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Mapping Model from Chord to Color

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Abstract— **As an art, music has been used by way of binding with some other modality or media, e.g. color and pictures. In this study, the multimodal perceptual cross representation between chord and color has been focused on. Most of cultures have some musical songs as well as language. Musical chord representation of human is not clear. The some musical representation was reported for some area, such as scaling. And some methods for the chord feeling were proposed. Mapping between language and chord could depend on their own culture. There are some evidences that indicate the interactive relationship between language and color categorization. The color concepts depend on language or culture but color discrimination would be independent of language. This indicates that it is necessary to use the non-verbal way in order to elucidate about color-chord representation independent of cultures. Our purpose in this study is to elucidate the relationship between chord and color and to validate the some chord features proposed in past musical studies. In this study, we examined chord-color mapping experiments. The mapped color data was analyzed in the HLS color space, consisting of hue, saturation and luminance. To elucidate the relationship between chord and color representation, we applied the statistical model analysis from chord features to color feature and model selection method by the AIC. As the result, we examined the relationship from musical stimuli to color mapping and showed that the relationship exists for color and chords by the linear model analysis. From the nonverbal mapping experiment in this study, we showed that the chord feature values have an important role about musical representation of chord perception. This indicates that the musical chord features was validated as the chord representation.**

Keywords; musical chord, color, multimodal mapping

I. INTRODUCTION

Music plays a special role in our life. Music industry is one of the most important areas as the market. Many people pay for music in accordance with their own preference or some social reason. Music has been used not only as a concert for special audience, but also as background music. As an art or an entertainment, music has been used to bind with some other modality, e.g. color and pictures. The multimodal media grows in importance. In this study, the multimodal perceptual cross representation between chord and color has been focused on.

Most of cultures have some musical songs as well as language. Not only songs but instrumental music has developed in many cultures. Particularly European music had developed chord theory which plays an important role for musical semantics and syntax. What kind of representation underlies in musical chord perception?

The visual and audial representation has some relationship. Recently it has been reported that the shape of symbol affects onomatopoeias [1]. Recently the synesthesia has been focused on as an evidence of the salient relationship about cross modal representation. Most of synesthetes were classified as color-grapheme that they had an association between color and letters/words [2] and colored-hearing synesthesia for color and musical sound had also been reported [3].

Chord has an important role for music. The chord theory has a long history for old European church music. However, the musical chord representation of human had not been clear yet. The some musical representation was reported for some area [4], such as scaling [5-6]. And some methods for the chord feeling were proposed [7-8].

Mapping between language and chord could depend on their own culture. There are some evidences that indicate the interactive relationship between language and color categorization. The color concepts depend on language or culture [9] but color perception would be universal [10]. This indicates that it is necessary to use the non-verbal way in order to elucidate about color-chord representation independent of cultures.

Our purpose in this study is to elucidate the relationship between chord and color and to validate the some chord features proposed in past musical studies [7,8,11,12]. In this study, we examined chord-color mapping experiments. The mapped color data was analyzed in the HLS color space, consisting of hue, saturation and luminance. To elucidate the relationship between chord and color representation, we applied the statistical model analysis from chord features to color feature and model selection method by the AIC.

II. METHOD

A. *Participants*

Participants were 41 adults (from 19 to 45 years-old). They were confirmed to have no problem for color-vision and auditory perception, and to be no synesthetes. They were not educated by the special musical program in the school. They are answered the questionnaire for musical ability and musical experience. In the experiments, we excluded 6 participant's data because they could not imagine color from chord at all. We used the other 35 data and they responded imagined color.

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B. Stimuli

As sound stimuli, we used 14 musical chords: 5 tri-chords, C, Cm, Caug, Cdim, Csus4, and 9 quad-chords, such as C7, CM7, Cm7, CmM7, C6, Cm6, Caug7, and C7sus4. We chose usually used chords in music. We chose all c-root chords to exclude the effect of scale or harmonic change as in music. We made the chord sound as piano sound by sequencer software (finale, MakeMusic, Inc.). The tempered scale was used as tones of chord because of widely used scale in music. The sound stimuli were recorded and played as 16bit wav sound files in the sampling rate of 44.1 kHz. Using computer, we prepared color interface for the experiment. In the experiment, each participant can choose color by slide bar for each red (R), green (G), and blue (B).

C. Procedure

The chords were presented by headphone controlled by computer. After listening to each chord stimulus, participants chose RGB color. The chosen color was recorded as 256 levels for each RGB by the same computer. The session consists of fourteen chord trials with respect to one participant. In each trial, they chose an associated color by listening of the chord sound.

D. Analysis

1) Musical Chord Model

Some sound feature values had been proposed to explain the musical representation of human. The dissonance between two tones was proposed [12]. It is defined as a difference of two exponential forms.

$$f(x;\alpha,\beta) = \gamma\{\exp(-\alpha x) - \exp(-\beta x)\} \quad (1)$$

Cook and his colleagues applied this type of the formulation to define dissonance chord feature D [7-8]. The dissonance of chord is described

$$D = \Sigma_i^N \Sigma_j v_{ij} f(x_{ij};\alpha,\beta) \quad (2)$$

In the equation, the coefficients are defined as α=1.20, β=4.00 and γ=3.53. The index j means the order for element of chord and the index i means i-th over tone. The N is 5, which is the number of over tone to calculate the chord feature values. We defined the coefficients v=1 for all index i and j.

The tension feature is proposed by Kameoka and Kuriyagawa [11]. The value was defined to model the tensional feeling for chords in music. This does not mean so-called "tension chord". We described the tension feature as T as follow:

$$T = \Sigma_{(i,j,k)} v_{ijk} h(z_{ijk};\omega)$$
$$h(z;\omega) = \exp(z/\omega). \quad (3)$$
$$z_{ijk} = x_{ij} - x_{jk}$$

where, the scaling parameter ω is equal to 0.6. In the equation, the z means the difference of tone intervals. The tension value is calculated summed over N overtones as calculated the dissonance D.

The Modality feature was defined as one of chord features [7-8]. The modality M was defined for tone interval x as follow:

$$g(x, y) = (x - y)\exp[-(x-y)^2) / 4] / \delta \quad (4)$$
$$M = \Sigma_{(i,j)} \Sigma_{(k,l)} v_{ijkl}\, g(x_{ij}, x_{kl})$$

And the δ is 0.6 and v_{ijkl} is calculated as all 1. The summation corresponds to the over tones as calculated the other chord feature value. Each chord feature values are calculated and shown as table 1.

2) Linear model from chord to color

The chosen color data was recorded as RGB values. We adopted the HLS color coordinates for the model analysis. For the saturation and the luminance, we applied the linear model of the chord features to the chosen color data.

About the hue value, we applied circular probability, von Mises distribution. Used as circular data analysis such as color hue [13] or direction [14], the von Mises distribution is defined on circle and called the circular normal distribution because of similarity for the normal distribution [15]. The von Mises distribution is described using the mean direction parameter Y and sharpness parameter κ.

The von Mises distribution is defined on circle.

$$f(h|\kappa, Y_h) = \exp[\kappa \cos(h - Y_h)] / (2\pi I_0(\kappa)) \quad (5)$$

In the equation, $I_0(\kappa)$ is the 0-order first modified Bessel function and the h is a probabilistic variable corresponding to observed hue data. The Y_h is a center parameter and the κ is sharpness parameter. To estimate the maximum likelihood, the logarithmic likelihood was described as,

$$L(\{Y_1, \ldots, Y_{14}\}) = \Sigma_{c=1} \Sigma_{m=1} \log f(h_{cm} | \kappa, Y_c), \quad (6)$$

and, the c is chord index and m is participants index. And M means the number of participants. More the sharpness κ, the shape of density function gets sharper. As shown, the center variables are different for each chord and were calculated by linear combination of the explanatory variables. When estimating in this study, we used the gradient method of the log likelihood function in order to estimate the coefficients for chord feature.

We assumed the mean direction value as the linear combination of chord features and estimated the coefficients by the maximum likelihood estimation. For easiness to calculate, we translate the hue value not by degree but radian unit from red to purple because the von Mises distribution is defined by radian scale.

Furthermore, we used model selection method, analyzed the relationship between chord feature and color feature. As the criterion for models we adopted the AIC.

III. RESULT

First, we applied the hierarchical cluster analysis of the Ward's method to chosen color value. As the distance between chords, we defined the distance of RGB vector for all participants. We evaluated the RGB value among all participants as the distance of cluster. As shown in Figure 1, there are two clusters in the highest level, which would correspond to major group and minor group. This result indicates that the modality value have a dominated role in musical chord representation.

As the next, we show the result of regression analysis using linear model (Figure 2). We applied model selection for the coefficients of chord feature by the AIC. We selected the model according to the least AIC.

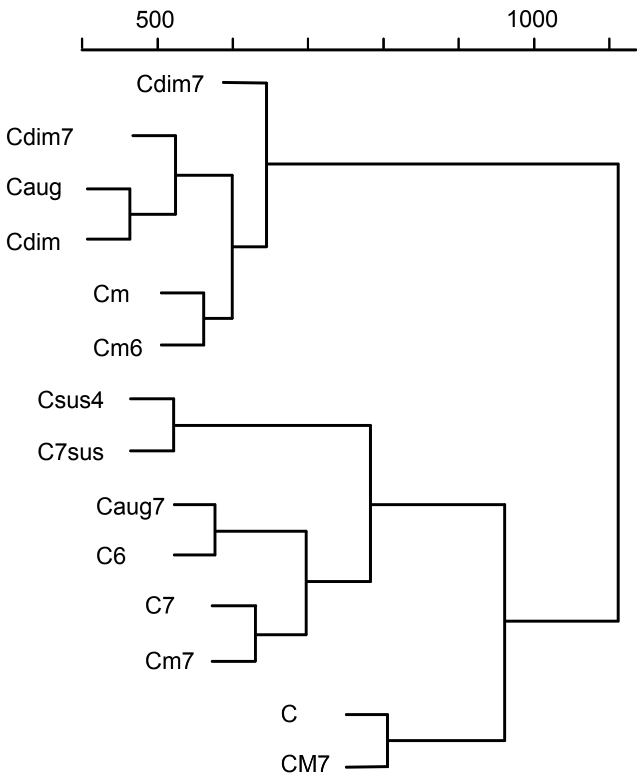

Figure 1. The distance was calculated as Euclidian distance for RGB color of all participants. The Ward's method was used as the clustering algorithm.

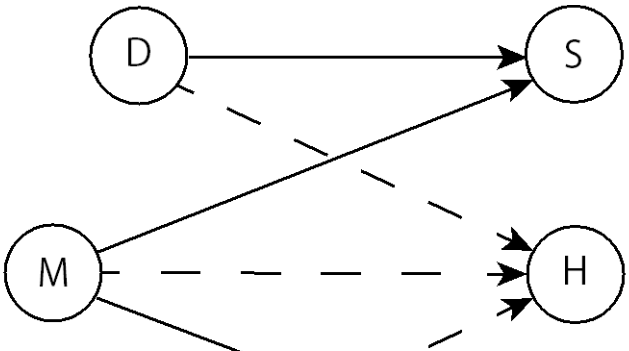

Figure 2. The graphical model of the chord features and color features.
The chord features are Dissonance (D), Tension (T) and Modality (M). The color features are Saturation (S), Luminance (L) and Hue (H).

For the saturation value, the selected equation is as followed.

$$Y_S=0.885+0.015M-0.042D$$

$$R^2=0.588.$$

About the saturation value, although the tension value T was excluded according to the model selection criterion, the other coefficients were remained to predict the saturation value. The residual was not small. These results mean that the correlated representation exists between the chord and the saturation.

For the luminance value, the selected equation is as followed:

$$Y_L=0.475+0.018M-0.021T$$

$$R^2=0.682.$$

About the luminance, although the dissonance D was excluded, the modality M and the tension T was remained to explain the luminance value. The high residual for the saturation and luminance equation showed that the equation fit the data well.

For the hue value, we applied the circular regression from chord features D, T and M. As mentioned above, the linear combination of chord feature values was corresponding to the center of the von Mises distribution. We estimated the coefficients by the maximum likelihood method.

$$Y_h=1.632+0.221M-0.159T-0.423D$$

$$\kappa=0.328$$

The equation is described as the center of the von Mises distribution in radian unit. And the Y_h means the mean hue direction parameter. For the hue value, any chord value was not excluded by model selection method. This result indicates that the hue representation also is associated with musical representation. However, the sharpness κ is too less to characterize the tendency of hue. From the latent mixture model analysis for hue data, the result showed that it was most possible that the mixture number was 6. This indicates that there is a lot of individual difference in hue.

IV. DISCUSSION

In this study, we examined the experiment for the mapping from musical chord stimuli to color. And we analyzed the chosen color data in the HLS color coordinates. We adopted the dissonance, the tension and the modality as the chord feature value to analyze the data. As the result, we showed that the relationship exists for color and chords by the linear model analysis.

From the nonverbal mapping experiment in this study, we showed that the chord feature values are important for musical representation of chord perception. From the model analyses, we showed that the dissonance, the tension and the modality were needed to explain chord representation by model selection method using the AIC.

From the hierarchical cluster analysis, the result showed that highest level clusters was associated with the categories for

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so-called, major and minor group. The modality as the chord feature corresponds to discrimination of the major and minor group. These suggest that the modality plays an important role for chord representation. From the model analysis, the paths from the modality feature were remained. This is consistent result with the result of hierarchical cluster analysis.

For the model selection analysis, the cross modal relationship exists from chord to color representation. For the linear model, the relationship was revealed from modality and dissonance in the chord to saturation in the color. And the modality and the tension have an effect for the luminance. For the synesthesia studies, it was reported that hearing-color synesthetes have a color-association or a color-projection for musical chord or other musical elements [2, 3]. It is possible that the synesthesia for sound and color is caused by the cross-representation phenomenon that we showed for non-synesthetes in this study.

By the latent mixture model analysis, we showed there is individual difference about the hue mapping. It was reported that individual difference for musical education made structural difference tonality representation [5, 6].

V. CONCLUSION

We examined and analyzed the relationship between color and chord. Our results showed that the relationship from chord to color exists. And this indicates that the musical chord features was validated as the chord representation.

TABLE I. CHORD FEATURES

Chord name	elements	D	T	M
C	C,E,G	3.9444	1.1606	5.3893
C7	C,E,G,A#	5.1847	2.059	2.8712
Caug	C,E,G#	4.99	6.173	1.495
CM7	C,E,G,B	4.843	0.803	1.1932
C6	C,E,G,A	4.962	1.2287	0.94456
Caug7	C,E,G#,A#	6.14	4.16	0.632
Cm7b5	C,D#,F#,A#	6.12226	2.6665	0.29159
C7sus4	C,F,G,A#	4.7313	2.7964	0.2592
Cdim7	C,D#,F#,A	6.29	2.234	0.087
Csus4	C,F,G	3.9909	3.03697	0.0389
Cm7	C,D#,G,A#	4.7279	1.0244	-0.06
Cdim	C,D#,F#	5.6428	3.7355	-2.12
Cm6	C,D#,G,A	5.494	1.5	-2.714
Cm	C,D#,G	4.06	1.19	-5.117

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REFERENCES

[1] KohlerW. (1947). Gestalt Psychology 2nd Ed. New York: Liveright.

[2] CytowicE.Richard, EaglemanDavidM. (2009). WEDNESDAY IS INDIGO BLUE: Discovering the Brain of Synesthesia. The MIT Press.

[3] RizzoMatthew, EslingerJ.Paul. (1989). Colored hearing synesthesia: An invitation of neural factors. Neurology, 39(6), 781.

[4] Thompson, W. F., & Schellenberg, E. G. (2002). Listening to Music. In R. Colwell (Ed.). Oxford University Press.

[5] Shepard, R. N. (1964). Circularity in judgements of relative pitch (Vol. 36).

[6] Shepard, R. N. (1982). Structural representations of musical pitch. In D. Deutsch, The psychology of music (pp. 343-390).

[7] CookD.Norman, FujisawaX.Takashi. (2006). The psychophysics of harmony perception: Harmony is a three-tone phenomenon. Empirical Musicology Review, 1(2), 106-126.

[8] CookD.Norman, FujisawaX.Takashi, TakamiKazuaki. (2006). Evaluation of the Affective Valence of Speech Using Pitch Substructure. IEEE Transactions on Speech and Audio Processing, 1(2), 142-151.

[9] RobersonD., DavisI., DavidoffJ. (2000). Color categories are not universal: replications and new evidence from a stone-age culture. Journal of Experimental Psychology: General; Journal of Experimental Psychology: General, 129(3), 369.

[10] Kay Paul, RegierTerry. (2007). Color naming universals: The case of Berinmo. Cognition, 102(2), 289-298.

[11] KameokaA., KuriyagawaM. (1969). Consonant Theory. Journal of Acoustical Society America, 45, 1452-1459.

[12] Plomp, R., & Levelt, W. J. (1965). Tonal Consonance and Critical Bandwidth. Journal of the Acoustical Society of America, 38, 548-560.

[13] Zhang, W., & Luck, S. J. (2008). Discrete fixed-resolution representations in visual working memory. Nature, 453(7192), 233-235.

[14] Feldman, J., & Singh, M. (2005). Information Along Contours and Object Boundaries. Psychological Review, 112(1), 243-252.

[15] FisherI.N. (1993). Statistical Analysis of Circular Data. CAMBRIDGE.

[16] PatelD.A. (2010). Language and the Brain. Oxford Univ Press.