Emotional Response to Color Across Media

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Abstract: In this study, the characteristics of emotional responses to color are explored in two empirical studies. In particular, the relationship between color attributes and emotional dimensions—valence, arousal, and dominance—is analyzed. To account for the cognitive quantity of color, 36 color stimuli were selected following hue and tone categorizations and based on the CIELAB LCh system. In one experiment, the colors were presented on A5-size glossy paper whereas the identical colors were displayed on CRT monitors in the other experiment. In both experiments, the subjects assessed the emotional responses to each color stimulus using a Self-Assessment-Manikin (SAM), which consists of three rows of five pictograms illustrating the three dimensions of emotion, respectively. The empirical results provide evidence that the patterns of affective judgment of colors can be profiled in terms of the three dimensions of emotion (Reliability coefficient, Cronbach's alpha > 0.7). All three attributes of colors, i.e. hue, Chroma, and Lightness, influenced the emotional responses (repeated measurement One-way ANOVA, $P < 0.05$), and especially, Chroma was always positively correlated with each of the three emotional dimensions ($r > 0.60$ $P < 0.01$). Moreover, the results indicate that emotional responses to color vary more strongly with regard to tone than to hue categories. Comparing the SAM ratings between the two experiments, a systemic explanation has yet to be found to conclude that there is a media effect on the emotional responses to colors. Furthermore, the process of affective judgment of colors and the limit of color as an emotion elicitor are discussed. © 2009 Wiley Periodicals, Inc. Col Res Appl, 00, 000–000, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/col.20554

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INTRODUCTION

The perception of color is essential to human's visual experience and is the most powerful information channel among human senses,[1] Goldstein[2] distinguished viewing color from other visual experiences proclaiming that the connection between the central characteristic of the physical properties and the experience of color is arbitrary, unlike some visual qualities such as shape, depth, location, and movement. This makes color a compelling visual cue for persuasive communication purposes.[3–5] In view of the foregoing, much concern has been directed toward research on color affectivity, and thus the emotional response to color has been investigated in multiple disciplines. Regarding concerns across disciplines, McCann[6] pointed out the psychological distinction between color sensation and color perception. According to McCann, color sensation concerns whether colors have the same physical properties, i.e. wavelength. A successful sensation model, for instance, must render the differences of color hue and visible gradients because of illumination, whereas a successful model of color perception must report the recognition thereof. In the case of color perception, color is a product of the brain's interpretation of the visual sensory information that it receives.

Affective Judgment of Perceived Color

Empirical studies of emotional responses to color have dealt with color as stimuli in terms of either a psychophysical quantity (color sensation) or cognitive quantity (color perception). The former takes advantage of the numeric order of the stimuli, nevertheless, it fails to provide a cognitive quantity of color perception. In a study by Valdez and Merhabian[7] on the affective judgment of color, for example, color stimuli were identified in terms of a psychophysical quantity and it was shown that yellow is a hue category that elicited negative valence (unpleasant). However, a color from the yellow hue category with a certain Chroma value (e.g., 40 from CIELAB LCh) is not recognized to be as saturated as the respective stimulus from the red or blue hue category. More drastically, if the lightness of colors in the hue category yellow is lower than 70 from CIELAB LCh ($0 \sim 100$), the colors are perceived as olive rather than as yellow. This is caused by a shortcoming in the discriminatory perception of Chroma and Lightness with respect to hue categories. The present study focuses on how people respond to perceived color stimuli. To this end, the authors attempt to choose colors that alone are recognized as belonging to the target hue category. For the selection of color stimuli in the experiments of this study, hue and tone categorization was applied, as will be explained in the experiment section.

Color in Mediated Presentation

Another issue discussed in this study is the media on which color stimuli are presented. Studies have focused on color stimuli presented in various digital media to investigate media influence on color perception. On the other hand, many studies benefit from inexpensive and flexible aspects of the digital media, with the expectation that the result could representatively explain the phenomenon, regardless of the media involvement. Another purpose of this study is to provide evidence as to the affective judgment of colors presented on digital media, such as a CRT monitor, is comparable to that presented as object colors, such as paper colors. To distinguish color stimuli mediated in these two manners, "digital color" will hereafter refer to self-illuminating color in digital media whereas "surface color" will refer to object-reflected color.

Feeling Color and Measuring Its Affectivity

In constructing theoretical frameworks of emotion, two approaches are taken: One conceptualizes emotion discretely and the other regards emotion as a dimensional construct. In the discrete approach, basic emotions are described in terms of unique and salient categories, whereas the approach of dimensional constructs provides a common frame of reference for describing the emotions. Osgood and his colleagues[8] proposed three factors consisting of two primary factors, evaluation and activity, and one minor factor called potency. Following Osgood's lead, Mehrabian[9] suggested that these three judgment factors are related to three fundamental emotion responses, labeled as pleasure, arousal, and dominance. Subsequent studies on measuring emotion have often combined both approaches of conceptualization. For example, the Circumplex model by Russell[10] maps emotion-related categories in emotion space defined by pleasure and arousal. Thus, it benefits from a geometric metaphor for the internal scale on which stimuli are judged that reconciles both discrete and dimensional approaches. In this study, the dimensional approach is advocated and is applied to construct an emotional space to depict the distribution of affective judgment of colors in the distribution.

Measuring Emotional Response to Color

Despite the difficulties of measuring emotional responses, a growing number of studies have used various representations, which assume that different emotion response elements, i.e., physiology, behavior, and experience, exhibit synchrony during emotion activation. Accordingly, concerning the measurement of emotional response to color, the three systems have also been applied.

Physiological Measurement. Researchers have measured physiological responses to color by means of the galvanic skin response, electroencephalograms, heart rate, respiration rate, oxiometry, eyeblink frequency, blood pressure, etc.[11] These studies have been largely motivated by the hypothesis that long-wavelength colors (warm colors such as red and yellow) are more arousing than short-wavelength colors (cool colors such as green and blue).[12] Reviewing studies on physiological responses to color, Kaiser[11] agreed there is a certain effect of color on response, but critically concluded that the evidence of various physiological tests is inconclusive and the results are not yet stringent enough to reveal a general tendency. Following this critical view, Detenber *et al.*[13] asserted that color does not have any effect on the physiological component of emotional experience.

Behavioral Measurement. Studies on the measurement of behavioral patterns of emotional response to color were carried out both under laboratory conditions (e.g. facial expressions) and field studies. The former are often conducted from a physiological perspective,[13] whereas the latter are mostly related to life experience.

Experiential Measurement. The foregoing considerations have prompted an effort to adapt the three dimensional evaluation of affective response to an emotional assessment of color for the entire aspects of the emotion system.[14] On the other hand, the three basic emotional dimensions would describe verbal expression, regardless of how each of the verbal items has been scaled.[15] If so, each of the three dimensions—valence, arousal, and dominance—can be visualized and the stimuli might be assessed directly by the illustration.

Self Assessment Manikin (SAM)

Originally derived from Osgood's[8] semantic differential, Lang[16] devised the "Self-Assessment-Manikin (SAM hereinafter)", a series of pictograms to judge the affective quality of stimuli. SAM is a nonverbal, culture-fair rating system based on a three-dimensional system of emotion.

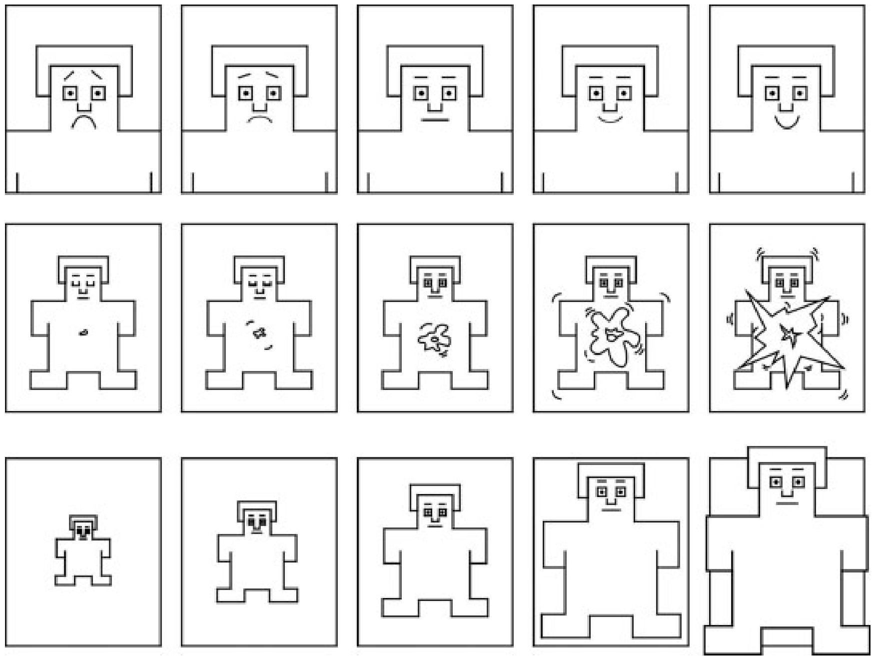

FIG. 1. Self-Assessment Manikins.

The SAM rating scale is comprised of three sets of graphic figures, respectively representing the three dimensions, are used to indicate emotional reactions. As shown in Fig. 1, the SAM figures range from frowning, unhappy to smiling, happy, on the valence dimension. For the arousal dimension, the figures range from relaxed, sleepy to excited and wide-eyed. For the dominance dimension, the figures range from small or dominated to large and controlling.[17] The subject can select any of the five figures comprising each scale.

During the introduction of the experiment, sets of adjectives are used to verbally describe SAM. Thus, subjects may capture the meaning of the dimensions, instead of depending on a specific expression. Different sets have been used in several studies[18,16,19] and bilingual experts in Hamm's[20] study provided 18 pairs of German adjectives, translated from English and cross checked (see Table I).

As a graphic representation of emotions implicates less "awareness" than verbal expression, SAM has been advocated for measuring emotion. Previous studies showed that SAM accurately measured emotional reaction to imagery,[17,19] sounds,[21] life experiences (e.g. financial investment[22]). In this study, SAM was used to measure emotional responses to colors.

GOAL AND HYPOTHESES

The purpose of this study is to describe emotional responses to perceived colors in terms of three dimensions of emotion and to investigate whether digital color induces an emotional response in a similar fashion as surface color does. Two hypotheses are thus formulated as follows:

[H. 1] Emotional profiles of colors can be characterized by valence, arousal, and dominance.

[H. 2] Digital colors elicit emotion in the same way surface colors do.

EXPERIMENTS

Two experiments were conducted and 36 color stimuli based on CIELab LCh data were used: colors were either presented on DIN A5-size glossy paper (Experiment I) or displayed on CRT monitors (Experiment II).

Method

36 Color Stimuli. Many empirical studies have employed colors as stimuli, but the issue of color perception as such and its characteristics have seldom been addressed. In this study, 36 color stimuli were collected based on Hue and Tone system and the RAL Design System was applied.

The RAL Design System. The RAL DESIGN™ System has been developed for professional color design. In the RAL Design System, each color is labeled with seven-digits that indicate the technologically measured values of hue (h), Lightness (L), and Chroma (C) by CIELAB LCh. RAL 210 60 30, for instance, is a color shade with a hue of 210, a Lightness of 60, and a Chroma of 30. RAL 210 70 30 is hence a color with higher lightness (70). Accordingly, five hue categories were selected and the hue degrees of categories in CIELab LCh system are as given: $h = 30^\circ$, the hue category of 'red', $h = 80^\circ$, the hue category of 'yellow', $h = 160^\circ$, the hue category of 'green', $h = 260^\circ$, the hue category of 'blue', $h = 320^\circ$, the hue category of 'violet'.

TABLE I. Emotional adjectives in German depicting SAM, English translation in parentheses.

− unzufrieden (unsatisfied)/ unglueckligh (unhappy)/ genervt (nervous)/ verzweifelt (desperate)/ schwermuetig (melancholy)	valence	+ Zufrieden (satisfied)/ gluecklich (happy)/ erfreut (pleased)/ hoffnungsvoll (hopeful)/ ausgeglichen (balanced)
− Traege (slow)/ unerregt (unexcited)/ schlaefrig (sleepy)/ ruhig (quiet)/ entspannt (relaxed)	arousal	+ Resend (rushing)/ erregt (excited)/ hellwach (awake)/ aufgeregt (aroused)/ stimuliert (stimulated)
− Kontrolliert (controlled)/ beeinflusst (influenced)/ gefuehrt (guided)/ ehrfuerchtig (reverent)/ versorgt sein (passive)	dominance	+ Dominant (dominant)/ kontrollierend (controlling)/ einflussreich (influential)/ autonom (autonomous)/ wichtig (important)

From each of these categories, representative colors of the following five tone segments were chosen: dark, deep, vivid, brilliant, and light. Table II presents CIELAB LCh data of chromatic color stimuli used in both experiments. In addition, five achromatic colors were included: black, dark gray, medium gray, light gray, and white. Medium gray corresponds to the lightness of a vivid tone. Moreover, warm grays and cool grays from dark, medium, and light tone categories were added (Table III).

Nuanced Grays. In this study, we examined whether gray nuances, such as cool and warm grays, influence emotional response to colors. Hogg[18] noted growing interest in "warm" versus "cool" colors, indicating that artists and designers have often distinguished nuances of colors. In accordance with his concept, the nuance of a color in this study indicates the color of the slight deviation from a color that determines the effect.

Emotional Baseline: International Affective Picture System (IAPS). Before asking the subjects to assess the emotional response to color stimuli, it was necessary to ensure whether they were not emotionally biased at that moment. Four color pictures were collected from the International Affective Picture System[17] (IAPS hereinafter), a set of normative emotional stimuli. IAPS was developed to provide a large set of standardized, emotionally evocative, and internationally accessible color photographs that include content across a wide range of semantic categories. The emotional responses to IAPS pictures have been assessed by means of a SAM ranging from 1 to 9 for more than a decade and more than 10,000 subjects have assessed the 956 pictures.

The selected four pictures occupy stereotyped emotional profiles and thus induce greater degrees of emotion. For instance, a picture with two bunnies (IAPS no. 1750) has a mean value of 8.28 on the valence dimension judged by a large group of people in the United States. If a subject would evaluate this picture "unhappy", this person should have felt highly biased at the moment or did not understand how to use the SAM. In this way, the SAM ratings of outliers were exempt in the analyses.

EXPERIMENT I

Goal

Experiment I tested whether three dimensions of emotion are reliable to characterize an emotional profile of colors. For this purpose, 36 colors were employed and SAM was facilitated to assess emotional response to a color stimulus.

Method

Subjects. Thirty seven students made up of 9 males and 28 females from the University of Mannheim served in exchange for extra credit. Participants were undergraduate students, 19 years of age or older (M of age = 23.57; SD = 5.55).

Stimuli. Besides the 36 color stimuli, two sets of stimuli were added: four IAPS achromatic pictures were employed to practice the SAM scale and four IAPS chromatic pictures were included for the emotional

TABLE II. Chromatic color stimuli, Experiments I and II.

	Tone categories				
Hue (°)	Dark	Deep	Vivid	Brilliant	Light
30 (red)	L: 30, C: 30	L: 30, C: 45	L: 40, C: 60	L: 50, C: 40	L: 70, C: 30
80 (yellow)	L: 60, C: 40	L: 60, C: 70	L: 80, C: 90	L: 80, C: 60	L: 80, C: 40
160 (green)	L: 30, C: 30	L: 40, C: 45	L: 50, C: 60	L: 40, C: 40	L: 70, C: 20
260 (blue)	L: 30, C: 20	L: 40, C: 30	L: 40, C: 45	L: 60, C: 35	L: 70, C: 25
320 (violet)	L: 20, C: 25	L: 30, C: 35	L: 40, C: 40	L: 50, C: 30	L: 70, C: 20

TABLE III. Achromatic color stimuli, including warm and cool grays, Experiments I and II.

	Tone categories				
	Black	Dark	Medium	Light	White
Achromatic color stimuli	L:0, C:0	L: 30, C: 0	L: 50, C: 0	L: 70, C: 0	L:100, C:0
Warm grays hue (80°)		L: 30, C: 10	L: 50, C: 10	L: 70, C: 10	
Cool grays hue (260°)		L: 30, C: 10	L: 50, C: 10	L: 70, C: 10	

baseline. These pictorial stimuli were provided on DIN A5-sized sheets and a two-digit-ID number was marked (approximately 0.8 cm × 0.5 cm) on a corner of each stimulus sheet. The experiment was conducted as a pencil-and-paper based study and subjects were asked to write down the ID number of the stimulus, before ticking off the SAM. Subjects were subjected to all stimuli.

Procedure. Printed versions of the instruction and sets of SAM pictograms were provided along with black carbon pencils to tick off SAM pictograms. The experiment was conducted in an approximately 9 m^2 (3 m × 3 m) size room at the Otto-Selz Institute in Mannheim and was conveyed in daylight. Subjects freely communicated with the experimenter. All the answering sheets were gathered and checked immediately after the survey was finished and no missing inputs were found.

Results. According to the baseline, one subject was filtered out as he assessed one of the four IAPS control pictures (no. 7175, a lamp) as extremely exciting.

Based on SAM ratings of 36 subjects, Cronbach's alpha were calculated and yielded a satisfactory level of internal constituency: 0.77 in valence, 0.89 in arousal, and 0.70 in dominance. Thus, the emotional profiles of surface colors are describable in terms of valence, arousal, and dominance, supporting [H. 1].

Emotional Responses to Hue Categories

It was analyzed whether hue categories affect emotional responses. For this purpose, the SAM ratings of colors within a hue category were averaged. The SAM ratings of colors in different tones in a same hue category were averaged for each individual subject, yielding a representative mean of each hue category per subject. For example:

$$\frac{SAM\ rating\ of\ \left\{\frac{dark}{red}+\frac{deep}{red}+\frac{vivid}{red}+\frac{brilliant}{red}+\frac{light}{red}\right\}}{5}$$

$$= averaged\ SAM\ rating\ for\ red \quad (1)$$

Therefore, each subject was characterized by averaged SAM ratings for five hue categories: red, yellow, green, blue, and violet. In doing so, the variance among tone categories within each hue category was eliminated. The three charts in Fig. 2 illustrate the averaged SAM ratings of 36 subjects alongside the hue categories. The averaged SAM ratings of the blue category are more positive, rated as less exciting, and more dominant than those of the other hue categories. Blue is, in fact, often found to be Germans' favorite color. In the beginning of Experiment I, subjects were asked to write down the term for their favorite color, and more than 38% of subjects answered blue ("Blau" in German).

Based on these data, a repeated measurement One-way ANOVA was performed (factor: five hue categories). The results in Table IV show that the influence of hue categories on affective judgment on three dimensions of emotion was significant ($P < 0.05$).

Emotional Responses to Tone Categories: Effect of Chroma Levels

Four Chroma levels are of interest. Starting from a group composed of achromatic color stimuli, the five tone

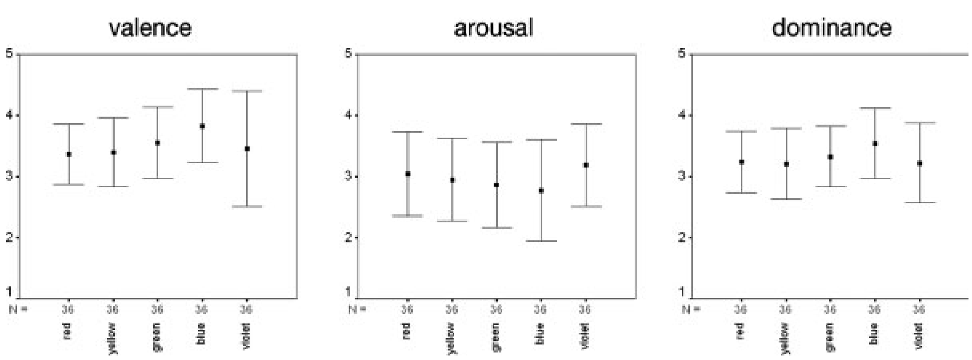

FIG. 2. Results of averaged SAM ratings of five hue categories, dot: mean, range of error bar: standard deviation, Experiment I, $N = 36$.

TABLE IV. Result of one-way repeated measurements ANOVA, factor: hue categories, Experiment I.

Valence	Arousal	Dominance
F (2.93, 102.54) = 3.35, ε = 0.73, P = 0.02*	F (4,14) = 3.41, P = 0.02*	F (4,14) = 2.76, P = 0.04*

Factor: five hue categories, ε: corrected by Greenhouse-Geisser.
* $P < 0.05$.

categories are grouped into three classes, according to their Chroma level: "dark" and "light" belong to the second level, "deep" and "brilliant" belong to the third level, and "vivid" belongs to the fourth level. Thus, in sum, there are one achromatic and three chromatic levels. In addition, individual SAM ratings for colors that belong to the same Chroma level were averaged. For example, SAM ratings of vivid colors were averaged and each subject obtained an averaged SAM rating for each Chroma level. In this way, four averaged SAM ratings for Chroma levels were generated for each subject.

$$\frac{SAM\ rating\ of\ \left\{\frac{vivid}{red}+\frac{vivid}{yellow}+\frac{vivid}{green}+\frac{vivid}{blue}+\frac{vivid}{violet}\right\}}{5} = averaged\ SAM\ rating\ for\ vivid \quad (2)$$

The averaged SAM ratings of each Chroma level were calculated for 36 subjects and are depicted in Fig. 3. A positive linear relationship between Chroma and the entire dimensions can be observed. Accordingly, a correlation analysis was conducted and yielded significant results between Chroma level and emotional responses (r = 0.67** in valence, r = 0.54** in arousal, and r = 0.45** in dominance; **Correlation is significant at an α level of 0.01, two-tailed).

Emotional Responses to Tone Categories: Effect of Lightness Levels

Lightness is a further aspect of tone categorization. Starting with black (Lightness = 0) as Lightness level 1, five tone categories were ordered from dark, and proceeding through deep, vivid, brilliant, and light in accordance with the increase of Lightness. As the selection of chromatic color stimuli confounds Lightness with Chroma, the influence of lightness is addressed in terms of achromatic color only. Subsequently, the SAM ratings of Lightness levels of achromatic color stimuli, such as black, dark gray, medium gray, light gray, and white were analyzed. As presented in Fig. 4, the results appear in a U-shape, indicating that black and white were assessed as rather neutral (around 3.0), whereas the other achromatic colors, i.e., grays, were evaluated to be rather negative, calm, or submissive (<3.0). The contrast of Lightness between achromatic color and context may have driven this tendency. However, the regression analysis (quadratic estimation) yielded significant effects on valence ($P < 0.01$) and dominance ($p < 0.01$), respectively explaining only 14.9% and 7.4% of the total variation.

Insight Into Color Nuance: Various Grays

As indicated, different nuances of gray have been increasingly applied in practice, e.g. visual communication and product design, as gray neutralizes the background and supports the focus contents. Experiment I investigates whether different nuances of gray influence emotional responses. Three different gray nuances were taken into account: cool, neutral, and warm. Each of the nuances included three Lightness levels: dark, medium, and light. Hence, a repeated measurement Two-way ANOVA was run to test for a significant influence of nuance, Lightness, or an interaction of these on SAM ratings to valence, arousal, and dominance. The analysis revealed that nuances influence emotional response to grays with regard to valence ($F_{2,70}$ = 23.55, $P < 0.01$) and dominance ($F_{2,70}$ = 5.01, $P < 0.01$), and especially

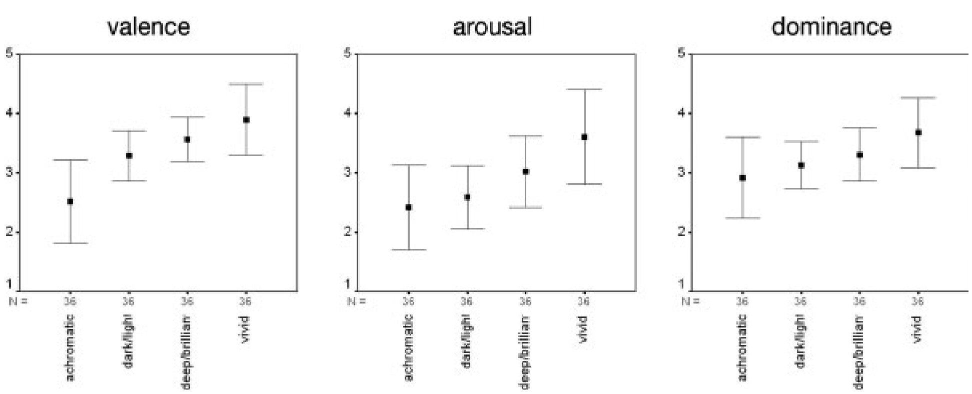

FIG. 3. Averaged SAM ratings of four Chroma levels, dot: mean, range of error bar: standard deviation, Experiment I, N = 36.

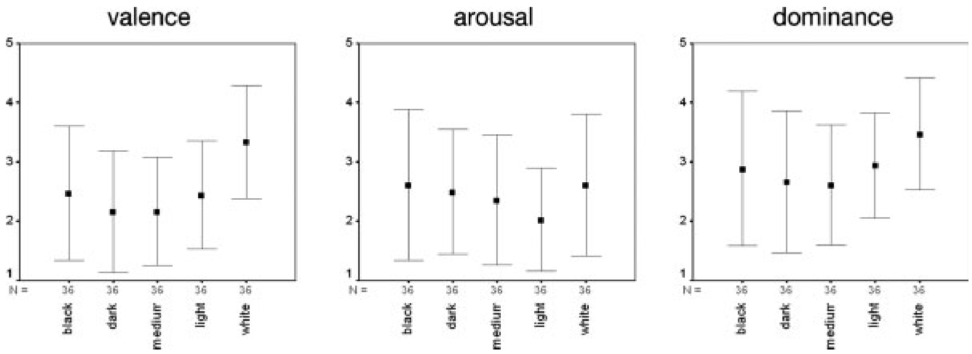

FIG. 4. Averaged SAM ratings of lightness levels: achromatic color stimuli, dot: mean, range of error bar: standard deviation, Experiment I, $N = 36$.

cool grays in particular induced more positive and more dominating responses than did warm gray. In addition, an interplay between nuances and Lightness influenced SAM ratings significantly with respect to the valence dimension ($F_{4,\ 140} = 2.86$, $P = 0.03$). Therefore, the "nuance effect" may open up another dimension of research on color affectivity. Further research may deal with other hue directions or focus on the effect of nuance on other cognitive performance measures.

What has a greater effect: hue or tone?

As shown in Fig. 5, the averaged SAM ratings of 25 chromatic colors are illustrated in terms of the hue category (the three charts in the upper row: see Equation 2) and the tone category (the other three charts in lower row: see Equation 3).

Since the repeated measurement One-way ANOVA yielded significant results ($P < 0.05$) for hue as well as tone categorizations, it is determined that both influence emotional responses with regard to all dimensions. Nevertheless, the results emphasize the importance of variations

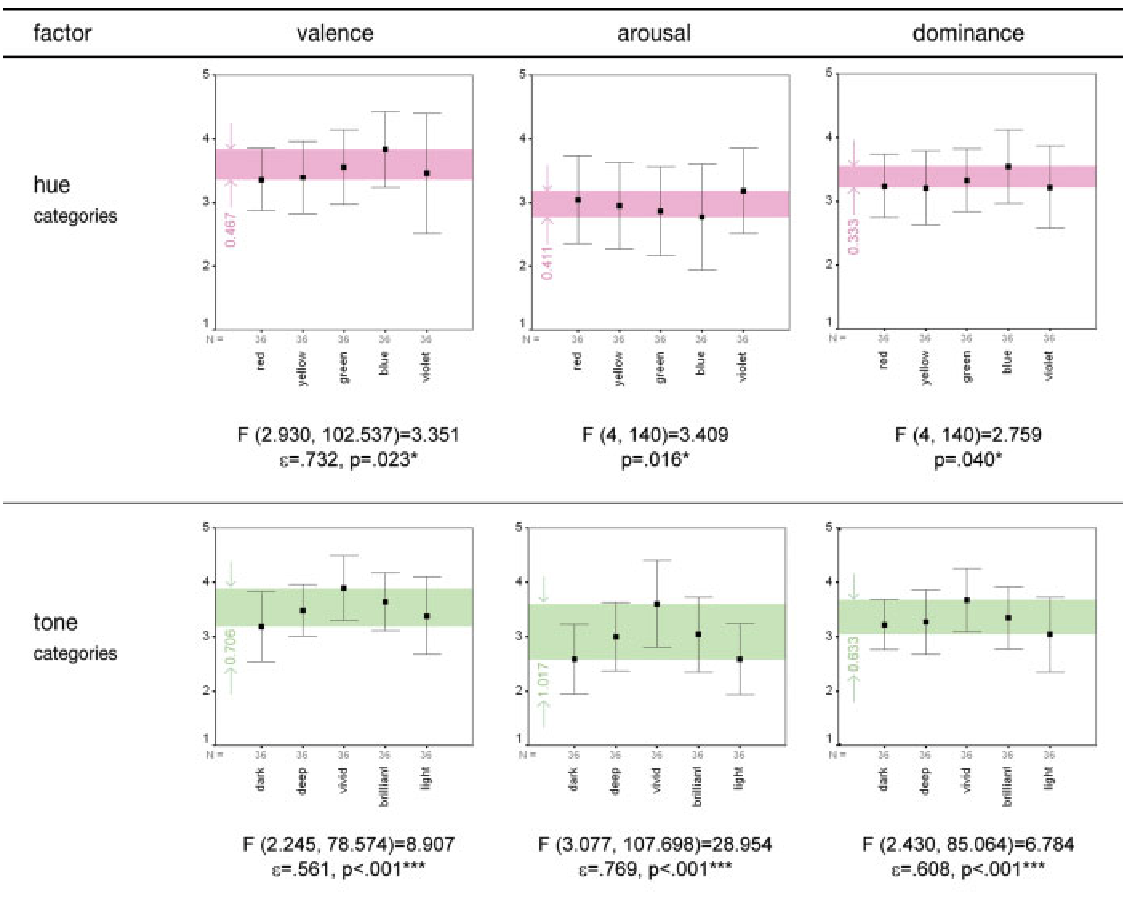

FIG. 5. Mean differences of values predicted by hue (charts in the upper row) and by Chroma (charts in the lower row), dot: mean, range of error bar: standard deviation, ε: corrected by Greenhouse-Geisser, * $P < 0.05$, *** $P < 0.001$. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

of Chroma and Lightness concerning emotional responses to colors.

In each chart, the mean difference is drawn, subtracting the minimum mean from the maximum. The subtraction areas are marked in the upper row, as the averaged SAM ratings varied with hue categories and those are marked in the lower row, as the averaged SAM ratings varied with tone categories. Across the entire dimensions, the subtracted amounts by tone categories are larger than those by hue categories.

In addition, it should be noted that the aforementioned five categories of hue and tone shall be representative of the visible wavelength spectrum and the entire tone variations of chromatic colors.

Discussion

In Experiment I, hypothesis I [(H. 1)] was examined focusing on surface color. Cronbach's alpha provided evidence that valence ($\alpha = 0.77$), arousal ($\alpha = 0.70$), and dominance ($\alpha = 0.70$) describe an emotional profile of surface colors. Because the stimuli were algorithmically selected the analyses of emotional responses to Chroma and Lightness resulted in more systemic explanations, as both color attributes were equally observed throughout the hue categories, regardless of the physical properties.

Based on the SAM ratings, it was found that blue was distinguished from the other hue categories and Chroma correlates with dimensions of emotion ($r = 0.67^{**}$ in valence, $r = 0.55^{**}$ in arousal, and $r = 0.46^{**}$ in dominance). The Lightness contrast between stimulus and background was predicted but proved inconclusive ($R^2 = 0.15$ in valence and $R^2 = 0.07$ in dominance, yielded by a regression analysis with quadratic estimation). From the analysis of the nuance effect, it was revealed that nuances influence emotional response to grays, and in particular, cool grays induced more positive and more dominating responses than warm gray. From the results, it is concluded that the "nuance effect" may open up another dimension of research on color affectivity.

In addition, it was analyzed as to what aspect, hue or tone, caused greater variation in the SAM rating. The SAM ratings of five hue categories were compared with those of five tone categories, and the results showed that tone creates a larger range of emotional responses than hue does. Considering that colors are communicated more easily in their names than in tone parameters (e.g. red for fear), the analysis provides insight that the tone of a color is essential to express affectivity.

EXPERIMENT II

Goal

The aim of Experiment II was to investigate whether digital color induces emotional response in the same manner as does surface color, shown in Experiment I.

Method

Subjects. Forty eight people served as subject in Experiment II. They were recruited through advertisements in the University of Mannheim. As reward, 4 Euros were offered for approximately 20-minute experiment (M of age = 24.43, SD = 8.99).

Stimuli. Identical color stimuli to the CIELab LCh data that were used in Experiment I were implemented with the PXLab© software.

Procedure. Experiment was conveyed in a laboratory of the Otto Selz Institut in Mannheim. The lighting of the closed room was dimmed. The stimulus presentation was implemented with the Java-based PXLab© software. At the beginning of the experiment, a gray stimulus (L = 30) was shown, to get acquainted with the SAM interface. Color stimuli were displayed centered on 17-inch CRT monitors, in a size of 25.1 cm width × 15.2 cm height. A row of SAM pictograms was presented on the display, in the order of valence, arousal, and dominance. Subjects could select a pictogram by a mouse click, until they pressed a key to go on to the next page. All subjects were exposed to all sets of stimuli. As a pictogram was selected, the background darkened, as illustrated in Fig. 6.

After filling out the demographic information and reading through the introduction, subjects started the experiment in front of a computer monitor. Two computers were set up in a seminar room of the library of social science of the University of Mannheim. Subjects were seated approximately 40 cm from the CRT monitor. Monitors were calibrated using a Gretag MacBeth Eye One Spectral Photometer, before starting the experiment.

Results. From the 48 subjects, two were filtered out, because they evaluated the aimed gun as very positive, rating it at the maximum for the valence dimension. Based on SAM ratings of 46 subjects, the reliability of internal consistency was tested. Cronbach's alpha yielded significant values to support the first hypothesis, which also concerns digital colors: 0.79 in valence, 0.88 in arousal, and 0.90 in dominance. Valence, arousal, and dominance are thus adequate to describe emotional responses to digital colors.

Comparison of Emotional Responses to Color Stimuli on Different Media

A mixed between-within subjects ANOVA was run to examine the influence of the medium effect. Since every subject of each experiment went through all stimuli, ANOVA was set with repeated measurement within colors. As Table V shows, there was no significant difference between the two experiments. Therefore, the emotional responses to color in both media, namely surface color and digital color did not differ significantly ($P > 0.05$). This supports the compatibility of digital color for research on color and emotion, advocating the second hypothesis.

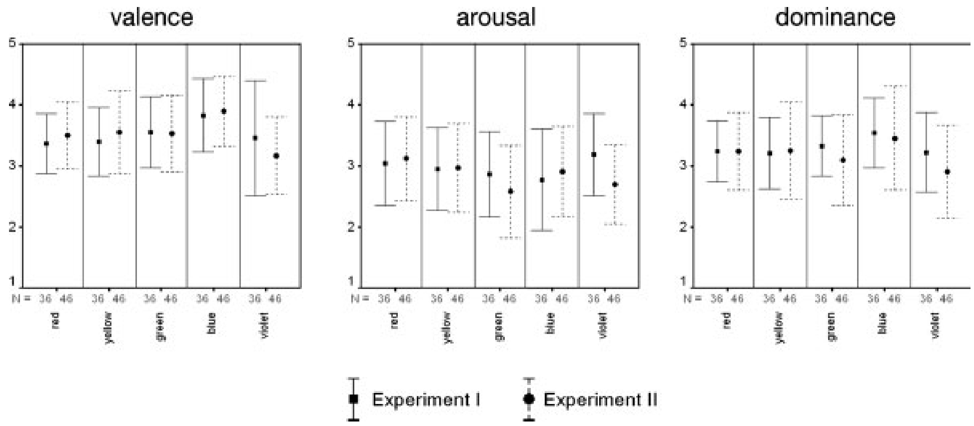

FIG. 6. Averaged SAM ratings of hue categories, Experiment I ($N = 36$) versus II ($N = 46$).

Furthermore, it was investigated whether the emotional responses to each color were different between the two experiments. The SAM ratings of the subjects of Experiment I and those of the subjects of Experiment II were compared with a *t*-test. P-values lower than 0.05 (Table VI) indicate that the SAM ratings of the color stimuli in the two experiments are significantly different.

A significant difference was found for seven colors in valence, five colors in arousal, and two colors in dominance dimensions. Violet colors in vivid, brilliant, and light tones induced significantly less excited emotion as digital colors than as surface colors. However, a systemic explanation for this has to be determined. Moreover, when making 36 × 3 tests at a significance level of 0.05, it is expected that 5 to 6 of the 108 tests will be significant simply by chance, even if there is no effect. Therefore, in general, the results tend to support similarity regarding affective judgments. Based on individual comparisons as presented in Table VI, it can be asserted that patterns of emotional responses to color attributes would have appeared in the similar manner in Experiment II. Nevertheless, some findings based on the observation of descriptive statistics can be pointed out.

Emotional Responses to Digital Colors: Hue Categories

The three charts in Fig. 7 present averaged SAM ratings of individual subjects within hue categories. Pairs of bars in each column compare the SAM ratings of the 36 subjects on the left (Experiment I) with those of the 46 subjects on the right (Experiment II, dotted line). Across the three dimensions, digital colors in the violet category were assessed as less positive, less excited, and less dominant than surface colors. Furthermore, digital colors in the green category were assessed as calmer than those in the blue category.

Emotional Responses to Digital Colors: Tone Categories

In Fig. 8, averaged SAM ratings of chromatic colors are depicted according to tone categories, comparing the results of Experiments I and II. The digital colors in the vivid tone category induce weaker emotional responses regarding the arousal and dominance dimensions. Thus, an inverted U-shape appears less evidently in those dimensions. In addition, the *t*-test did not yield significant differences for any achromatic color (Table VI). The U-shaped trend is thus consistently observed in both Experiments I and II.

Discussion

As media continue to change, their impact on the cognitive performance of people has increasingly interested researchers in various disciplines. Investigating the psychological significance of formal properties and their interaction with message content is essential to attain a complete understanding of how media effects occur.[13] The comparisons of Experiments I and II comprise an attempt at such an investigation in terms of presentation medium: surface color and digital color.

The SAM ratings of the 36 colors were compared by running mixed between (experiments)-within (colors) sub-

TABLE V. Result of mixed between-within subjects ANOVA, Experiment I versus II.

Factor	Valence	Arousal	Dominance
Experiment (between)	$F(1, 80) = 0.01$, $P = 0.93$	$F(1, 80) = 0.69$, $P = 0.41$	$F(1, 80) = (0.99)$, $P = 0.32$
stimulus: color (within)	$F(13.88, 1110.18) = 39.82$ $\varepsilon = 0.40$, $P = 0.000$***	$F(16.00, 1280.28) = 18.26$ $\varepsilon = 0.46$, $P = 0.000$***	$F(13.98, 1118.37) = 9.64$ $\varepsilon = 0.40$, $P = 0.000$***

N of Experiment I = 36, N of Experiment II = 46. ε: corrected by Greenhouse-Geisser.
*** $P < 0.001$, F value in parenthesis: variances of dependent variables are not homogeneous.

TABLE VI. Mean comparisons of SAM ratings between Experiments I and II.

	Mean comparison (*M*) (*P* values yielded by *t*-test, two-tailed, df = 80)								
	Valence			Arousal			Dominance		
Colors	M Exp. I	M Exp. II	*P*	M Exp. I	M Exp. II	*P*	M Exp. I	M Exp. II	*P*
dark red	2.78	2.78	(0.98)	2.69	2.83	0.58	3.03	2.91	0.62
deep red	3.89	3.46	**(0.04*)**	3.14	3.35	0.36	3.53	3.33	0.35
vivid red	4.06	4.08	0.89	4.08	3.85	0.26	3.78	3.76	0.94
brilliant red	3.06	3.48	**0.02***	2.67	2.89	0.32	2.97	3.04	0.75
light red	3.03	3.67	**0.01****	2.61	2.70	0.73	2.89	3.15	0.31
dark yellow	2.47	2.74	0.26	2.28	2.48	0.34	2.81	2.94	0.57
deep yellow	2.56	3.30	**0.00***	2.92	3.11	0.45	2.64	2.96	0.18
vivid yellow	4.33	4.24	0.66	3.69	3.63	0.81	3.92	3.67	0.37
brilliant yellow	4.14	4.02	0.58	3.47	3.26	0.39	3.64	3.41	0.38
light yellow	3.47	3.50	0.94	2.39	2.37	0.94	3.06	3.26	(0.39)
dark green	3.81	3.15	**0.00****	2.67	2.67	0.97	3.44	3.07	0.096
deep green	3.83	3.76	0.73	3.03	2.61	0.09	3.56	3.13	0.088
vivid green	3.58	3.87	0.21	3.39	2.83	**0.02***	3.67	3.11	**0.014***
brilliant green	3.44	3.52	0.73	2.97	2.57	0.09	3.19	3.13	0.77
light green	3.11	3.35	0.29	2.28	2.22	0.80	2.78	3.04	0.29
dark blue	3.47	3.17	0.18	2.39	2.74	0.13	3.25	3.24	0.97
deep blue	3.64	3.70	0.78	2.44	2.76	0.17	3.39	3.35	0.85
vivid blue	4.11	4.11	0.99	3.44	2.89	**0.04***	3.94	3.50	(0.05)
brilliant blue	4.14	4.33	0.29	2.92	3.22	0.26	3.70	3.65	0.87
light blue	3.78	4.15	0.08	2.67	2.94	0.30	3.44	3.52	0.74
dark violet	3.42	2.52	**0.00****	2.89	2.85	0.86	3.58	2.52	**0.00*****
deep violet	3.50	3.11	0.08	3.47	3.08	0.07	3.22	2.91	0.19
vivid violet	3.39	3.24	(0.58)	3.39	2.83	**0.02***	3.06	2.78	0.25
brilliant violet	3.44	3.35	0.68	3.17	2.54	**0.01***	3.22	3.22	0.98
light violet	3.53	3.61	(0.74)	3.00	2.17	**0.00*****	3.03	3.09	0.810
dark gray	2.17	2.07	0.65	2.50	2.33	0.48	2.67	2.59	0.78
medium gray	2.17	2.20	0.89	2.36	2.17	0.45	2.67	2.637	0.94
light gray	2.44	2.44	0.96	2.03	2.09	0.79	2.94	2.83	0.59
dark warm gray	2.06	1.96	0.64	2.31	2.37	(0.77)	2.53	2.70	0.47
medium warm gray	2.14	2.24	0.63	2.22	2.02	0.31	2.47	2.67	0.42
light warm gray	2.11	2.54	**0.05***	2.11	2.00	0.58	2.50	2.83	0.16
dark cool gray	2.61	2.28	0.09	2.42	2.24	0.42	2.72	2.59	0.59

TABLE VI. (*Continued*)

Colors		Mean comparison (*M*) (*P* values yielded by *t*-test, two-tailed, df = 80)								
		Valence			Arousal			Dominance		
		M Exp. I	M Exp. II	*P*	M Exp. I	M Exp. II	*P*	M Exp. I	M Exp. II	*P*
	medium cool gray	2.69	2.57	0.49	2.25	2.17	0.71	3.08	2.76	(0.10)
	light cool gray	3.22	3.30	0.68	1.94	2.02	0.71	3.06	2.89	(0.53)
	white	3.33	3.24	0.70	2.61	2.46	0.58	3.47	3.15	(0.21)
	black	2.47	2.15	0.21	2.61	3.09	0.12	2.89	2.70	(0.56)

N of subjects of Experiment I: 36, *N* of subjects of Experiment II: 46, *P* values in parentheses: equal variances not assumed by Levene's F test.

jects ANOVA, yielding no significant difference in all three dimensions of emotion ($P > 0.05$). The results thus support the second hypothesis: color affectivity is consistent within both media.

A mean comparison was then conducted for single color stimuli. Based on 108 *t*-tests (36 colors by three dimensions), 30 colors (83.3%) in valence, 31 colors (86.1%) in arousal, and 33 colors (91.7%) in dominance were found to be unaffected by medium change. Although there were a few pairs of colors that showed significant differences, no systemic pattern of such cases could be observed. Respectively, emotional responses to hue and tone categorizations exhibited similar trends with surface colors.

GENERAL DISCUSSION

Emotional Responses to Color Stimuli

In both experiments, the subjects were provided with 36 color stimuli, and they assessed their emotional responses using the SAM scale. Based on the ratings of the stimuli, a reliability test was performed, and Cronbach's alpha, the reliability coefficient, yielded a satisfactory level of internal consistency among the variables in both experiments ($\alpha > 0.70$). This supports the first hypothesis that the emotional responses to color can be profiled in terms of valence, arousal, and dominance. Consequently, the pattern of emotional responses to the attributes of color, such as hue, Chroma, and Lightness were analyzed in terms of valence, arousal, or dominance. The SAM ratings varied with regard to all three color attributes (repeated measure One-way ANOVA, $P < 0.05$), but a stronger pattern appeared by the change of tone, the categorization combining Chroma and Lightness, than by that of hue. In particular, the subjects rated the SAM scale to color stimuli in vivid tone the most positively, the most aroused, and the most dominant. This provides insight that color selection aiming toward affective communication should refer to the tone of color across the hue categories.

The Media Influence

In this study, after discovering that the emotional profile of colors can be profiled in terms of valence, arousal, and dominance dimensions of emotion, it was investigated as to whether the emotional responses to color are universal across the media. Based on the SAM ratings to each color stimulus repeatedly shown in both experiments, two sample *t*-tests were conducted to compare means. As shown in Table VI, significant cases were found for seven colors in valence, five colors in arousal, and two colors in dominance dimensions. However, there is yet no systemic explanation for this and, in general, the results tend to support similarity in affective judgments of color stimuli in both media.

Extended Debates I: Affective Judgment of Color: What Was Judged?

Although empirical evidence supports various tendencies of emotional response to color, there remains debate regarding internal processes of affective judgment of color for individual subjects. In particular, exactly what has been judged should be made clear. After this is explained, the question of what determines such judgment arises.

Regarding the process of emotion, it was assumed that emotions are the results of the cognitive judgment of transactions between individuals and the environment in general.[9,23] Emphasizing the involvement of the cognitive judgment during an emotional process, Shaver and his associates explained that emotion implicates subjects' accounts of self and typical emotion episodes.[5] On the other side, researchers such as[24] Helson,[25] and Zajonc[26] have asserted that sensorial processes produce emotions immediately from changes in basic physiological patterns of response to muscular, visceral, and organic activities. Under this argument, a person can come to like or even develop pleasant feelings for something without the intervention of any cognition. Valdez and Mehrabian[12] summarized that many studies on physiological measurement of emotional response to color revealed that the color red

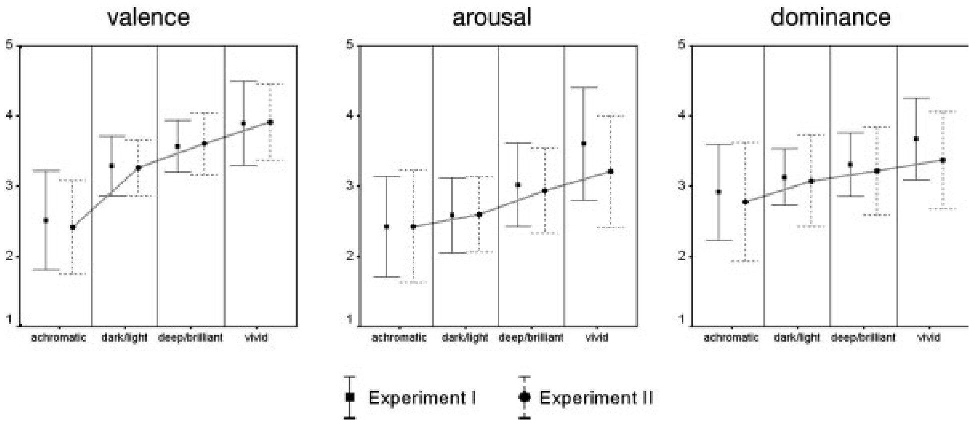

FIG. 7. Averaged SAM ratings of chromatic, Experiment I ($N = 36$) versus II ($N = 46$).

(long wavelength) is more arousing than blue (short wavelength).

Dealing with these two different perspectives, Gellatly[27] drew a distinction between visual experience, "seeing as", and visual information processing, "seeing". The distinction is useful for drawing attention to many different ways in which any one visual scene may be consciously experienced. With regard to color, some recent studies[3,28] agree that biology may constrain the potential recognition of color experience, such as color categorization, although it cannot determine how colored objects will be "seen as". The studies pointed out the relevance of cognitive performance subjected to color stimuli without semantic association. During the experiments, no semantic cues were provided to avoid the emotional influence of semantic associations or mediated objects. "Seeing" color was desired in this study as the input of the emotional process, which was supposed as the "color perception" to address the cognitive quantity of color.

Extended Debate II: Categorization of Color in Emotion Space

The color stimuli employed in both experiments are categorized into eight emotional profiles, according to the averaged SAM ratings. In Table VII, each category of emotional profiles includes sets of adjectives, numbers of IAPS pictures, and color stimuli. Adjectives in Table VII were originally derived from ratings of 240 emotions on the PAD scales.[10] Interestingly, it is shown that the colors as well as IAPS pictures are not equally distributed into the eight categories. For example, 331 of the 956 pictures (34.62%) belong to the category profiled with '+' valence, '−' arousal, and '+' dominance. However, since the 36 color stimuli were not selected with regard to even distances from each other in color space, the number of color stimuli in Table VII does not necessarily correspond to the frequency of colors of each emotional profile. Nevertheless, some emotional profiles, for example, '−' valence, '+' arousal, and '+' dominance, may be difficult to obtain through any color stimulus. Lang *et al.*[17] discussed the different number of IAPS pictures in each of the eight categories. In a similar way, each category has a different number of colors and the contrast is noticeable. Future research should focus on the underlying circuit of logic why the emotional responses to color stimuli are not evenly distributed in emotion space.

SUMMARY

The main purpose of the study was to characterize the emotional profile of color. Before the experiments, views

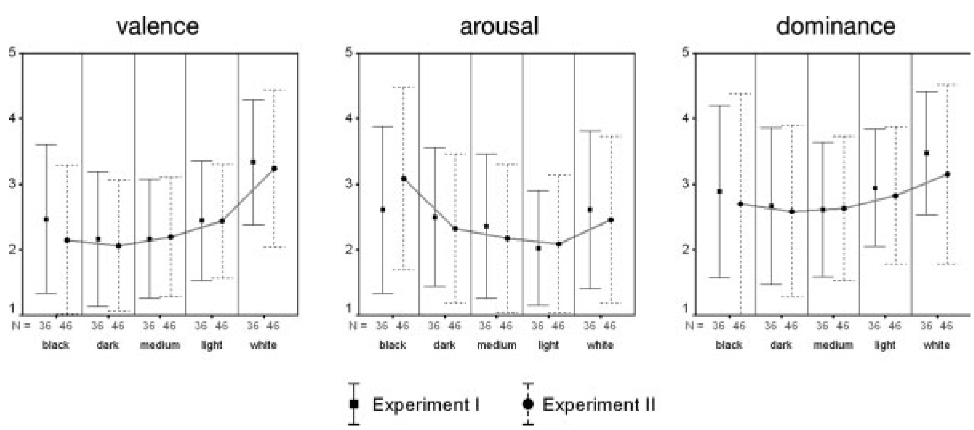

FIG. 8. Averaged SAM ratings of achromatic colors, Experiment I ($N = 36$) versus II ($N = 46$).

TABLE VII. Categorization of adjectives, IAPS pictures (%) and colors into eight emotional profiles V: valence, A: arousal, D: dominance; total number of IAPS pictures: 956.

Dichotomized dimensions			Categorized adjectives, pictures, and colors		
V	A	D	Adjectives	% (IAPS pictures)	Color stimuli
+	+	+	admired, bold, creative, powerful, vigorous	16.95% (162)	
+	+	−	amazed, awed, fascinated, impressed, infatuated	2.51% (24)	
+	−	+	comfortable, leisurely, relaxed, satisfied, unperturbed	34.62% (331)	
+	−	−	consoled, docile, protected, sleepy, tranquilized	0.73% (7)	
−	+	+	antagonistic, belligerent, cruel, hateful, hostile	0.73% (7)	
−	±	−	bewildered, distressed, humiliated, in pain, upset	25.73% (246)	
−	−	+	disdainful, indifferent, selfish-uninterested, uncaring, unconcerned	10.67% (102)	
−		−	bored, depressed, dull, lonely, sad	8.05% (77)	

on the perceptual process of color affectivity were addressed, and measurements of the emotional response to color were reviewed. The dimensional approach to conceptualize the affective judgment of color was advocated and thus emotion spaces were utilized to reconcile both the dimensional and discrete approaches of conceptualizing emotion. As a nonverbal assessment system, a SAM[29] was introduced. Each row represents valence, arousal, or dominance dimensions of emotion respectively. The dimensional structure of the SAM was derived from the semantic differential[8] and later revised as PAD—pleasure, arousal, and dominance.[10] In both experiments, based on SAM ratings of colors, internal consistency-reliability alpha coefficients provided evidence of satisfactory levels of internal consistency for dependent measures of emotion supporting Hypothesis I ([H. 1]).

In composing a set of color stimuli, hue and tone categorization was introduced to select representative Chroma and Lightness for each hue category, emphasizing the cognitive quantity of color perception. Tone categorization combined Chroma and Lightness levels based on ISCC-NBS block separation for subjective variables for cognitive quantity of colors. Five categories were applied to all hues, and in doing so, the analyses referred to color perception and a systemic explanation about Chroma and Lightness levels across hue categories was made possible.

Analyzing the SAM ratings on three dimensions, the characteristics of the emotional profile of color were addressed according to color attributes such as hue, Chroma, and Lightness, following the CIELAB LCh system.

Hue. Although there was statistical evidence that hue influences SAM ratings of color, emotional responses to hue varied in weak patterns and no systemic trend between hue and emotional dimensions has yet been found. Nevertheless, in both experiments, colors in the blue hue category turned out to be significantly more positive and more dominant than the others. In previous studies,[1,30] on color preference, empirical results show that blue consistently induces a positive emotional reaction in general.

Chroma. Confirming previous studies[1,12] the emotional responses vary more strongly with regard to Chroma and Lightness than with regard to hue. Empirical results from both experiments provided a positive linear correlation between Chroma levels and SAM ratings with regard to all dimensions, with significant correlation coefficients.

Lightness. The SAM ratings of lightness of achromatic colors were exclusively analyzed. A U-shape between lightness of achromatic colors and SAM ratings was observed, the statistical significance was too weak to make any conclusions regarding this tendency. It was notable that the larger discrepancy between the Lightness of achromatic colors and that of context induced greater SAM ratings in all three dimensions.

Moreover, the medium effect was investigated by examining the emotional responses to 36 identical colors presented differently: surface color (representing object reflected color) versus digital color (self-luminous color on CRT monitor). The pattern of the averaged SAM ratings of colors did not differ between the two experiments, and paired comparisons made individually did not yield significant differences in general. Accordingly Hypothesis II ([H. 2]) was confirmed.

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