Individual Differences in the Affective Evaluation in Chord Listening

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Abstract. Chords are one of the most important elements of music, and their sound evokes various impressions and emotions. It is known that the way people perceive the sound of chords differs from person to person, but this has not been sufficiently studied until now. In this study, we analyzed individual differences in chord perception using kansei engineering methods. As a result, it was found that the impression of a chord consists of eight aspects, which are perceived comprehensively, including not only the pitch structure of the chord but also other acoustic features such as timbre structure. Furthermore, the relationship between acoustic features and chord impressions suggested that there are three different types such as the integrative type, the pitch structure type, and the timbre structure type, of human chord perception and that qualitative differences in musical experience affect chord perception.

Keywords. Chords, Individual differences, kansei/sensibility engineering, Psychophysical Model

1 Introduction

Chords, along with melody and rhythm, are one of the basic elements of music and are some of the factors that enrich the impression of music and evoke various emotions. The various expressions that chords can bring about have been studied mainly from the musical and psychological aspects [1]. In recent years, the importance of chords in sound design in non-music fields such as soundscape (environmental sounds, spatial acoustics, noise) and artificial sounds (operation response sounds, warning sounds) has been increasing, and a systematic understanding of the emotional effects of chords on people has become an issue.

Theoretical approach include studies that have attempted to provide an acoustic explanation for the perception of chord resonance based on pitch structure (pitch, including relative ones) [2]–[5]. Based on the qualitative features of chords commonly found in these studies, it has been shown that the sonority of a chord requires the consideration of three factors (impression factors)—dissonance, tension, and modality—

and that these factors can be predicted from the pitch structure (acoustic features). However, it has been shown that timbre structure, in addition to pitch structure, affects the sound of chords used in actual music [6] and that pitch structure alone cannot explain the sound of some chords [7].

On the other hand, an experimental approach has large-scale surveys that have revealed acoustic and cultural predictors in the perception of consonance/dissonance [8]. The results revealed that familiarity, harmonicity, roughness, and spectral envelope contributed in that order. However, many other types of impressions formed from chords are known besides consonance/dissonance, and there are also various possible acoustic factors involved in impression formation. These impression and acoustic factors have not been fully elucidated.

Furthermore, it has been reported that individual differences exist when focusing on the way humans perceive sound. For example, it has been shown that there are individual differences in emotional responses when listening to engine sounds [9]. It has also been suggested that there are differences in emotional responses in chord listening between musicians and non-musicians [10][11]. In other words, in order to understand how the sound of chords can be perceived, it is necessary to consider factors on the human side as well. Furthermore, many studies have focused on the differences between musicians and non-musicians in terms of years of musical experience and subjective musical experience, but few have focused on the qualitative differences in musical experience.

In this study, in order to clarify aspects of how users perceive the sound of chords, the following questions were set up: (1) What are the impression factors of chords, which also take timbre into account; (2) can the impression factors be explained by pitch and timbre structures; and (3) are there individual differences in the relationship between acoustic features and harmonic impression?

We then show the results for the questions above using the kansei engineering method. kansei engineering is a technology for quantifying the values and impressions evoked by physical factors, and for determining the physical factors that bring about values and impressions, measuring the physical factors and the emotional responses they evoke, and modeling the relationship between the physical factors and emotional quantities obtained as grand truth [12]. This method assumes that kansei/sensibility has a hierarchical structure consisting of three layers: value, impression, and physical features, and kansei is quantified and analyzed as a hierarchical structure model (Fig.1). The value layer includes a variety of concepts such as emotions, goodness, preference, and so on. In this study, we analyzed the sonority of chords using the framework outlined above. First, we studied the impression factors of chord sonority to clarify the first question. Next, to clarify the second question, we analyzed the relationship between the chord impression and the chord features, which describes the pitch structure. Finally, to clarify the third question, we compared the relationship between the impression and physical layers for each individual.

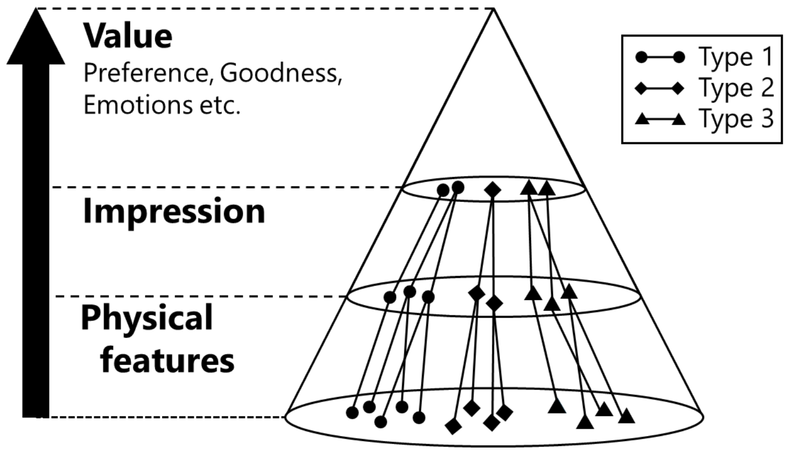

Fig. 1. Concept of a hierarchical structure model of kansei/sensibility.

2 Factors for Chord Impression

Purpose

In this study, in order to clarify the impression factors of chords, (1) impressions and emotions during triad listening were measured using a subjective evaluation experiment, and (2) the impression factors of chord sound were extracted using factor analysis.

Method

Subject

Participants included 30 adults (15 males and 20 females, aged 19 to 24 years, with a mean age of 22.17 years). The overall mean number of years of music training was 8.03 (*SD* = 6.37).

Evaluation words

The selection of evaluation words used in the impression evaluation experiment was conducted in the following procedure. First, the evaluation words collected from the free description experiment were combined with those from previous studies, and those that were considered to be identical were deleted. Next, a goodness-of-fit experiment was conducted to create a dataset of evaluation words appropriate for the impression evaluation experiment. Among them, evaluation words such as “high” and “clear,” which are directly related to acoustic features, were classified as lower-order impression layer, and evaluation words such as “calm” and “bright” were classified as higher-order impression layer. Then, a distance measurement experiment was conducted to measure the similarity between the evaluation words, and the evaluation words were structured using the multidimensional scaling method. Cluster analysis was performed from the two-dimensional coordinates obtained via the multidimensional scaling method, and the evaluation words closest to the center of gravity within each cluster were extracted as representative words.

Stimulus

Twenty chord stimuli, which were combinations of the basic forms of four instruments (piano, violin, trumpet [in B♭], and clarinet [in B♭]) and five major triads (Major, Minor, Dim, Aug, and Sus4), were used in the experiment. To remove the effect of pitch, the lowest and highest tones were fixed at E♭4 and E♭5, as shown in Figure 2. These stimuli were unified to be 4 seconds in length and were created using Musescore3 music composition software. The sound font used was Arachno SoundFont Version 1.0.sf2. To control the sound pressure in terms of RMS (Root Mean Square), the amplitude was normalized using Audacity.

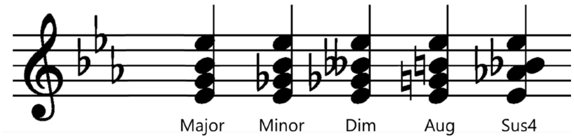

Fig. 2. Triads used as experimental stimuli

Experimental environment

The experimental stimuli were played on a PC and presented through an acoustic amplifier (nano iDSD and iFi audio) and headphones (SONY MDR-CD900ST).

Procedure

After listening to each chord stimulus, the participants rated their emotions and impressions. For the emotional evaluation, the degree of "pleasant-unpleasant" and "arousal-sleepiness" was recorded using the AffectGrid method [13]. For each stimulus, the session from stimulus listening to response was repeated four times. In the impression evaluation, the degree to which each of the evaluation words extracted by the method described above was applied to the stimuli and measured using a 7-point Likert scale. The emotional evaluation was not analyzed; only the impression evaluation was assessed in order to focus on the relationship between the impression of the chords and the acoustic features.

Factor Analysis

Using the collected subjective evaluation data, we extracted the evaluation axes constituting the impression layer using factor analysis. To focus on the psychological responses related to the chord structure, we excluded the trumpet stimulus, which was found to have different arousal levels in a preliminary study, from the analysis in this study. We used HAD17.10 for factor analysis, the maximum likelihood method for the extraction method, and the Promax rotation method for the rotation method. We determined the number of factors using parallel analysis. As a result, we extracted three factors (consonance [−], strength [−], and thickness) from the lower-order impression layer, and five factors (brightness, gloominess, beauty, blandness, and excitement) were extracted from the higher-order impression layer. Table 1 shows the factor loadings for the lower-order impression layer, and Table 2 shows the factor loadings for the higher-order impression layer. The results indicate that the sound of a chord has a complex aspect. In particular, we subdivided the factors that have been called modality in previous studies into “brightness,” “gloominess,” and “beauty,” suggesting the need to look at individual aspects.

In addition, we examined whether there is a factor that corresponds to the instability explained by the combination of dissonance and tension in the previous study [4]. Specifically, we calculated Spearman’s rank correlation coefficients between our psychological evaluation values and instability, and then we compared items with high correlations. First, the rank correlation coefficients and their significance tests (α = 0.05) showed significant correlations for consonance (−), strength (−), brightness, and beauty, but as shown in Figure 3, no factor showed a consistent ordinal relationship with instability. This suggests that instability, an impression factor identified in previous studies, is not included in the overall sound component. In other words, we clarified the chord impression as the totality of the perceived components, including the components of individual chord impressions.

TABLE I: FACTOR LOADING (LOWER-ORDER IMPRESSION LAYER)

Items	**Consonance (−)**	**Strength (−)**	**Thickness**
muddy	**0.821**	−0.073	0.216
dull	**0.630**	−0.052	0.238
not blend	**0.553**	−0.345	−0.185
complex	**0.543**	−0.009	0.379
monotonous	**0.429**	0.125	−0.411
soft	0.038	**0.794**	0.017
blend	−0.304	**0.633**	0.332
float	0.041	**0.613**	−0.075
clear	−0.374	**0.530**	−0.105
weakly	0.417	**0.457**	−0.384
thick	0.211	0.091	**0.830**
stretchy bass	0.250	0.144	**0.552**

TABLE II: FACTOR LOADING (HIGHER-ORDER IMPRESSION LAYER)

Items	Brightness	Gloominess	Beauty	Blandness	Excitement
warm	**0.902**	0.151	0.072	−0.126	0.057
cheerful	**0.799**	−0.046	−0.087	−0.054	0.281
bright	**0.696**	−0.163	0.051	−0.032	0.209
mild	**0.621**	0.018	0.363	0.141	−0.092
pleased	**0.603**	−0.207	0.223	0.161	0.148
happy	**0.592**	−0.208	0.287	0.129	0.126
lonely	0.119	**0.853**	0.049	0.065	−0.139
anxious	−0.078	**0.818**	−0.191	−0.031	0.147
sentimental	0.092	**0.773**	0.191	0.079	0.009
depressing	−0.120	**0.748**	−0.119	0.040	0.060
dark	−0.279	**0.631**	0.090	0.067	−0.002
cold	−0.237	**0.527**	0.275	0.287	0.061
elegant	−0.070	−0.026	**0.748**	−0.032	0.041
beautiful	0.176	−0.048	**0.708**	0.034	0.040
leisurely	0.288	0.224	**0.597**	0.054	−0.392
deep	−0.111	0.271	**0.555**	−0.216	0.188
rich	0.380	0.178	**0.487**	−0.225	0.141
mysterious	−0.274	0.297	**0.329**	−0.014	0.216
dry	−0.234	−0.032	0.070	**0.784**	0.198
bland	0.148	0.043	−0.062	**0.774**	−0.021
boring	0.176	0.204	−0.211	**0.572**	−0.071
exciting	−0.111	0.113	−0.018	0.048	**0.757**
bustling	0.177	0.187	−0.434	0.086	**0.668**
animated	0.403	−0.125	0.126	0.018	**0.513**

3 Sonority Model Based on Acoustic Features

Purpose

We performed multiple regression analysis to analyze the relationship between impression factors and acoustic features.

Acoustic Features

We extracted acoustic features explaining the impression factor of the chords for the chord stimuli used in the impression evaluation experiment. In addition to the acoustic features, we also calculated a sound quality evaluation index, which is a standardized index based on the subjective perception of sound, and acoustic features related to spectral bandwidth information other than the above acoustic features. We conducted multiple regression analysis using JMP to investigate the acoustic feature elements that explain each factor of the chord impression.

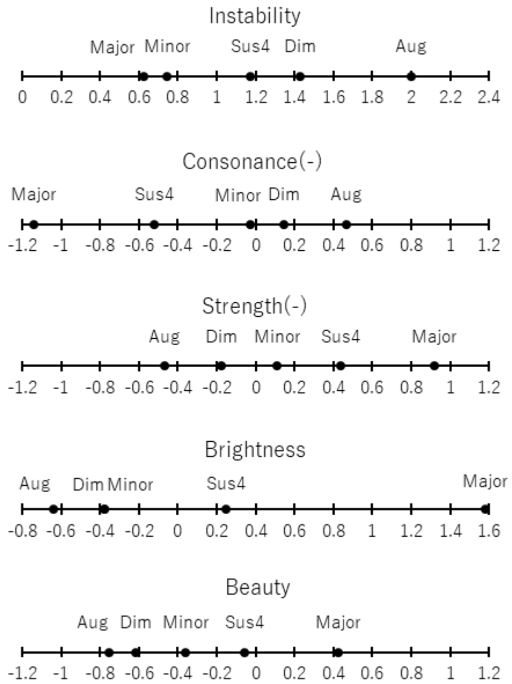

Fig. 3. Comparison of instability and psychological values

First, as acoustic features based on pitch structure, we used the model of the previous study [4] to calculate dissonance, tension, and modality from the pitches of the chord components.

Next, we employed four indices (loudness, sharpness, roughness, and fluctuation strength) used in general sound quality evaluation as sound quality evaluation indices [14]. Then, we performed the calculations using MATLAB's Audio Toolbox.

In addition to the above acoustic features, we used the following spectral bandwidth information: spectral centroids, spectral flatness, spectral skewness, spectral spread, spectral kurtosis, spectral entropy, spectral centroids, spectral flatness, spectral skewness, spectral spread, spectral kurtosis, spectral entropy, spectral rolloff, and attack slope. We used the MIR Toolbox in MATLAB for the calculations. The timbre of a musical instrument has a temporal variation of amplitude called amplitude envelope, and the frequency components included until the maximum amplitude (Attack) and after that (Delay, Sustain, and Release) are different. For this reason, we also calculated the features in the Attack interval for the mean loudness, mean roughness, spectral flatness, spectral spreads, and spectral kurtosis indices.

Multiple Regression Analysis

We conducted multiple regression analysis based on the AIC stepwise method of variable selection using the impression and emotion layers as objective variables and the acoustic features and their interaction terms as explanatory variables. We used the factor scores of each factor as the representative values for the impression stratum, as well as the standardized mean values of the four evaluations as the representative values for the emotion stratum. The results of the analysis are shown in Table 3. We obtained a model with high explanatory power (adjusted $R^2 > 0.7$) for all the factors in the table. For “consonance (-),” “brightness,” and “gloominess,” the pitch structure contributed particularly strongly to their formation, whereas for the other elements, the influence of other acoustic features was significant. Furthermore, the interaction effect was significant for several items.

The results of the modeling of the impression evaluation of chords showed a clear distinction between factors that can be adequately explained by the pitch structure and factors that cannot be explained only by features based on the pitch structure. In particular, for the “thick,” features based on the pitch structure were not employed as explanatory variables, but the sound quality evaluation index “loudness” and the spectral bandwidth information “spectral flatness” were employed. Factors such as “strength (-),” “beauty,” and “blandness” were also strongly influenced by the attack interval features and the sound quality evaluation indices such as fluctuation strength and loudness.

As for the interaction effects, the effects of feature interactions based on pitch structure were strong for “brightness” and “gloominess.” This suggests that we do not perceive pitch structure–based factors in a discriminative manner but rather as a whole when perceiving sound.

Based on these results, we believe that the addition of sound quality evaluation indices and spectral bandwidth information to the pitch structure–based features can provide a comprehensive explanation of the entire impression layers. In addition, the results suggest the necessity of examining the integration style of the discriminatively obtained factors in order to explain the resonance.

Validation of Model Prediction for Consonance

Among the impression factors obtained in the present study, the consonance (-) is considered to be the factor corresponding to dissonance. In conventional C&F models, it has been reported that this dissonance sometimes does not match the psychological ratings [8]. If the model constructed in this study can improve this discrepancy, it can be said that we constructed a more valid sonority model than in the conventional model. In this study, we evaluated the validity of the model by calculating the dissonance of the conventional model and the estimated value of the consonance (-) for each timbre of the model, obtaining a ranking, and comparing them. The results are shown in Table 4. The estimated values of the model showed the same rank for all instrumental tones. The estimated values of the model showed the same rank for all instrumental tones.

We conducted a one-way ANOVA to examine whether there were differences in the psychometric evaluation of the degree of harmony among the five types of chords in the piano tone. The results showed a main effect of chord type (F [4, 116] = 11.898, $p < 0.001$). In addition, we performed Bonferroni’s multiple comparisons to examine specific differences among the chords. The results showed a significant difference between the first-ranked Major and the second-ranked Sus4 ($p < 0.05$). Next, we found no significant difference between Sus4 and Minor, the third rank, but we found a significant difference between Sus4 and Dim, the fourth rank ($p < 0.05$). In addition, we found no significant difference between Minor and Dim, but we found a significant trend between Minor and Aug, the fifth rank ($p = 0.177$). These results indicate that the relationship between the degree of harmony between the chords can be ex-

TABLE III: RESULT OF MULTIPLE REGRESSION ANALYSIS

Object Variable	**Explanatory Variable**	**β**	**R²**
Consonance (−)	tension	0.709***	0.763***
	modality	−0.548**	
	spreads	−0.363*	
Strength (−)	tension	−0.661***	0.814***
	attack slope	0.599**	
	spreadsA	1.096***	
	attack slope・spreadsA	−0.947***	
Thickness	loudness	1.093***	0.977***
	flatness	0.014	
	meanLoudnessA	0.072	
	flatness・meanLoudnessA	0.283**	
Brightness	dissonance	0.773**	0.974***
	tension	3.009**	
	modality	−16.374***	
	tension・modality	−17.463***	
Gloominess	dissonance	−0.926**	0.964***
	tension	−3.651***	
	modality	19.247***	
	tension・modality	20.411***	
Beauty	tension	−0.528***	0.946***
	modality	0.384***	
	fluctuation strength	0.841***	
	kurtosisA	0.239*	
Blandness	tension	0.266*	0.905***
	modality	−0.279**	
	loudness	−1.257***	
	spreads	−0.839***	
	loudness・spreads	−0.453**	
Excitement	modality	−0.273*	0.832***
	loudness	−1.153***	
	spreads	−0.744**	
	loudness・spreads	−0.523**	

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

For variables in the table, “Spectral” is omitted for notational convenience.

TABLE IV: COMPARISON OF CONSONANCE ESTIMATES

	Psychological Values			Estimated Values	
	Piano	**Clarinet**	**Violin**	**C&F [4]**	**This Study**
Major	1	1	1	1	**1**
Minor	3	3	3	1	**4**
Dim	4	4	5	5	**3**
Aug	5	5	4	3	**5**
Sus4	2	2	2	4	**2**

pressed as follows:

Major ≫ Sus4 ≫ Minor ≒ Dim > Aug

When the values estimated by this model are compared with the psychological evaluation, the ranks of the third and fourth-order chords are reversed, but there is no significant difference between them in terms of psychological evaluation, indicating that this model can estimate the ranks of degree of congruence with greater accuracy than the conventional theory-based model [4].

4 Analysis of Individual Differences Based on Acoustic Features

To clarify individual differences in chord perception, we conducted a type classification based on differences in the relationship between acoustic features and chord impressions. Specifically, we conducted multiple regression analysis based on the AIC stepwise method using the evaluation data for each individual, with "brightness" and "gloominess," which contribute to the modality that divides Major and Minor, as objective variables as well as the acoustic feature values and their interaction terms as explanatory variables. The results showed that the acoustic features focused on for each factor differed among the participants. We found that participants were broadly categorized into three types (four types in detail): the integrative type, which listens to pitch structure in an integrated manner as shown in Figure 4(a), the pitch structure type, which listens to pitch structure in a discriminative manner as shown in Figure 4(a) and Figure 4(b), and the timbre structure type, which listens to pitch structure almost exclusively as shown in Figure 4(c).

We compared the mean years of music experience for each type of "gloominess": 12.3 years (*SD* = 4.45) for the integrative type, 5.7 years (*SD* = 5.92) for the pitch structure type, and 6.6 years (*SD* = 6.62) for the timbre structure type as shown in Table 5. Then, we conducted a one-way ANOVA to determine whether there was a difference in the mean years of musical experience between the two types. We discovered a main effect for years of music experience ($F\ [2, 29] = 3.958$, $p = 0.031$). In addition, Bonferroni's multiple comparisons were conducted to examine specific differences between types. The results showed a significant difference between the integrative type and the pitch structure type ($p < 0.05$). This suggests that the tendency to listen to pitch structure in an integrated manner may increase with musical training. This result is consistent with the results suggested in previous research [15], where the preference for overtone frequencies was amplified by the experience of playing a musical instrument. Furthermore, when the qualitative differences in musical experience were investigated, as shown in Figure 5, more people with string instrumental and choral experience belonged to the integrative type. These results suggest that the acoustic properties of musical instruments may influence perception through performance experience.

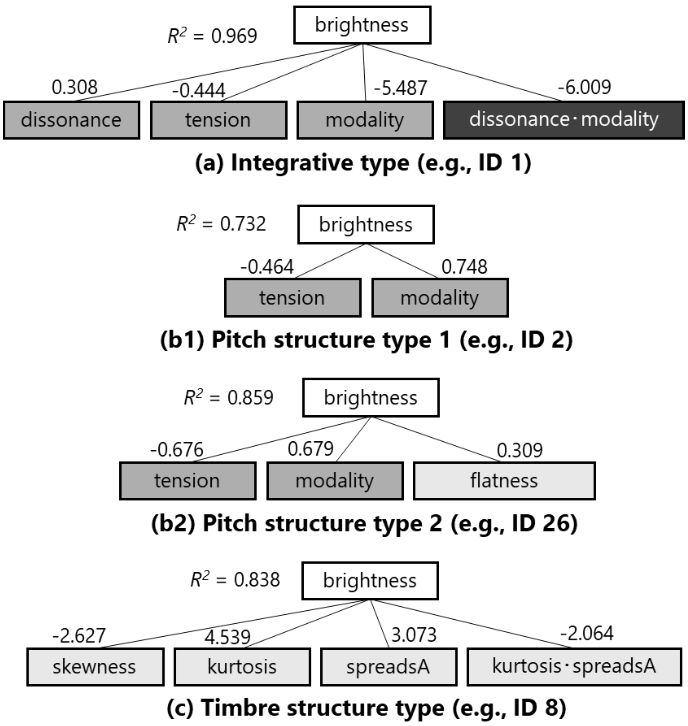

Fig. 4. Models of each type

TABLE V: Years of Music Experience

Participant ID	Brightness	Gloominess	Years of Music Experience
1	a	a	10
3	a	a	14
16	a	a	15
23	a	a	15
24	a	a	19
29	a	a	2
5	b	a	14
7	b	a	8
9	b	a	12
22	b	a	14
2	b	b	3
4	b	b	0
10	b	b	5
11	b	b	0
12	b	b	17
13	b	b	0
14	b	b	9
17	b	b	7
18	b	b	0
19	b	b	4
20	b	b	3
21	b	b	0
25	b	b	13
26	b	b	18
30	b	b	6
27	b	c	0
6	c	c	8
8	c	c	0
15	c	c	18
28	c	c	7

*a: Integrative type, b: Pitch structure type, c: Timbre structure type

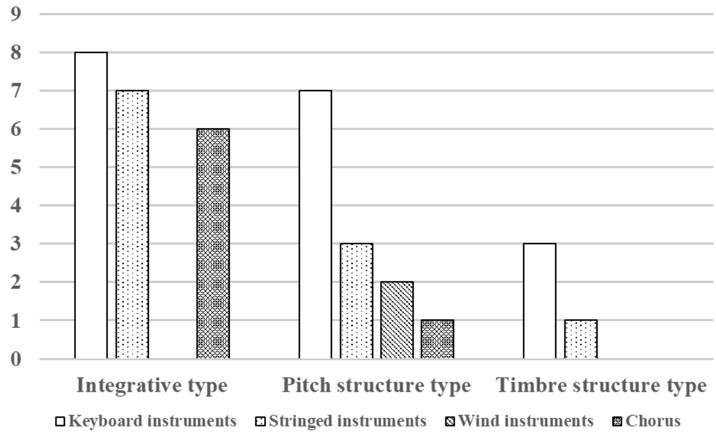

Fig. 5. Number of players of each instrument

5 Conclusion

In this study, we investigated the quantification of chord impressions based on kansei engineering methods. First, we conducted an impression evaluation experiment using evaluation words collected from a free description experiment, and then we clarified the complex aspects of how sounds are perceived when listening to chords. Next, we analyzed the relationship between chord impressions and acoustic features. First, we extracted features based on pitch structure, sound quality evaluation index, spectral bandwidth information, and acoustic features of the attack section. Then, we conducted multiple regression analysis using chord impression as the objective variable and acoustic features as explanatory variables to investigate the relationship between chord impression and acoustic features, resulting in a model with high explanatory power in all impression and emotion layers. Furthermore, we examined the validity of the model and found that the model was able to estimate the ranking of the degree of harmony with high accuracy. These results suggest that it is effective to clarify the individual aspects of chord impressions and their correspondence with acoustic features using kansei engineering methods. Furthermore, the results of an examination of individual differences in the relationship between acoustic features and chord impressions revealed three different types such as the integrative type, the pitch structure type, and the timbre structure type, suggesting that differences in the quality of musical experience influence the affective evaluation.

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