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# Chord Character Evaluation Model Based on Real Acoustic Sources: Introduction to Differences in Timbre

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**Summary**
Chord is a factor as important as a melody and rhythm in the creation of music. However, it is unclear whether any acoustical features of each chord affect the impression of the chord. In previous studies, psychophysical models were constructed to evaluate chord impression (i.e., chord character evaluation models). These models can quantitatively evaluate the relevance of physical acoustical features, psychological impressions, and sensibilities of each chord. Nevertheless, in previous chord character evaluation models, virtual acoustic sources were used for evaluation. Thus, the correspondence between real acoustic sources and the output of the chord character evaluation models has not been considered much. Therefore, differences in the timbre of instruments have not been able to be validated. In order to add the function to be able to understand the difference in timbre, peaks of frequency were extracted from real acoustics sources and power and frequency were used to calculate the impression of the chords. In order to validate the correlation between the psychological impression and chord character evaluation model, an experiment that evaluates the impression of primary triads in theory of harmonics was performed through the paired comparison method in the primary triads of the theory of harmonics. The results suggest that the psychological impression differs depending on timbre. Furthermore, theoretical values that were calculated by previous chord character evaluation models and the chord character evaluation model proposed in this study were compared to the experimental result. The results suggest that our proposed theoretical value had a stronger correlation with experimental results than previous theoretical values. In the case of the same audio source, a stronger correlation was found in the experimental results and theoretical values. In conclusion, our study found that a timbre is one of the important factors that affect the impression of the chord.

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## 1. Introduction

Chord is a factor that is as important as melody and rhythm in the creation of music; and, as such, it is one of the most essential factors needed in order to evoke various emotions through music. Various impressions brought about by a chord are influenced by the sound that constitutes it, and this unique feature is seen in every chord. For example, a major chord brings an impression of consonance (a combination of notes that sound pleasant to most people when played at the same time), while diminished or augmented triads give the impression of dissonance. This is a common reaction regardless of cultural or social background, and has been a widely used technique not only in works such as film background music but also in soundscapes and sound design for media transmissions. Many psychological models have been proposed on the relationship between physical characteristics (such as tone frequency ratio) and psychological characteristics of chords [1][2][3]. However, these studies have largely been restricted to the most fundamental chord group (triads), and a model that can be fully explained is yet to be constructed.

In particular, in previous chord character evaluation models, virtual acoustic sources were used for evaluation. Thus, the correspondence between real acoustic sources and the output of the chord character evaluation models has not been considered much. Therefore, differences in the timbre of instruments have not been able to be validated.

In this study, in order to add the ability to understand the difference in timbre, theoretical value was calculated by use of real acoustic sources, which were compared with the experimental result.

## 2. Previous Chord Character Evaluation Model

Cook et al. defined chord character as the “general nature of sensibility given by chords.” They also calculated a theoretical curve for psychological indexes such as the levels of dissonance (D, consonant-dissonant), tension (T, tensed-calm), and modality (M, major-minor), with reference to the frequency ratio of the two interval structures (a root note to a third tone, a third tone to a fifth tone) that compose a triad. Each equation is shown below [4]:

$$D = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1} v_{ij}\alpha_3\left[\exp(-\alpha_1 x_{ij}^{\beta}) - \exp(-\alpha_2 x_{ij}^{\beta})\right] \quad (1)$$

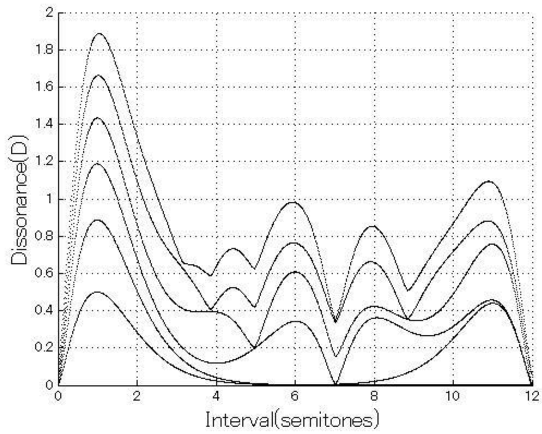
$$T = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1}\sum_{k=0}^{n-1} v_{ijk}\exp\left[-\left(\frac{x_{jk}-x_{ij}}{\gamma}\right)^2\right] \quad (2)$$

$$M = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1}\sum_{k=0}^{n-1} -v_{ijk}\left[\frac{2(x_{jk}-x_{ij})}{\varepsilon}\right]\exp\left\{-\left[\frac{(x_{jk}-x_{ij})_{ijk}^4}{4}\right]\right\} \quad (3)$$

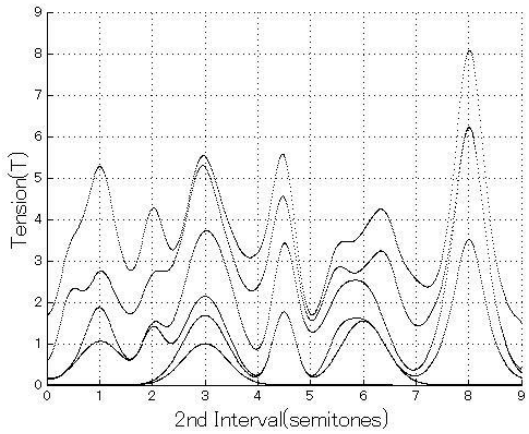
Here, $\alpha$, $\beta$, $\gamma$ and $\varepsilon$ represent constant values, $x$ is an interval, $n$ is the number of harmonic overtones used in the equation, and $v$ is volume. The expanded theoretical curves shown in Fig.1 (a), (b) and (c) are obtained by adding up each overtone to six harmonic overtones. The intervals between the root notes and the third tones in Fig.1 (b) and (c) are all five semitones.

In the psychological indexes, the instability obtained from combining the dissonance level and tension level is reportedly similar to the results obtained from the behavioral experiment, revealing the human impression effect against chords. The equation is shown below:

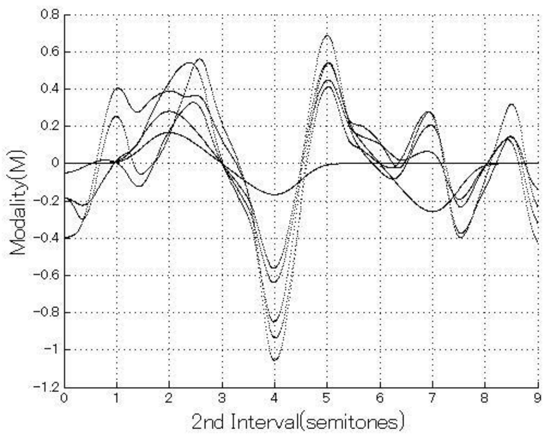
$$I = \frac{1}{3}\sum_{i=1}^{3} D_i + \delta T \quad (4)$$




(a) Dissonance Curve




(b) Tension Curve




(c) Modality Curve

Figure 1. Psychophysical Function of Chord Perception

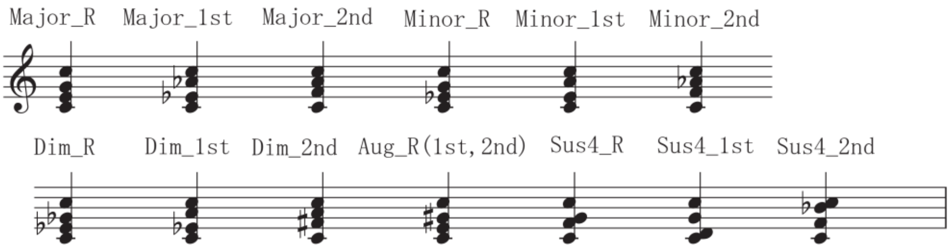



Figure 2. Chordal Stimulus

## 3. Theoretical Calculation

Real acoustic sources were windowed in a Hamming window and then a frequency analysis was performed by use of FFT (Fast Fourier Transform). In order to suppress pitch tolerance and noise, frequency peaks were extracted from real acoustics sources and power and frequency were used to calculate the impression of the chords.

## 4. Experiment

The subjects consisted of fourteen university students from ages twenty-one to twenty-three (years of musical experience between zero and seventeen years). An experiment that evaluates the impression of primary triads in the theory of harmonics was performed through the paired comparison method in the primary triads of the theory of harmonics. The primary triads of the theory of harmonics that were used in an experimental stimulus constituted five types (major, minor, diminished, augmented and suspended fourth) (Fig.2). The inversions of the chord were three kinds (root, first inversion and second inversion) (Chord names henceforth were called "triad_inversion"). In order to suppress the impression evoked by pitch, stimulus unified the root note as C (261.6 Hz) and the added C1 (523.2 Hz). There were twenty stimulus pairs in total. The chordal stimuli were generated by piano via SoundFont and organ via VSTi. The experiment was performed on a PC via a speaker in a soundproof room. "Dissonance," one of the chord impressions, was evaluated in five steps ("the former chord was dissonant," "the former was slightly dissonant," "almost the same," "the latter chord was slightly dissonant," and "the latter chord was dissonant.") Ura's procedure, modified from Scheffe's Paired Comparison, was used for analysis. Evaluative words related to "Dissonance" were used an experimental stimulus and included five kinds of words (dissonance, immiscible, unpleasant, unsteadiness, complexity). In order to suppress the impression evoked by the chordal progression, stimulus presentations were designed to promote a "grouping." In particular, each chord was played three times, then a rest of between 1.2 and 1.4 beats was inserted, then the next chord was played three times (Fig.3).

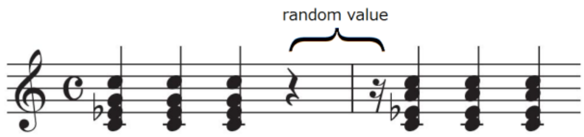



Figure 3. Chordal Stimulus Presentation

## 5. Results and Discussion

### 5.1. Experimental Result

This experiment shows a stronger correlation between each sub-experiment by using evaluative words. Therefore, the results for each evaluative word were compressed through the analysis of each principal component. These values represent "Dissonance." Experimental results using two timbres are shown in Fig.4. Significant differences were found in the following experimental results: Major_R, Major_1st, and Sus4_R. The results suggest that psychological impression differs depending on the timbre.

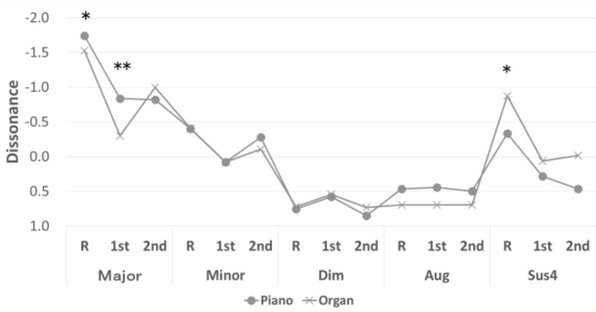



Figure 4. Experimental Result

### 5.2. Compare with Theoretical Value and Experimental Result

Theoretical values calculated by previous chord character evaluation models and the one proposed in this study were compared to the experimental results. The results suggest that the theoretical value we proposed had a stronger correlation with the experimental results than previous theoretical values. In the case of the same audio source, a stronger correlation was found in the experimental results and theoretical values (Fig.5, Table.1). Therefore, theoretical values using real acoustic sources fit better into the chord impression than virtual acoustic sources.

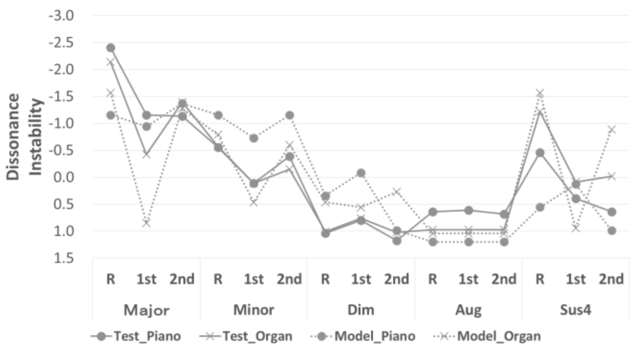



Figure 5. Comparison between Theoretical Value and Experimental Results

## 5.3. Evaluation Difference in Musical Experience

In order to investigate evaluation difference in musical experience, correlations between the evaluation of each subject and theoretical value were calculated (Table.2). Correlation value increases as the period of musical experience in piano timbre increases. However, there were no relations between correlation value and the period of musical experience in organ timbre. The results show that evaluation of chord impression changes depending on the period of musical experience.

Table 1. Correlation between Theoretical Value and Experimental Results

| | | Theoretical Values | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Virtual Acoustic Sources | | | Real Acoustic Sources | | | | | |
| | | | | | Piano | | | Organ | | |
| | | Dissonance | Tension | Instability | Dissonance | Tension | Instability | Dissonance | Tension | Instability |
| Experiment | Piano | .544* | .586* | .657** | .341 | .686** | .758** | .423 | .760** | .624* |
| | Organ | .487 | .658** | .715** | .108 | .705** | .687** | .641* | .863** | .826** |

* p<0.05, ** p<0.01

Table 2. Correlations between Evaluation of Each Subject and Theoretical Value
(a) Piano timbre; (b) organ timbre

| | | Piano | | | | |
|---|---|---|---|---|---|---|
| | | dissonance | unmixable | unpleasant | unstable | complex |
| the period of musical experience | 0 | .292 | .737** | .300 | .603* | .190 |
| | 0 | .028 | .155 | .394 | .316 | −.060 |
| | 0 | .475 | .070 | .353 | .203 | .419 |
| | 0 | .395 | −.206 | .217 | .038 | .143 |
| | 2 | .367 | .175 | .178 | .226 | .371 |
| | 3 | .316 | .386 | .550* | .272 | .564* |
| | 5 | −.033 | .421 | .199 | −.036 | .272 |
| | 7 | .510 | .282 | .471 | .462 | .567* |
| | 7 | .598* | .601* | .212 | .432 | .174 |
| | 8 | .657** | .603* | .672** | .716** | .735** |
| | 10 | .724** | .704** | .517* | .476 | .540* |
| | 10 | .571* | .495 | .750** | .809** | .822** |
| | 12 | .503 | .774** | .387 | .359 | .426 |
| | 17 | .875** | .338 | .888** | .883** | .889** |

* p<0.05, ** p<0.01

| | | Organ | | | | |
|---|---|---|---|---|---|---|
| | | dissonance | unmixable | unpleasant | unstable | complex |
| the period of musical experience | 0 | .612* | .562* | .519* | .626* | .592* |
| | 0 | .821** | .337 | .848** | .687** | .368 |
| | 0 | .472 | .356 | .454 | .445 | .691** |
| | 0 | .577* | .373 | .631* | .569* | .596* |
| | 2 | −.062 | .033 | .541* | .627* | .623* |
| | 3 | .675** | .706** | .799** | .818** | .709** |
| | 5 | .706** | .705** | .454 | .378 | .815** |
| | 7 | .857** | .803** | .683** | .714** | .870** |
| | 7 | .505 | −.338 | −.368 | −.544* | −.013 |
| | 8 | .815** | .817** | .713** | .772** | .781** |
| | 10 | .379 | .269 | −.095 | .256 | .152 |
| | 10 | .792** | .737** | .697** | .670** | .801** |
| | 12 | .618* | .401 | .285 | .298 | .447 |
| | 17 | .511 | .329 | .551* | .476 | .557* |

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

### 5.4. Correlations between Theoretical Values

Table 3 shows the correlations between theoretical values in piano and organ. Correlation in dissonance level is low, while correlation in tension level is high. The results show that dissonance level is dissonance of timbre and tension level is dissonance of interval.

Table 3. Correlations between Theoretical Values

| | Correlation Value |
|---|---|
| Dissonance | −0.314 |
| Tension | 0.755 |
| Instability | 0.482 |

## 6. Conclusion

In this study, in order to introduce the difference in timbre, theoretical values calculated using real acoustic sources were compared with the experimental results. The experimental results show 3 key points. First, the psychological impression differs depending on timbre. Therefore, theoretical value through the use of real acoustic sources fits better into chord impression than virtual acoustic sources. Second, evaluation differs in musical experience. Finally, dissonance level is dissonance of timbre, and tension level is dissonance of interval.

In the future, accurate signal processing, amplitude envelope and calculation of modality should be considered as the study problem.

## References

[1] H. v. Helmholtz, A. J. Ellis, and H. Margenau, *On the sensations of tone as a physiological basis for the theory of music*, 2nd ed. New York: Dover, 1954.

[2] R. Plomp and W. J. Levelt, "Tonal consonance and critical bandwidth," *J Acoust Soc Am*, vol. 38, no. 4, pp. 548–60, 1965.

[3] A. Kameoka and M. Kuriyagawa, "Consonance theory part i: consonance of dyads," J Acoust Soc Am, vol. 45, no. 6, pp. 1451–9, 1969.

[4] D. Cook Norman and T. Fujisawa X., "The psychophysics of harmony perception: Harmony is a three-tone phenomenon," Empirical Musicology Review, vol. 1, no. 2, pp. 106–126, 2006.