Structural Equation Modeling for Relationships between Color Attributes and Dimensions of Emotional State

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Abstract: A topic of interest in color research is the exploration of emotional responses to color stimuli, referred to as color emotion. Although some subjects in color research have been well documented, many aspects of the evaluative and descriptive dimensions of color emotion have not been sufficiently studied. In this paper, we measured the emotional states elicited by single color stimuli with the Self-Assessment Manikin (SAM) scale, which consists of valence, arousal, and dominance dimensions of emotional state. To clarify the relationships between color appearance and emotional state (L^* , C^* and h in CIELCh), we conducted structural equation modeling (SEM) on the empirical data provided by Suk & Irtel (2010) and those provided by the present study. The resulting models for each data set illustrated that emotional states are influenced by color attributes; valence is principally influenced by lightness (L^*) and chroma (C^*), and arousal is influenced principally by chroma.

Keywords: Color emotion, self-assessment manikin scale, structural equation modeling

1. INTRODUCTION

A topic of interest in color research is the exploration of emotional responses to color stimuli, referred to as color emotion. Color emotion is measured by using rating scales such as Semantic Differential (SD) Scales, and is often analyzed via multivariate analytical techniques such as factor analysis, principal component analysis, and multiple regression analysis. Research in color emotion is mainly divided into two categories: one concerns evaluative dimensions and the other concerns descriptive dimensions [3]. The “harmonious–disharmonious” scale, which is strongly linked with “pleasantness,” belongs to an evaluative dimension, and the “light–dark,” “soft–hard,” and “warm–cool” scales, which are used to describe color appearance, belong to descriptive dimensions. Factor analysis has revealed that the primary common factors in color emotion are the evaluation factor, which is referred to as “color preference,” the lightness factor, the chroma factor, and the hue factor [6]. Lightness, chroma, and hue factors correspond to the three attributes of color, and parallel the three descriptive dimensions mentioned above.

According to Sivik [9], while people are relatively concordant about attributes of color appearance such as “warm” or “cold,” more emotionally evaluative scales such as “like” or “dislike” show a much smaller degree of generality. Experimental data obtained from eight

countries [6] show high correlations among scales of descriptive dimensions and low correlations between these scales and a “like–dislike” scale. More emotionally evaluative scales are likely to depend on regional or cultural factors.

Many researchers in this field are interested in evaluative and descriptive dimensions of color emotion, and others are interested in emotional state-related dimensions [10,11]. However, little research in the field has focused on emotional states, and not enough information on the topic has been revealed. Moreover, little is known about the regional and cultural contexts on which evaluative scales depend.

In the present study, we construct statistical models of relationships between color attributes and dimensions of emotional states using data from an experiment that employs established color stimuli and rating scales [10]. Then, we compare the models derived from previous and present research to clarify the relationships between emotional states and color attributes.

2. EMOTIONAL STATES AND COLOR EMOTIONS

The most common factors or dimensions of emotional states obtained by factor analysis are known as “pleasure,” “arousal,” and “dominance” (PAD). The PAD Scale [5] is a psychological scale that was created to measure these three dimensions. Valdez & Mehrabian [11] analyzed the relationships between color attributes and emotional

Figure 1: Self-Assessment Manikin Scales

states by using the PAD Scale. According to their multiple regression analysis, pleasure, arousal, and dominance are all explained by lightness and chroma.

Another study focusing on emotional states was published by Suk & Irtel [10]. They conducted an experiment using the Self-Assessment Manikin (SAM) Scale for visual evaluation of single color stimuli. The SAM Scale was proposed by Lang [4], and it consists of three series of pictograms of manikins representing the valence, arousal, and dominance dimensions of emotional state. In this scale, valence and arousal are strongly correlated with pleasure and arousal in the PAD scale, respectively [1]. The leftmost pictogram in each series is assigned the lowest value, and the rightmost one is assigned highest value. In experiments, subjects are asked to assess their own emotional states and to choose the single pictogram most suitable for the assessment. Unlike the SD Scale, the SAM Scale is not linguistically expressed; therefore, it can be used to assess emotional state directly and independently of cultural context.

In the experiment conducted by Suk & Irtel [10], color stimuli were categorized into five tones, and their chroma levels were positively correlated with values of valence, arousal, and dominance. Graphs of color tones sorted by lightness levels as an independent variable and their values of valence, arousal, or dominance as dependent variables appear as inverted U-shaped curves. This implies that the pleasure/valence, arousal, and dominance dimensions of emotional state have close relationships with lightness and chroma. However, little is known about how dimensions of emotional state are affected by color attributes.

3. EXPERIMENT

3.1 Materials and Statistical Analysis

The aim of the present study is to clarify the relationships between color attributes and emotional states. First, we conducted a visual assessment experiment and

performed statistical analysis on the results. Second, we compared the model derived from the analysis of our data to one derived in a previous study [10]. Finally, we considered the effect of hue angle in these models.

In the visual assessment, we used the same color stimuli as the previous study (Table 1). These stimuli are sorted by hue and tone. The results indicate weak correlations between lightness and chroma and between chroma and hue angle. Therefore, the data cannot be analyzed to estimate path coefficients via multiple regression analysis due to the multicollinearity of the variables. Therefore, we conduct structural equation modeling (SEM) in order to estimate overall relationships among variables, including correlations. The classical model of multiple regression analysis has a single objective variable and multiple explanatory variables. On the other hand, an SEM model has multiple objective and explanatory variables.

3.2 Procedure

We conducted an experiment in which subjects assessed twenty-five single color stimuli on a seven-point SAM scale. The stimuli consist of all combinations of five hues (red, yellow, green, blue, and violet) and five tones (dark,

Table 1: Color attributes of color stimuli

hue	tone	L*	C*	h
red	dark	30	30	30
red	deep	30	45	30
red	vivid	40	60	30
red	brilliant	50	40	30
red	light	70	30	30
yellow	dark	60	40	80
yellow	deep	60	70	80
yellow	vivid	80	90	80
yellow	brilliant	80	60	80
yellow	light	80	40	80
green	dark	30	30	160
green	deep	40	45	160
green	vivid	50	60	160
green	brilliant	40	40	160
green	light	70	20	160
blue	dark	30	20	260
blue	deep	40	30	260
blue	vivid	40	45	260
blue	brilliant	60	35	260
blue	light	70	25	260
violet	dark	20	25	320
violet	deep	30	35	320
violet	vivid	40	40	320
violet	brilliant	50	30	320
violet	light	70	20	320

deep, vivid, brilliant, and light). The CIELCh data of the color stimuli were implemented with a Java-based software package (PXLab, <http://irtel.uni-mannheim.de/pxlab/>) and displayed on a previously calibrated TFT monitor (EIZO ColorEdge CG245W). Colors to be tested were displayed inside of a circular area of the monitor, and the background had a medium gray color ($L^* = 50$). The SAM scale was displayed at the bottom of the monitor. Eighteen participants (13 male, 5 female) were asked to choose the pictogram that best matched each dimension of their emotional states.

3.3 Result

Figure 2 shows average SAM scale results for each hue. While the previous study used five-point scales, the present study used seven-point scales. We converted values from our seven-point scale to values on the five-point scale by applying approximation formulas [2]. Data plots of valence, arousal, and dominance are similar between the two studies. The color blue yielded lower SAM scale scores in the present study than in the previous study. The hue categories red, yellow, green, blue, and violet have respective h coordinates of 30, 80, 160, 260, and 320 in CIELCh color space. Thus, values signifying emotional states and hue angles are expected to be negatively correlated in the present study. However, dominance had high values for violet hues, so a more complex relationship is expected between these two variables. Values for emotional states obtained in the previous study are expected to be weakly correlated with hue angle; however, valence and dominance were likely to be high for blue, so a more complex relationship is expected between these two variables.

Figure 2: Averaged SAM scale value for each hue category

Figure 3 shows averaged SAM scale values for each tone category. Tone can be described in terms of lightness and chroma levels. The five tone categories, in increasing order of lightness, are dark, deep, vivid, brilliant, and light. The five tone categories are divided into three groups according to their chroma levels: dark and light belong to the first level, deep and brilliant belong to the second level, and vivid belongs to the third level. The averaged SAM scale values in the previous study were lower for dark tones than for light tones, and light tones had lower SAM scale values than did brilliant tones. Thus, the values for emotional states are expected to be positively correlated with lightness and chroma. For the present study's data, the correlations between valence and lightness and between arousal and chroma are expected to be positive, and the correlation between dominance and lightness is expected to be negative.

4. STRUCTURAL EQUATION MODELING

4.1 Estimation of Path Coefficients

We conducted structural equation modeling to estimate path coefficients among variables using the statistical computing environment R (Ver. 2.13.0) and its "sem" (Ver. 0.9-21) package. Objective variables were averaged values of valence, arousal, and dominance ($N = 25$), and explanatory variables were the L^* , C^* , and h coordinates in CIELCh color space, which correspond to lightness, chroma, and hue. Analyzed models were evaluated by calculation of indices of strength of fit such as the chi-squared value, GFI, AGFI, RMSEA, CFI, AIC, and BIC. Comparing these indices of strength of fit, we proposed the best models for the present and previous studies' data.

Figure 3: Averaged SAM scale value for each tone category

A low chi-squared value, which indicates nonsignificance, would point to a good fit. Generally, it is recommended that GFI, AGFI, and CFI values exceed .95 and that the RMSEA value be less than .01. AIC and BIC can serve as references to compare models that satisfy these indices of strength of fit. Table 2 shows the indices of strength of fit in the initial and alternative models.

We prepared initial models for the present study's data on the basis of expectations discussed in the previous section, assuming correlations among the explanatory variables. In the initial model, valence and dominance had three paths, from L^* , C^* , and h , and arousal had two paths, from C^* and h . We then created alternative model 1 by adding three paths, between valence and arousal, between arousal and dominance, and between dominance and valence, assuming correlations among all of the objective variables. Finally, we made alternative model 2 by deleting the path from hue to dominance, because its p -value was .6474.

For the previous study's data, valence, arousal, and dominance each had three paths, from L^* , C^* and h , in the initial model. We created alternative model 1 by adding three paths, between valence and arousal, between arousal and dominance, and between dominance and valence, assuming correlations among all of the objective variables. We created alternative model 2 by deleting the path from hue to dominance, because its p -value was .7774. Further, we created alternative model 3 by deleting the path from hue to arousal, because its p -value was .7275.

As shown in Table 2, alternative model 2 provides the best fit with the present study's data, and alternative model 3 provides the best fit with the previous study's data. Figures 4 and 5 show all the paths among variables and their standardized path coefficients. These results show that there are effective paths between dimensions of emotional states and color attributes, assuming some correlations among explanatory variables. When alternative model 2 is applied to the present study's data,

determination coefficients (R^2) for valence, arousal, and dominance are .837, .710, and .66, respectively. When alternative model 3 is applied to the previous study's data, determination coefficients for valence, arousal, and dominance are .372, .524, and .218, respectively. All values of emotional state variables obtained in the present study have more linear relationships with color attributes than do the values obtained in the previous study. Low determination coefficients in the model for the previous study's data are assumed to be caused by that data set's large variance for each variable. While the present study was conducted in Japan, the previous experiment was conducted in Germany. The cultural differences at play might induce these changes in the variances of each variable.

Figure 4: Alternative model 2 for the current study data

Figure 5: Alternative model 3 for the previous study data

Table 2: Indices of strength of fit in initial and alternative models for the present and previous data

Model	χ^2	(d.f., p-value)	GFI	AGFI	RMSEA	CFI	AIC	BIC
Cur. initial model	26.799	(4, 0.00002)	0.763	-0.243	0.487	0.809	48.798	13.923
Cur. alternative model 1	0.162	(1, 0.68697)	0.997	0.952	0	1	28.162	-3.056
Cur. alternative model 2	0.370	(2, 0.83078)	0.994	0.946	0	1	26.370	-6.067
Pre. initial model	40.607	(3, 0.000000008)	0.700	-1.098	0.722	0.455	64.607	30.951
Pre. alternative model 1	0.0508	(1, 0.82152)	0.999	0.985	0	1	28.050	-3.168
Pre. alternative model 2	0.00957	(1, 0.92206)	0.999	0.997	0	1	28.009	-3.209
Pre. alternative model 3	0.1307	(2, 0.93674)	0.998	0.981	0	1	26.130	-6.307

4.2 Effect of Hue Angle

In this section, we examine effect of hue angle on the model for the present study's data. While we expected that hue would have paths to valence, arousal, and dominance, as was mentioned earlier, the result of structural equation modeling showed that the path from hue to dominance is nonsignificant. One explanation for this result is that hue angle has a higher value for violet ($h = 320$). Hue and dominance do not have a simple linear relationship, but a nonlinear, quadratic relationship. Therefore, we consider the effect of the direction of hue angle on dominance, comparing its strength of fit to primary and quadratic expressions, and propose a model that includes the direction of hue angle as a factor.

Figure 6 shows primary and quadratic regressions of dominance scale values by hue angle. Hue angle is represented along the x-axis as $h/360$, which ranged from 0 to 1. The best-fit regression line as a primary expression is $y = -0.382x + 4.001$, and the best-fit quadratic expression is $y = -3.992x^2 + 4.272x + 4.59$. The residual sums of squares of the primary and quadratic expressions were 14.54 and 12.96, respectively (Table 3). Thus, the quadratic expression fits the data slightly better than does the primary expression. The value of h is 192.625 at the vertex of the quadratic formula; this is the point at which the direction of the effect of hue angle on dominance changes.

Figure 6: Primary and quadratic regressions of averaged dominance scale value by hue angle

Table 3: Residual sum of squares for primary and quadratic expressions

Formula	Residual sum of squares
Primary expression	14.54
Quadratic expression	12.96

In order to verify this assumption, we conducted structural equation modeling with a new parameter, h_{190} . h_{190} is defined as $|h - 190|$ and represents the fact that the direction of the effect of hue angle on dominance changes when the hue angle is approximately 190 degrees. The reason why we did not divide the data into conditions with hue angles above and below 190 degrees is because the sample size ($N = 25$) is too small to produce stable results by structural equation modeling if the data are split.

We adopted alternative model 2 (Figure 4), which was obtained through analysis of the previous study's data, as an initial model. Then, we made an alternative model by adding a path from hue to dominance and estimating the model's path coefficients. Table 4 shows the fit indices of these models, and Figure 7 shows all paths and their coefficients in the alternative model. In this alternative model, the determination coefficients for valence, arousal, and dominance are .819, .765, and .731, respectively. Thus, the alternative model that assumes the direction of the effect of hue angle on dominance fits the data better than do the other models.

Figure 7: Alternative model assuming the direction of effect of hue angle

Table 4: Indices of strength of fit in alternative model 2 for the present study's data

Model	χ^2	(d.f., p-value)	GFI	AGFI	RMSEA	CFI	AIC	BIC
h_{190} initial model	6.6757	(2, 0.035)	0.923	0.199	0.312	0.961	32.675	0.237
h_{190} alternative model	1.2673	(2, 0.530)	0.983	0.822	0	1	27.267	-5.170

5. DISCUSSION

5.1 Features of Color Emotion as Emotional States

In this paper, we constructed two models to explain the present study's and the previous study's data. Both models are valid for their data, as they have high strength of fit indices. Differences between the two models reflect different characteristics between the two groups of subjects, namely cultural differences between Japanese and German people. Therefore, we can interpret the similarities and differences between these two subject pools by analyzing their respective relationships between emotional states and color attributes and by comparing the path coefficients of the two models.

The path coefficients from lightness, chroma, and hue to valence are .67, .376, and $-.132$ for the present study's data and .433, .407, and .212 for the previous study's data. Thus, valence is mainly affected by lightness and chroma, and Japanese people seem to be more affected by lightness than do German people. In the model for the present study's data, arousal has two paths, and their coefficients are .664 from chroma and $-.28$ from hue. On the other hand, in the model for the previous study's data, arousal has three paths, and their coefficients are .433 from lightness, .407 from chroma, and .212 from hue. Both models have large values for the coefficient from chroma, and arousal is mainly affected by chroma. Dominance has two paths in both models. The present study's coefficients for paths to dominance are $-.749$ from lightness and .612 from chroma. On the other hand, the previous study's coefficients for paths to dominance are .396 from lightness, .287 from chroma, and .212 from hue. Dominance is affected by lightness, chroma, and valence. While the effects of lightness on valence and dominance have different directions in the present study's model, these effects have the same the direction in the previous study's model.

Common to both models are the facts that valence is affected mainly by lightness and chroma and that arousal is affected mainly by chroma. The differences between the two models lie in the presence versus absence of an effect of lightness on arousal and in the opposite direction of the effect of lightness on dominance.

The resulting models were similar to multiple regression models by Valdez & Mehrabian [11]; however, the explanatory variables of those models were derived from the Munsell color system, which does not concern itself with the basis of colorimetric quantities. Concerning general emotion, the pleasure (valence in the present study) and arousal dimensions of emotional state are considered to have neurophysiological ramifications [7, 8].

That is to say, valence and arousal reflect innate rather than cultural factors at the level of nervous systems. Hence, the commonalities in the models we observed regarding valence and arousal are reasonable, and they represent primitive relationships between emotional states and color attributes.

5.2 Direction of Color Attributes

We constructed another model on the basis of considerations regarding the direction of the effect of hue angle on dominance. According to the two regression formulae we derived, the hue angle's effect on dominance changes direction when the hue angle is approximately 190 degrees. Dominance and hue are negatively correlated when the hue angle is below 190 degrees, and they are positively correlated above that hue angle. The change in the direction of hue angle effect was validated through another structural equation model introducing a new parameter, h_{190} . This implies the importance of the assumption that the relationship between dominance and hue is more complex than a simple linear relationship. However, the large variance of dominance scale values compared to those of valence and arousal can also be interpreted as being caused by other effects, such as preference or personal context. This remains a question for future study.

6. CONCLUSION

In order to elucidate the relationships among emotional states and color attributes, we conducted visual assessments and performed structural equation modeling on the data from visual assessments. The resulting models, which are derived from present and previous studies, both fit the data strongly. We discussed commonalities regarding the models' path coefficients: valence is affected mainly by lightness and chroma, and arousal is affected mainly by chroma. Two differences between the two models lie in the presence versus absence of an effect of lightness on arousal and the opposite direction of the effect of lightness on dominance. Another model assuming changes in the direction of the effect of hue angle on dominance was constructed. This proposed model had better determination coefficients for valence, arousal, and dominance than did the initial model. Thus, our assumption that the direction of the effect of hue angle on dominance would change was empirically confirmed.

As mentioned in neurophysiological studies, the dimensions of valence and arousal have ramifications in the nervous system. Therefore, the relationships between

color attributes and these two dimensions are expected be primitive elements of human emotions. Further empirical research focusing on physiological indices and their modeling will lead us to a more precise understanding of color emotion.

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REFERENCES

1. M.M. Bradley, P.J. Lang.; Measuring emotion: The self-assessment manikin and the semantic differential, *Journal of Behavior Therapy and Experimental Psychiatry*; 25(1), pp.49-59 (1994).
2. A.M. Colman, C.E. Norris, C.C. Preston; Comparing rating scales of different lengths: Equivalence of scores from 5-point and 7-point scales, *Psychological Reports*; 80, pp.355-362 (1997).
3. X.-P. Gao, J.H. Xin; Investigation of human's emotional responses on colors, *Color Research & Application*; 31(5), pp.411-417 (2006).
4. P.J. Lang; Behavioral treatment and bio-behavioral assessment: computer applications. In: J.B. Sidowski, J.H. Johnson, T.A. Williams (Ed.) *Technology in Mental Health Care Delivery Systems*; Ablex Publishing, Norwood (1980).
5. A. Mehrabian; Measures of individual differences in temperament, *Educational and Psychological Measurement*; 38(4), pp.1105-1117 (1978).
6. L.-C. Ou, M.R. Luo, P.-L. Sun, N.-C. Hu, H.-S. Chen, S.-S. Guan, A. Woodcock, J.L. Caivano, R. Huertas, A. Tremeau, M. Billger, H. Izadan, K. Richter; A cross-cultural comparison of colour emotion for two-colour combinations, *Color Research & Application*; 36(1), pp.23-43 (2011).
7. J. Posner, J.A. Russell, B.S. Peterson; The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology, *Development and Psychopathology*; 17(3), pp.715-734 (2005).
8. J.A. Russell; Core affect and the psychological construction of emotion, *Psychological Review*; 110(1), pp.145-172 (2003).
9. L. Sivik; Color systems for cognitive research, In: C.L. Hardin, L. Maffi (Ed.) *Color categories in thought and language*; pp.163-193, Cambridge University Press, Cambridge (1997).
10. H.-J. Suk, H. Irtel; Emotional response to color across media, *Color Research & Application*; 35(1), pp.64-77 (2010).
11. P. Valdez, A. Mehrabian; Effects of color on emotions, *Journal of Experimental Psychology: General*; 123(4), pp.394-409 (1994).

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