Front. Comput. Sci., 2012, 6(4): 469–476
DOI 10.1007/s11704-012-0154-y

RESEARCH ARTICLE

A qualitative and quantitative study of color emotion using valence-arousal

Shangfei WANG (✉), Rui DING

Key Lab of Computing and Communicating Software of Anhui Province, School of Computer Science and Technology, University of Science and Technology of China, Hefei 230027, China

Abstract This paper describes qualitative and quantitative analysis of color emotion dimension expression using a standard device-independent colorimetric system. To collect color emotion data, 20 subjects are required to report their emotion responses, using a valence-arousal emotion model, to 52 color samples that are chosen from CIELAB Lch color spaces. Qualitative analysis, including analysis of variance (ANOVA), Pearson's correlation and Spearman's rank correlation, shows that significant differences exist between responses to achromatic and chromatic stimuli, but there are no significant differences between chromatic samples. There is a positive linear relationship between lightness/chroma and valence-arousal dimensions. Subsequently, several classic predictors are used to quantitatively predict emotion induced by color attributes. Furthermore, several explicit color emotion models are developed by using multiple linear regression with stepwise and pace regression. Experimental results show that chroma and lightness have stronger effects on emotions than hue, which is consistent with our qualitative results and other psychological studies. Arousal has greater predictive value than valence.

Keywords color emotion, valence and arousal, qualitative, quantitative

1 Introduction

Colors have considerable impact on human emotions. Some colors make people feel happy, while others make people feel depressed. Color emotion, simply defined as the relationship between color and the viewer's psychological response, is of interest to both artists and scientists. It can be widely used in many fields. For example, Wei et al. [1] applied models of color-mood association to automatic film genre classification. Papachristos et al. [2] and Coursaris et al. [3] explored appropriate color schemes for websites. Tsai et al. [4] and Hsiao et al. [5] focused on computer-aided color selection systems for baby walkers and fashion design. Solli and Lenz [6] adopted a color emotion metric in content-based image retrieval. Bresin [7] explored which colors are most suitable for an emotional expression of music. Küller et al. [8] focused on the psychological and physiological effects of colored room interiors on people. Anter and Billger [9] discussed recent studies of color appearance and color emotion, with connection to architecture. Thus, the study of color emotion has been very active and many interesting results have been reported. Among these studies, adjectives are commonly used to express the viewers' psychological responses. Language expression, however, is very complex and may be influenced by the age and sex of the subjects, as well as their national and cultural background [10]. Furthermore, it is very hard to assemble all possible adjectives expressing color emotion and it is difficult to consider new words with existing research results. Analyzing emotion dimension expression [11], such as valence and arousal, may be a more direct and clearer way of studying color emotion. Thus, this paper describes a qualitative and quantitative study of color and emotion dimensions using a valence-arousal model.

Received August 31, 2010; accepted August 31, 2011

E-mail: sfwang@ustc.edu.cn

52 color stimuli that were chosen from CIELAB Lch color spaces were displayed on a computer screen and 20 subjects were asked to report their emotion responses to colors using valence and arousal. Subsequently, analysis of variance (ANOVA) was used to analyze hue influences and correlation analysis was used to analyze lightness and chroma influences. Several interesting qualitative conclusions were obtained: 1) Significant differences are found only between achromatic and chromatic stimuli; 2) The lightness and chroma of color stimuli and emotional responses are significantly positively correlated. Several classical predictors, including multiple linear regression (MLR), pace regression (PR), a support vector machine (SVM), and multi-layer perception (MLP) were used to quantitatively analyze emotional reactions to color attributes. Several explicit color emotion models were developed by using MLR with stepwise and PR. Other predictors only provide implicit models, such as SVM and MLP. Experimental results showed that chroma and lightness have stronger effects on emotions than hue, which is consistent with our qualitative analysis and other psychological studies [11,12]. Besides, arousal has greater predictive value than valence.

2 Related work on color emotion

Many qualitative and quantitative studies of color emotion have been reported. Xin et al. reviewed previous works on the quantification of color emotion [13]. Here we focus on recent studies, listed in Table 1, with respect to color samples, subjects, color space, emotion expression, analysis methods, and deduced models.

Two primary theoretical frameworks exist for studies of emotion. One conceptualizes emotion discretely, while the other regards emotion as a dimensional construct. Many emotion theorists have claimed that there is a set of basic emotions, but different theorists have proposed different types of basic emotions. In most studies of color emotion, adjective pairs are used to describe emotions induced by color as demonstrated in Table 1. The number of pairs varies from 10 to 66. Since there are a myriad of words to describe emotions, it is hard to assemble all the adjectives. Furthermore, use of particular adjectives may vary with age, sex, and national and cultural backgrounds of subjects. Dimensional views of emotion have been advocated and used by a large number of researchers for many years. Most researchers agree that three dimensions are sufficient to describe subjective response. However, a consensus has not yet been reached on the best labels for these dimensions. One of the most common frameworks suggests that affective experiences are best characterized by two key dimensions, arousal and valence, which are described in more detail in [22]. The valence dimension ranges from highly positive to highly negative, whereas the arousal dimension ranges from calming or soothing to exciting or agitating. Therefore, these frequently used concepts of valence and arousal are used here.

Some studies have described quantitative relationships between colors and emotions. Xin et al. derived a series of mathematical models for 12 adjective pairs with color attributes in different regions [14,15]. Ou et al. extracted 3 factors, activity, weight, and heat, from 10 pairs of adjectives by factor analysis and built a color preference model for the factors [16,17]. Valdez and Mehrabian are some of the few investigators who employed emotion dimension, conducted three experiments to investigate the emotional impact of color saturation and brightness, color hue, and achromatic colors, and deduced three kinds of relationship between color attributes and pleasure, arousal, and dominance (PAD) dimensions [12]. However, they did not consider the effects of saturation, brightness, and hue on emotions at the same time in their deduced models. Other investigators, such as Suk [11], who used valence and arousal (VA), have not presented quantitative color emotion models.

In summary, only a few studies report quantitative analysis of color emotion dimensions. Our study, therefore, focuses

Table 1 Brief summary of color emotion research in recent years

	Number of colors	Number of subjects	Color space	Emotion expression	Analysis methods	Models
Xin et al. [14,15]	218	210	CIELAB Lch	12 adjective pairs	Correlation methods	Yes
Ou et al. [16,17]	20	31	NCS Color Atlas/CIELAB	10 adjective pairs	Factor analysis	Yes
Gao et al. [18]	214	440	CIELAB Lch	12 adjective pairs	Factor analysis	No
Gao et al. [19]	214	70	CIELAB Lch	12 adjective pairs	Cluster analysis	No
Suk [11]	36	37	CIELAB Lch	VA dimension	Correlation methods	No
Valdez and Mehrabian [12]	76/50/5	250/121/25	Munsell	PAD dimension	Regression analysis	Yes
Manav [20]	41	50	Polisan Natura interior space color	30 adjective pairs	χ^2 test	No
Kuo [21]	207	10	CIELAB Lch	66 adjective pairs	Factor Analysis	No

on both qualitative and quantitative color emotion models in which valence and arousal are used to describe viewers' psychological responses and the CIELAB Lch color space, which is another device-independent space, is used to choose color samples. All three color attributes are considered in our quantitative analysis.

3 Psychological experiments and data collection

3.1 Stimuli

52 color stimuli were used to induce subjects' emotional responses; they were chosen from the CIELAB Lch color space[1] which is a device-independent color space. Table 2 lists the color stimuli, including 46 chromatic and six achromatic colors. For chromatic colors, there were seven hue levels, including Red (R), Orange (O), Yellow (Y), Green (G), Indigo (I), Blue (B), and Violet (V). A minimum of three samples was chosen from each hue so as to provide representative variations of lightness and chroma. While for achromatic colors, there were four Greys (Gr), one Black (Bk), and one White (W).

3.2 Subjects

Twenty college students, including 18 males and two females, participated in the experiment. Their ages ranged from 20 to 29, and the average age was 23.95. None of the subjects have X-linked color blindness.

3.3 Procedure

Subjects were required to report their emotion responses to the color stimuli using a 9-point scale for valence and arousal. Firstly, the subjects were told the meaning of valence and arousal. The valence ranges from highly positive to highly negative, whereas the arousal ranges from calming to exciting. Then seven pictures chosen from international affective picture system (IAPS) [23] (No. 2071, 2102, 1019, 2095, 1120, 1230, and 7010) with representative variations of valence and arousal were displayed on a CRT monitor (Samsung 763 MB) to provide the baseline. Secondly, four training color stimuli were displayed full screen on the same monitor to help the subjects become familiar with the operation of the experiment. Finally, 52 color stimuli were randomly displayed full screen. Each color stimulus was displayed only once until the subject pressed any key to display the next stimulus. There was no time limit for changing to the next stimulus. The subjects were asked to write down the values of valence and arousal for each color stimulus. Thus, there were 20 × 52 data samples of color emotion responses for both valence and arousal.

4 Qualitative analysis of color emotion

4.1 Emotional response to hue

First, the ratings for different lightness and chroma in the same hue were averaged for each subject by Eqs. (1) and (2). Figure 1 illustrates the average ratings of the 10 hue categories.

$$VHue_{ij} = \frac{\sum\limits_{color \in hue_j} V_{ik}}{\text{the number of } hue_j}, \tag{1}$$

$$AHue_{ij} = \frac{\sum\limits_{color \in hue_j} A_{ik}}{\text{the number of } hue_j}, \tag{2}$$

where $i = 1, 2, ..., 20,\ j = 1, 2, ..., 10, k = 1, 2, ..., 52$. V_{ik} and

Table 2 Color stimuli

Hue	L, C, H	L, C, H	L, C, H	L, C, H	L, C, H	L, C, H	L, C, H	L, C, H	L, C, H
R	30, 30, 30	30, 45, 30	40, 90, 30	50, 40, 30	70, 30, 30	26, 61, 38	53, 104, 40	68, 53, 25	25, 31, 27[a)]
O	32, 53, 54	62, 90, 53	79, 43, 59						
Y	60, 30, 80	60, 70, 80	80, 90, 80	80, 60, 80	80, 40, 80	51, 57, 102	97, 97, 103	98, 61, 105	
G	30, 30, 160	40, 45, 160	90, 60, 160	40, 40, 160	70, 20, 160	46, 72, 136	88, 120, 136	91, 77, 140	72, 94, 137[a)]
I	48, 30, 194	91, 51, 195	93, 37, 196	75, 40, 197[a)]					
B	30, 20, 260	40, 30, 260	40, 45, 260	30, 35, 260	70, 25, 260	13, 80, 306	33, 134, 306	60, 71, 297	30, 98, 304[a)]
V	20, 25, 320	30, 35, 320	40, 40, 320	50, 30, 320	70, 20, 320	30, 69, 329	60, 114, 329	72, 75, 327	
Gr	27, 0, 297	41, 0, 197	78, 0, 297	66, 0, 197					
Bk	0, 0, 0								
W	100, 0, 297								

a) Denotes training color stimuli.

1) http://www.cie.co.at/

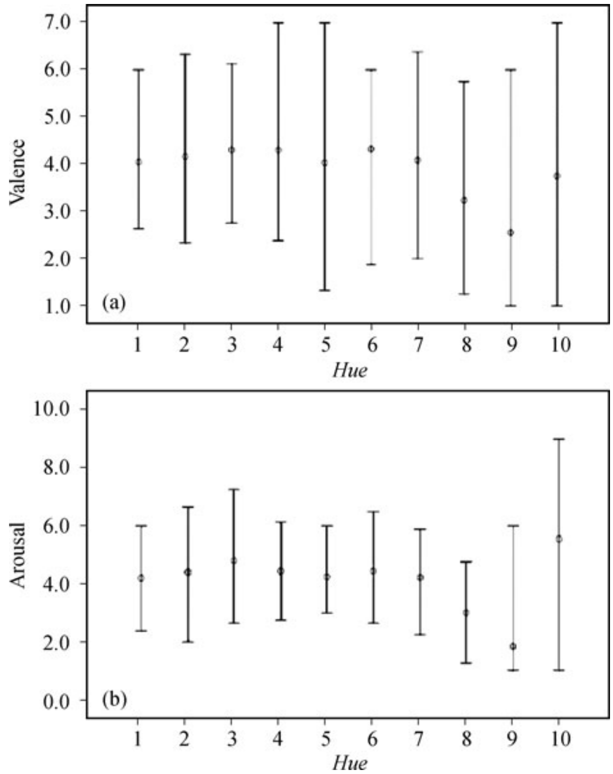

Fig. 1 High-low charts of averaged ratings for 10 hues in (a) Valence; (b) Arousal

A_{ik} are the ith subject's respective valence or arousal response to the kth color.

Then, a one-way ANOVA was carried out to compare the mean values of valence and arousal on 10 hue categories. The results in Table 3 show that the influences of hue categories on affective judgment in two dimensions of emotion are significant ($p < 0.05$).

Table 3 Result of one-way ANOVA of color-emotion

Valence	Arousal
$F(9, 190) = 4.195$, $p = 0$	$F(9, 190) = 11.549$, $p = 0$

Factor: hue categories

After that, a pair-wise multiple comparison, least significant difference (LSD) analysis was carried out. The results in Tables 4 and 5 show that the mean differences between gray, black, white, and other hue categories were often significant in valence responses at an α level of 0.05 (two-tailed), which was also the case for arousal. It can be seen that these differences were mainly between achromatic stimuli (gray, black, and white) and chromatic stimuli, while the differences between chromatic stimuli were small. This is an indication that the hue's effect on emotion may be very small.

Table 4 Result of LSD on valence

	O	Y	G	I	B	V	Gr	Bk	W
O	–0.12								
Y	–0.26	–0.14							
G	–0.25	–0.13	0.01						
I	0.01	0.13	0.27	0.27					
B	–0.28	–0.16	–0.02	–0.02	–0.29				
V	–0.04	0.08	0.22	0.21	–0.05	0.24			
Gr	0.81[a)]	0.93[a)]	1.07[a)]	1.06[a)]	0.80[a)]	1.08[a)]	0.85[a)]		
Bk	1.50[a)]	1.62[a)]	1.75[a)]	1.75[a)]	1.48[a)]	1.77[a)]	1.54[a)]	0.69	
W	0.30	0.42	0.55	0.55	0.28	0.57	0.34	–0.51	–1.20[a)]

[a)] Mean difference is significant at the 0.05 level.

Table 5 Result of LSD on arousal

	R	O	Y	G	I	B	V	Gr	Bk
O	–0.19								
Y	–0.59	–0.40							
G	–0.23	–0.04	0.36						
I	–0.04	0.15	0.55	0.19					
B	–0.23	–0.04	0.36	0.00	–0.19				
V	–0.02	0.17	0.57	0.21	0.02	0.21			
Gr	1.20[a)]	1.39[a)]	1.79[a)]	1.43[a)]	1.24[a)]	1.43[a)]	1.22[a)]		
Bk	2.36[a)]	2.55[a)]	2.95[a)]	2.59[a)]	2.40[a)]	2.59[a)]	2.38[a)]	1.16[a)]	
W	–1.34[a)]	–1.15[a)]	–0.75	–1.11[a)]	–1.30[a)]	–1.11[a)]	–1.32[a)]	–2.54[a)]	–3.70[a)]

[a)] Mean difference is significant at the 0.05 level.

4.2 Emotional responses to lightness

Lightness in CIELAB Lch color space ranges from 0 to 100 units. Therefore it was divided into five groups with 20 units per group. Individual ratings for colors that belonged to the same lightness level were averaged by Eqs. (3) and (4).

$$VLight_{ij} = \frac{\sum\limits_{color \in Lightness_j} V_{ik}}{\text{the number of } Lightness_j}, \tag{3}$$

$$ALight_{ij} = \frac{\sum\limits_{color \in Lightness_j} A_{ik}}{\text{the number of } Lightness_j}, \tag{4}$$

where $i = 1, 2, ..., 20$, $j = 1, 2, ..., 5$, $k = 1, 2, ..., 52$. V_{ik} or A_{ik} is the ith subject's valence or arousal response to the kth color.

A positive linear relationship between lightness and the valence/arousal response can be observed from Fig. 2.

Accordingly, a correlation analysis between lightness and emotion responses was conducted. The Pearson's product-moment correlation coefficients in Table 6 indicate that lightness and emotion responses were significantly positively correlated. Furthermore, a correlation analysis with Spearman's rho was carried out since the distances between lightness categories were not identical. This analysis yielded a similar result.

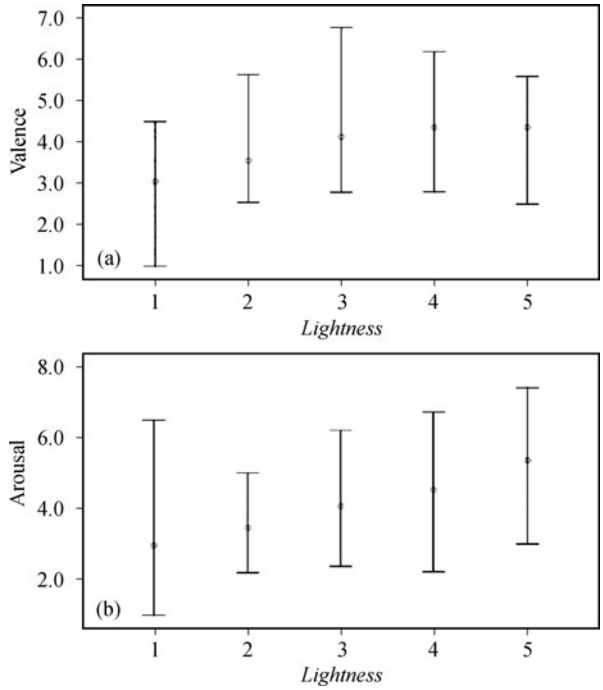

Fig. 2 High-low charts of averaged ratings for five lightness levels for (a) Valence; (b) Arousal

Table 6 Correlation coefficients for lightness and emotion responses

	Valence	Arousal
Pearson's correlation	0.462[a)]	0.578[a)]
Spearman's rho	0.455[a)]	0.583[a)]
N	5×20	5×20

a) Correlation is significant at α level of 0.01(two-tailed).

4.3 Emotional response to chroma

Chroma in this experiment ranged from 0 to 137 units. Therefore it was divided into seven groups with 20 units per group. Individual ratings for colors that belonged to the same chroma level were averaged by Eqs. (5) and (6).

$$VChroma_{ij} = \frac{\sum\limits_{color \in Chroma_j} V_{ik}}{\text{the number of } Chroma_j}, \tag{5}$$

$$AChroma_{ij} = \frac{\sum\limits_{color \in Chroma_j} A_{ik}}{\text{the number of } Chroma_j}, \tag{6}$$

where $i = 1, 2, ..., 20$, $j = 1, 2, ..., 7$, $k = 1, 2, ..., 52$. V_{ik} or A_{ik} is the ith subject's valence or arousal response to the kth color.

A positive linear relationship between chroma and valence/arousal can be observed in Fig. 3. Accordingly, correlation analysis was conducted. The Pearson and Spearman coefficients were significant. The results in Table 7 show that chroma and emotion responses were significantly positively correlated.

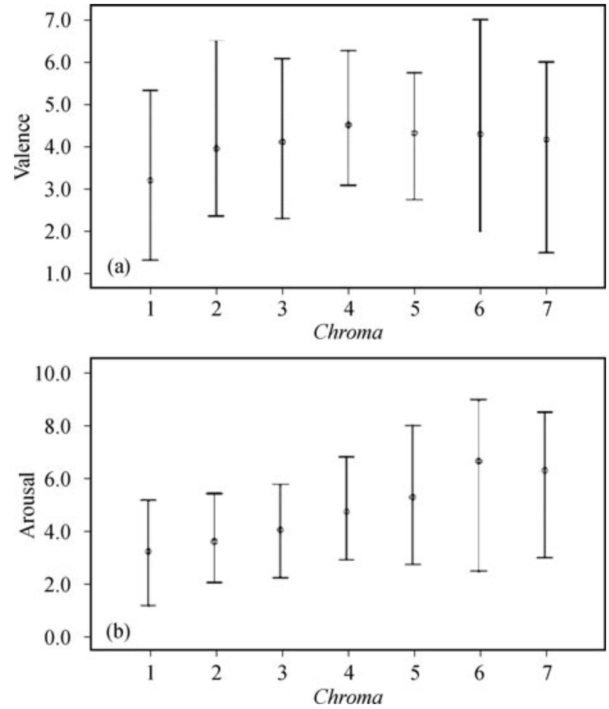

Fig. 3 High-low charts of averaged ratings for seven chroma levels for (a) Valence; (b) Arousal

Table 7 Correlation coefficients for chroma and emotion responses

	Valence	Arousal
Pearson's correlation	0.356[a)]	0.551[a)]
Spearman's rho	0.333[a)]	0.529[a)]
N	7×20	7×20

a) Correlation is significant at α level of 0.01(two-tailed).

5 Quantitative analysis of color emotion

Following statistical analysis, the qualitative relationship between color attributes and emotion dimensions were obtained. Significant differences between achromatic and chromatic samples were found, but the differences between chromatic samples were small. Furthermore, there is a positive linear relationship between lightness and valence, lightness and valence, chroma and valence, and chroma and arousal. Quantitative relationships between color attributes and emotion responses are required in many application fields, such as production design. Therefore, we carried out quantitative analysis. Several classical predictors, including MLR [24], PR [25,26], SVM [27,28], and MLP [29] were adopted to predict emotion responses to color.

5.1 Data preprocessing and experimental conditions

We first averaged the emotional responses for the 20 subjects to each color stimulus according to Eqs. (7) and (8).

$$V_j = \frac{\sum_{i=1}^{20} V_{ij}}{20}, \tag{7}$$

$$A_j = \frac{\sum_{i=1}^{20} A_{ij}}{20}, \tag{8}$$

where V_{ij} or A_{ij} is the ith subject's valence or arousal response to the jth color. Thus, a sample set including 52 cases was obtained. The average valence ranged from 2.40 to 5.25 units with the variance wihtin the range of 0.00 to 0.18, and the average arousal ranged from 1.85 to 7.00 units with the variance within the range of 0.00 to 0.26.

Weka [30] was then used as a tool to compare the performance of different predictors. A 10-fold cross-validation strategy was applied, which is quite useful in dealing with small data sets since it utilizes the greatest amount of training data from the data set. Two parameters, correlation coefficient (*CC*) and root mean squared error (*RMSE*), were chosen to indicate the performance of the predictors. Supposing p_i is the predicted emotion value for the color sample i, and a_i is the target value for sample j, and n is the number of samples. *CC*s and *RMSE*s are calculated according to following equations:

$$CC = \frac{S_{PA}}{\sqrt{S_p S_A}}, \tag{9}$$

where $S_P = \frac{\sum_i (p_i-\bar{p})^2}{n-1}$, $S_A = \frac{\sum_i (a_i-\bar{a})^2}{n-1}$, and $S_{PA} = \frac{\sum_i (p_i-\bar{p})(a_i-\bar{a})}{n-1}$.

$$RMSE = \sqrt{\frac{(p_1 - a_1)^2 + \cdots + (p_n - a_n)^2}{n}}. \tag{10}$$

From the above equations, it can be seen that the larger the *CC* and the smaller the *RMSE*, the better the fit.

5.2 Experimental results of emotion prediction with three color attributes

Table 8 shows the experimental results for emotion prediction with three color attribute combinations. Arousal has a greater predictive value than valence since the *CC*s for arousal are larger than those for valence, and the *RMSE*s for arousal are smaller than those for valence. Further, MLP appears better suited for predicting valence and SVM appears better for predicting arousal with the largest *CC*s and smallest *RMSE*s among the four methods.

Since some predictors can infer explicit models, such as MLR and PR, the regression equations for three attributes and valence/emotion responses are listed in Table 9. Hue is not in the model deduced by MLR. Although it appears in the equation deduced by PR, its coefficient is relatively small. This means that the effect of hue on emotion is very small. The coefficients for lightness and chroma are positive, agreeing with our qualitative results that lightness and chroma are significantly positively correlated with emotional responses.

Table 8 Results of emotion prediction from color attributes

Methods	Valence-*CC*	Valence-*RMSE*	Arousal-*CC*	Arousal-*RMSE*
MLR	0.5760	0.3497	0.8702	0.2209
PR	0.6005	0.3406	0.8676	0.2232
SVM	0.6027	0.3428	0.8874	0.2066
MLP	0.6584	0.3328	0.8469	0.2408

Table 9 Deduced mathematical models

methods	models
MLR	Valence = 3.078 + 0.011L + 0.008C
	Arousal = 1.734 + 0.024L + 0.024C
PR	Valence = 3.1083 + 0.0101L + 0.0085C
	Arousal = 1.4548 + 0.0249L + 0.0249C + 0.0013H

6 Conclusions

Color affects our emotions. Analyzing color emotion dimensions using a standard device-independent colorimetric system may be beneficial for both color theory and application. This paper presents both qualitative and quantitative analysis on color and emotion dimensions. In summary, our results show:

1) Significant differences exist between achromatic stimuli and chromatic stimuli, but differences between chromatic stimuli are very small. The influence of hue on emotion is very small.
2) There is a positive linear relationship between lightness and valence, lightness and valence, chroma and valence, and chroma and arousal.
3) It is easier to predict arousal than valence.

Compared with previous reports on color emotion, our contribution can be summarized as follows:

1) We present both qualitative and quantitative analysis of color emotion using an emotion dimension model and a standard device-independent colorimetric system.
2) We present comparative analysis on quantifying color emotion. We use not only linear models, such as MLR and PR, but also nonlinear models, including SVM, and MLP, to predict emotion from color attributes. The ef-

fects of three color attributes, saturation, brightness and hue, are all considered in our models. These models may be useful in future investigations. In addition, several explicit models are described, which may be used in many application fields, such as design, color support systems, and color image retrieval.

Acknowledgements This paper is supported by the National High Technology Research and Development Program of China (863 Program) (2008AA01Z122), the National Natural Science Foundation of China (Grant No. 61175037), Youth Creative Project of USTC and SRF for ROCS, SEM. We would like to express our appreciation to all the subjects who participated in our experiments.

References

1. Wei C Y, Dimitrova N, Chang S F. Color-mood analysis of films based on syntactic and psychological models. In: Proceedings of the 2004 IEEE International Conference on Multimedia and Expo. 2004, 831–834
2. Papachristos E, Tselios N K, Avouris N M. Inferring relations between color and emotional dimensions of a web site using Bayesian networks. In: Proceedings of IFIP TC13 International Conference on Human-Computer Interaction. 2005, 1075–1078
3. Coursaris C K, Sweirenga S J, Watrall E. An empirical investigation of color temperature and gender effects on web aesthetics. Journal of Usability Studies, 2008, 3(3): 103–117
4. Tsai H C, Hung C Y, Hung F K. Computer aided product color design with artificial intelligence. Computer-Aided Design and Applications, 2007, 4(1–6): 557–564
5. Hsiao S W, Chiu F Y, Hsu H Y. A computer-assisted colour selection system based on aesthetic measure for colour harmony and fuzzy logic theory. Color Research and Application, 2008, 33(5): 411–423
6. Solli M, Lenz R. Color based bags-of-emotions. In: Proceedings of the 13th International Conference on Computer Analysis of Images and Patterns. 2009, 573–580
7. Bresin R. What is the color of that music performance? In: Proceedings of the International Computer Music Conference. 2005, 367–370
8. Küller R, Mikellides B, Janssens J. Color, arousal, and performance-a comparison of three experiments. Color Research and Application, 2009, 34(2): 141–152
9. Anter K F, Billger M. Colour research with architectural relevance: how can different approaches gain from each other? Color Research and Application, 2010, 35(2): 145–152
10. Nakamura T, Sakolnakorn O P N, Hansuebsai A, Pungrassamee P, Sato T. Emotion induced from colour and its language expression. In: Proceedings of Interim Meeting of the International Color Association. 2004, 29–36
11. Suk H J. Color and emotion — a study on the affective judgment across media and in relation to visual stimuli. Dissertation for the Doctoral Degree. Mannheim: University of Mannheim, 2006
12. Valdez P, Mehrabian A. Effects of color on emotions. Journal of Experimental Psychology, 1994, 123(4): 394–409
13. Xin J H, Cheng K M, Chong T F, Sato T, Nakamura T, Kajiwara K, Hoshino H. Quantifying colour emotional-what has been achieved. Research Journal of Textile and Apparel, 1998, 2(1): 46–54
14. Xin J H, Cheng K M, Taylor G, Sato T, Hansuebsai A. Cross-regional comparison of colour emotions part I: quantitative analysis. Color Research and Application, 2004, 29(6): 451–457
15. Xin J H, Cheng K M, Taylor G, Sato T, Hansuebsai A. Cross-regional comparison of colour emotions part II: qualitative analysis. Color Research and Application, 2004, 29(6): 458–466
16. Ou L C, Luo M. R, Woodcock A, Wright A. A study of colour emotion and colour preference. Part I: colour emotions for single colours. Color Research and Application, 2004, 29(3): 232–240
17. Ou L C, Luo M. R, Woodcock A, Wright A. A study of colour emotion and colour preference. Part III: colour preference modeling. Color Research and Application, 2004, 29(5): 381–389
18. Gao X P, Xin J H, Sato T, Hansuebsai A, Scalzo M, Kajiwara K. Analysis of cross-cultural color emotion. Color Research and Application, 2007, 32(3): 223–229
19. Gao X P, Xin H. Investigation of human's emotional responses on colors. Color Research and Application, 2006, 31(5): 411–417
20. Manav B. Color-emotion associations and color preferences: a case study for residences. Color Research and Application, 2007, 32(2): 144–150
21. Kuo W G. The feasibility of establishing new color image scales using the magnitude estimation method. Color Research and Application, 2007, 32(6): 463–468
22. Arapakis I, Arapakis I. Theories, methods and current research on emotions in library and information science, information retrieval and human-computer interaction. Information Processing & Management, 2011, 47(4): 575–592
23. Lang P, Bradley M, Cuthbert B. International affective picture system (iaps): instruction manual and affective ratings. Technical Report A-6, The Center for Research in Psychophysiology, University of Florida, 2005
24. Cohen J, Cohen P, West S G, Aiken L S. Applied multiple regression/correlation analysis for the behavioral sciences. 3rd ed. Hillsdale: Lawrence Erlbaum, 2003
25. Wang Y, Witten I H. Modeling for optimal probability prediction. In: Proceedings of the 19th International Conference on Machine Learning. 2002, 650–657
26. Wang Y. A new approach to fitting linear models in high dimensional spaces. Dissertation for the Doctoral Degree. Hamilton: University of Waikato, 2000
27. Shevade S K, Keerthi S S, Bhattacharyya C, Murthy K R K. Improvements to the SMO algorithm for SVM regression, IEEE Transactions on Neural Networks, 2000, 11(5): 1188–1193
28. Smola A J, Schölkopf B. A tutorial on support vector regression. Technical report, Statistics and Computing, 2003
29. Haykin S. Neural Networks: A Comprehensive Foundation. 2nd ed.

Upper Saddle River: Prentice Hall, 1998

30. Witten I H, Frank E, Hall M A. Data Mining: Practical Machine Learning Tools and Techniques. 3rd ed. San Francisco: Morgan Kaufmann, 2011

Shangfei Wang received her MSc in Circuits and Systems, and her PhD in Signal and Information Processing from the University of Science and Technology of China (USTC), China, in 1999 and 2002, respectively. From 2004 to 2005, she was a postdoctoral research fellow in Kyushu University, Japan. She is currently an associate professor of the School of Computer Science and Technology, USTC. Dr. Wang is an IEEE member. Her research interests cover computation intelligence, affective computing, multimedia computing, information retrieval, and artificial environment design. She has authored or coauthored over 40 publications.

Rui Ding received his BSc from the School of Basic Medical Science from Anhui Medical University, China, in 2006. He received his MSc from the School of Computer Science and Technology from the University of Science and Technology of China, in 2010.