation using air-jet stimulation for Hearing Impaired Person. In: SOBIM 2006 Society of Biomechanisms, Japan, pp. 115–118 (2006) (in Japanese)
8. Fletcher, N.H., Rossing, T.D.: The Physics of Musical Instruments, 2nd edn. Part V Percussion Instrument, pp. 581–707. Springer, Heidelberg (1998)
9. Kitamura, O., Ni-i, S.-i., Kuriyama, J., Masuda, N.: The factor analytical research on tone color for the youth of today - in the case of monophonic sound. Transactions on Technical Committee of Psychological and Physiological Acoustics, Acoustical Society of Japan, H-51–H-11 (1978) (in Japanese)
10. Yoshida, M.: Dimensions of tactual impressions. Memoirs of the Japan weman's university 13, 47–68 (1963) (in Japanese)
11. Namba, S., Kuwano, S., Hashimoto, T., Berglund, B., Da Rui, Z., Schick, A., Hoege, H., Florentine, M.: Verbal expression of emotional impression of sound: A cross-cultural study. Journal of Acoustical Society of Japan (E) 12(1), 19–29 (1991)