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Correspondence analysis of color–emotion associations

Mitsuhiko Hanada

Department of Complex and Intelligent Systems, Future University Hakodate, 116-2 Kamedanakano-cho, Hakodate, Hokkaido 041-8655, Japan

Correspondence
Mitsuhiko Hanada, Department of Complex and Intelligent Systems, Future University Hakodate, 116-2 Kamedanakano-cho, Hakodate, Hokkaido 041-8655, Japan.
Email: hanada@fun.ac.jp

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Abstract

Emotions are often associated with colors, but what mediates color–emotion associations is not fully understood. This study examined associations between colors and emotions using correspondence analysis. The hypothesis that emotions are associated with colors through the correspondence between the hue circle and the circumplex model of emotion/affect was tested. Participants viewed 40 colors and reported a word that expressed an emotion that they associated with or felt in response to each color. Participants' responses were aggregated into a contingency table of colors and emotion words, and a correspondence analysis was conducted. An eight-dimensional biplot was obtained. The first and second dimensions were related to hue, and the hue configuration was similar to colors' spectral trajectory in the CIE *xy* space or the CIELAB a^*b^* color space. The configuration of emotions was not consistent with the circumplex model of emotion, which rejected the above hypothesis. The associations in dimensions 1 and 2 appeared to be mediated by the perceived temperature of colors and emotions. In dimensions 3–6, dimensions that seemed to reflect secondary associations based on cultural convention or personal experiences (such as white with emotionless and purity and blue with depression) were obtained. These results also demonstrated the usefulness of correspondence analysis for analyzing color–emotion associations due to its ability to reveal the underlying statistical structure of associations.

KEYWORDS
color, correspondence analysis, emotion

1 | INTRODUCTION

Color is an important cue for object recognition. Additionally, color may cause an observer to experience emotion and feeling. Because objects necessarily exhibit colors, and the emotions elicited by colors affect everyday life, colors' emotional associations are consequential. For example, the effect of colors on emotions and preferences is critical in marketing; the colors of products positively or negatively influence viewers' attitudes toward them,[1] and colors contribute to the differentiation of products and brand and corporate images.[2] A number of studies have examined emotional associations with colors using various measuring methods and populations. Wexner examined colors associated with 11 representative mood tones, such as exciting and comforting.[3] Schaie investigated the degree of color–mood associations using a sorting method[4] and a paired comparison method.[5] Murray and Deabler examined socioeconomic and regional differences in color–mood associations among different populations (university students in two different regions, nursing assistants, and neuropsychiatric patients) and reported socioeconomic differences in color–mood associations.[6] Odbert et al. examined associations of colors and moods induced by music.[7] Hupka et al. examined associations of colors with four emotions (anger, envy, fear, and jealousy) cross-culturally.[8] Relatively recently, Kaya examined color–emotion associations using objectively specified colors,[9] and Clarke and Costall investigated the emotional connotations of colors using a qualitative descriptive approach based on semi-structured interviews.[10] Color–emotion associations were observed across these previous studies using different methods and populations; red is associated with anger and excitement,[3–10] green with peacefulness and calmness,[3,6,9,10] yellow with happiness and cheerfulness,[3–6,9,10] blue with calmness and comfort,[3–6,9,10] and black and gray with sadness, despondence, and depression.[3–7,9] Although these associations have been observed across multiple cultures, culture-specific associations have also been observed. For example, blue is associated with depression in some contexts[6] but not others,[3–5] and white is associated with cleanness and purity as well as emptiness, and those associations vary across cultures.[11] Furthermore, Hupka et al. reported less consistent associations of colors with envy and jealousy than with anger and fear across different cultures.[8] On the other hand, studies have examined color–emotion associations in different cultural backgrounds and found similarities in color–emotion associations. Emotions were associated with colors similarly for US college students, Tzeltal-speaking people in Chiapas,[12] and Arawakan speaking Machiguenga in Peru.[13] Although the extent to which color–emotion associations are culture-specific or universal across cultures remains unknown, the cross-cultural variations in color–emotion associations do not seem to be large. Although sex differences in color preferences have been reported,[14,15] Wexner reported no sex differences in color–emotion associations,[3] and few studies have reported sex differences in color–emotion associations in adults (except the study of Hupka et al., which reported minor sex differences in color–emotion associations interacting with nationality[8]). In contrast, considerable sex differences in color–emotion associations have been reported in children;[16–18] for example, girls associated pink with happiness more than boys whereas boys matched blue with happiness.[17] These sex differences might be attributed to stereotypical associations of girls with pink and boys with blue, which may cause sex differences in color preferences, eventually leading to associations of preferred colors with positive emotions. Despite these sex differences, the overall pattern of color–emotion associations was similar for girls and boys. In support of this finding, Lawler and Lawler reported no sex differences in the color–emotion associations of children.[19]

Color–emotion associations have also been examined indirectly with psychological scales, such as semantic-differential (SD) scales, in different cultures. Tanaka et al. examined affective meanings of colors (sometimes also called color emotions) in Japanese and US college students using SD scales and obtained similar results for Japanese and US students.[20] Adams and Osgood measured affective meanings of colors in 23 groups of male high school students in 20 countries with SD scales.[21] In addition, they reviewed many studies on affective meanings of colors performed in different countries, and they reported high consistency in affective meanings of colors among different countries; for example, red has high activity and potency, yellow and white have low potency, blue and green have high evaluation, and black has high potency and low activity.[21] Ou et al. and Gao et al. also examined affective meanings of colors using a method similar to the SD technique, and they reported similarities between British and Chinese[22] participants and small differences among seven different regional groups.[23] Ou et al. also compared female and male responses regarding color emotions and found similar results between them.[22] In addition, few studies on SD ratings of colors have reported sex differences. Thus, sex difference in SD ratings for colors seems to be small, if it exists at all.

Although some emotional associations with colors are universally observed, there are still considerable variations across cultures.[8,21] This may suggest that color–emotion associations have been formed by convention, which may reflect accumulating common experiences. Children have various experiences with colors, and colors are associated with the emotions that they feel in those experiences. As such experiences accumulate; individuals' color–emotion associations are formed. Because people living near each other often have common experiences, and people in the same culture likely have many opportunities to interact and communicate with each other, cultural conventions of color–emotion associations may be formed through common experiences. Many studies support this hypothesis of personal experiences and cultural conventions. For example, Kaya and Epps[9] reported that college students in the US associated yellow-green with disgust and sickness, probably because it reminded them of vomit, and they associated green with relaxation and comfort because of an underlying association with nature. They also showed that other color–emotion associations could be explained by the emotional experiences accompanied by colors. Nonetheless, this hypothesis does not explain the observed consistency between 3- and 4-year-old children and adults' color–emotion associations[19,24] because 3-year-old children would not have had as many opportunities to learn cultural conventions or have enough common experiences with others. Furthermore, the fact that some color–emotion associations are universally observed across considerably different cultures[12,13] may not be completely consistent with this hypothesis.

Alternatively, colors may directly induce emotions through an underlying physiological mechanism. Consistent with this hypothesis, colors have been observed to elicit consistent physiological responses; red and violet generally increase participants' arousal, whereas blue and green decrease it.[25–30] However, these effects have sometimes been insignificant.[31,32] Colors' effects on human physiology seem to depend heavily on experimental conditions (e.g., stimulation duration and size of stimuli).

Previous research has examined colors' effects on emotion using psychological scales either with[26,28,31] or without physiological measurement.[33–36] Warm colors (e.g., red, yellow) promote anxiety more than cool colors (blue, green).[34]

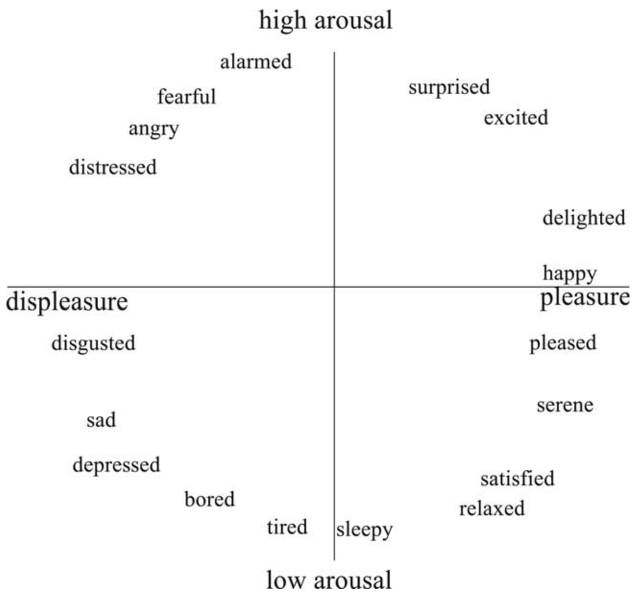

FIGURE 1 Representation of emotions based on the circumplex model of emotion/affect by Russell.[41] It was adapted to include the six basic emotions (angry, happy, surprised, sad, disgusted, and fearful)

Blue enhances feelings of relaxation and calmness more than other colors do.[26] These findings, in addition to the physiological studies mentioned above, suggest that warm colors are more arousing than cool colors. However, some studies have not found significant effects of color on emotional states or moods,[31,33] and others have found more complex patterns of mood induction than the claim that red is arousing and blue is sedating.[37–39] There are also other studies that suggest that saturation and lightness are more important for the effects of colors on emotions than hue.[35,36] Although it is partly unclear whether the psychological scales used in these studies measured induced emotions or color–emotion associations, these studies support the notion that colors actually have some effects on emotions. However, the effects of colors on physiological processes or emotions may be not the cause of the color–emotion associations but, rather, the results of them; physiological effects may be caused by the color–emotion associations formed by processes other than physiological ones. Emotional associations of red with excitement or memory of experiences related to red increase arousal. Kaiser raised the possibility that the physiological effects of colors are cognitively mediated.[25]

This research tested an alternative hypothesis that the configurations of emotional space and color space correspond. Colors can be represented by three-dimensional space, and hue, saturation, and brightness are sometimes used to represent the three-dimensional space of colors, as in the Munsell color system and the CIELAB color space. Circular figures often represent hues in the hue-saturation plane at a given brightness. Emotions are also often represented circularly in a two-dimensional space. For example, Schlosberg[40] analyzed errors in the judgment of facial expression and obtained a two-dimensional space of facial expression, which was characterized by two dimensions of pleasantness and arousal. Furthermore, Russell[41] presented a circumplex model of emotion/affect using scaling techniques such as multidimensional scaling. The model also represents emotions in a two-dimensional space with pleasantness and arousal axes. Representative emotions were arranged in a circle, as shown in Figure 1. Other studies found similar circular patterns of emotions in a two-dimensional space with minor variations of this configuration.[42–45]

Thus, hues and emotions can be represented as a circle in a two-dimensional space. Here, we hypothesize that emotions are associated with colors by matching the hue and emotion circles. Evidence in psychophysics and psychology of thinking widely shows that humans match the levels of completely different dimensions without difficulty,[46,47] such as the severity of crimes and music (mass murder to fortissimo and accumulating unpaid parking tickets to pianissimo).[47] The intensity matching between unrelated dimensions is considered to be performed by the fast, intuitive, emotional, and automatic thinking mode.[47] Considering this human tendency in thinking, this type of matching may occur between the circular orders of colors and emotions.

In fact, attempts have been made to match a hue circle with a mood circle to explain color–mood associations. Ross investigated suitable colors of illumination to theatre plays and found that suitable colors were related to the mood of plays; warm colors are suitable to comedy and cool colors to tragedy.[48] In addition, he matched Hevner's mood circle[49] to the hue circle. Similarly, Odbert et al. attempted to align Hevner's mood circle with the hue circle using music–mood and color–mood associations.[7] However, there were some issues in these studies. First, Hevner's mood circle was based on mood induced by music and did not include some of the basic emotions (anger, fear, surprise, and disgust), perhaps because music cannot induce such strong emotions (though it can induce less intensive moods). Hevner's mood circle was presented long before the circumplex model of emotion and was not as widely supported. Second, the mood–color correspondence was performed not directly but indirectly through the mediation of music or theatre. Third, colors were not matched with moods by advanced statistical methods.

From theoretical backgrounds of emotion, Plutchik also proposed another version of a circular model of emotions, motivated by the analogy between the opponent–color theory and the circularity of emotions.[50,51] He proposed that there are eight primary emotions consisting of four pairs of opposite emotions (joy–sadness, trust–disgust, fear–anger, surprise–anticipate) like complementary colors. Other emotions are mixtures of primary emotions like colors other than primary colors. Although he implied similarities between the color and emotion circles, he did not seem to argue that his emotion circle matches the color circle and did not present empirical evidence for it. However, Fromme and O'Brien found some experimental evidence that partially support correspondence between Plutchik's emotion circle and the hue circle,[52] though they did not directly evaluate the consistency between them.

In interactive systems and arts, emotions are often represented by colors, usually together with animations and shapes.[53–58] In such interactive systems, the correspondence between the emotion circle of Russell or Plutchik and the hue circle was assumed, and the color that represents an emotion was presented based on that correspondence. In information and communication technology, correspondence of the hue and emotion circles has been fairly accepted, though there is not firm empirical evidence to support it.

This study investigated the hypothesis that the hue circle corresponds to the emotion circle based on the circumplex model of emotion with data on direct color–emotion associations using a data visualization method, correspondence analysis. To test our hypothesis, data on color–emotion associations were collected. Many previous studies have been criticized for using colors' names as stimuli instead of actual colors or imperfect specifications of colors. Colors specified in the Commission Internationale de l'Éclairage (CIE) color space were used. Participants voluntarily reported their emotions associated with color stimuli. These data were subsequently arranged into a contingency table (colors × emotions), and a correspondence analysis[59,60] was conducted. The results of correspondence analysis are generally presented in a biplot with row and column items (in this case, colors and emotions) in a single multidimensional space to visualize the degree of associations between the row and column items. The distance between a color and an emotion in a biplot roughly represents the degree of association between them. If color–emotion associations reflect an underlying correspondence between the hue and emotion circles, these circles should appear in the biplot and overlap. In contrast, if a different principle mediates color–emotion association, the configurations of colors and emotions in the biplot will not resemble the hue and emotion circles. Although correspondence analysis was used to test the hypothesis, it is usually used for exploratory data analysis through visualizing data with the biplot. This study will also show that correspondence analysis can reveal the statistical structures of color–emotion associations by decomposing association data into dimensional components, and useful insights can be gained by the biplot visualization.

2 | METHODS

2.1 | Apparatus

Stimuli were displayed on a cathode ray tube monitor (SONY CPD-G420). The viewing distance was approximately 80 cm. The display size was 1024 pixels × 768 pixels (35.0 cm × 26.3 cm). Participants viewed the display in a dark room.

2.2 | Participants

Forty-seven Japanese undergraduate and graduate students participated (age: 19–23 years; 39 male; 8 female). Although there were more male participants, the male–female ratio reflected the sampled population. (The proportion of female students was approximately 0.2 in the university from which participants were sampled.) All participants were unaware of the experiment's purpose and were majoring in computer and information sciences. Each participant's color vision was confirmed to be normal using Ishihara's test. None of the participants was excluded as a result of the test, but people who knew that they have color deficiencies might not apply for this experiment to begin with.

2.3 | Stimuli

In the center of the display, a square of a given color was presented on a gray background. The size of the square was 200 pixels × 200 pixels (6.8 cm × 6.8 cm); squares could be any of 40 colors. Table 1 presents the background and stimulus colors' luminance; CIE *xy* color coordinates; and L^*, a^*, b^* of the CIE$L^*a^*b^*$ 1976 color space (CIELAB). (Color 13 [the white stimulus] was used as the reference white point for CIELAB.) The luminance and *xy* coordinates for each color were measured using a colorimeter (Konika-Minolta CS-100A). The first 13 colors approximated those used by Kaya and Epps[9] using the correspondence table (JIS Z 8721[61]) of Munsell colors and *xyY* values in the CIE 1931 color space. The remaining colors were chosen mainly from colors corresponding to some Japanese color names to provide adequate variations in hue, brightness, and saturation between stimuli.

2.4 | Procedure

The overall procedure was similar to that used by Kaya and Epps.[9] In the beginning, an experimenter read aloud 27 representative Japanese words expressing an emotion, including the six basic emotions (pleasure, delight, curiosity, relief, love, praise, pride, desire, fear, anger, irritation, jealousy, rage, contempt, hatred, envy, condemnation, unease, disgust, sarcasm, boredom, worry, resignation, regret, shame, sadness, and dismay). In a preparatory experiment, it sometimes seemed that appropriate emotion words did not come into the participants' minds. Hence, the candidates for emotion words were presented in advance before the experiment to refresh participants' memories of emotion words before the

TABLE 1 Luminance and color coordinates (CIE xy) of colors used for the stimuli

No.	Luminance (cd m^{-2})	CIE x	CIE y	L*	a*	b*
1	17.9	0.54	0.31	53.7	60.8	31.0
2	71.9	0.42	0.46	94.8	−11.7	76.1
3	18.1	0.26	0.48	54.0	−52.2	27.1
4	27.7	0.20	0.23	64.6	−14.5	−38.2
5	17.7	0.29	0.21	53.4	33.7	−32.0
6	39.5	0.50	0.41	74.7	30.1	67.1
7	54.6	0.40	0.49	85.1	−23.8	73.6
8	39.8	0.24	0.34	74.9	−40.9	−4.5
9	17.7	0.22	0.18	53.5	19.5	−49.8
10	10.7	0.49	0.27	42.8	55.7	9.0
11	0.7	0.31	0.31	8.0	0.5	−0.9
12	18.0	0.31	0.32	53.8	0.1	0.4
13	82.6	0.31	0.32	100.0	0.0	0.0
14	44.6	0.39	0.31	78.4	32.4	11.0
15	38.0	0.32	0.20	73.6	67.3	−42.1
16	30.0	0.32	0.17	66.8	86.3	−52.6
17	24.1	0.32	0.17	60.9	80.5	−49.2
18	10.7	0.32	0.19	42.8	50.8	−31.9
19	3.9	0.29	0.16	26.0	40.9	−30.8
20	28.0	0.53	0.33	64.9	60.5	39.8
21	22.7	0.62	0.35	59.4	71.6	73.0
22	15.1	0.61	0.35	49.9	62.0	60.9
23	11.1	0.45	0.47	43.5	−2.7	47.0
24	19.0	0.57	0.39	55.0	44.1	63.8
25	9.1	0.57	0.38	39.7	36.2	47.9
26	4.7	0.60	0.35	28.7	39.5	36.5
27	64.0	0.30	0.44	90.6	−51.2	36.9
28	55.3	0.29	0.59	85.5	−88.3	76.4
29	42.6	0.28	0.46	77.0	−59.6	32.9
30	9.7	0.21	0.29	40.8	−23.5	−13.1
31	6.5	0.29	0.57	33.8	−41.5	34.7
32	68.0	0.24	0.31	92.7	−33.5	−14.7
33	61.2	0.22	0.33	89.0	−55.3	−9.7
34	13.5	0.17	0.11	47.4	46.8	−85.2
35	7.5	0.15	0.07	36.2	66.9	−103.8
36	9.5	0.16	0.12	40.4	26.2	−70.5
37	2.9	0.15	0.07	22.1	44.6	−71.7
38	77.9	0.37	0.40	97.8	−9.2	42.2
39	70.6	0.44	0.48	94.1	−11.7	90.1
40	53.1	0.43	0.48	84.1	−14.1	80.7
background	47.1	0.31	0.32	80.2	0.0	0.0

(Continues)

TABLE 1 (Continued)

experimental trials. In each trial, one stimulus was presented in the center of the monitor, and an empty text box was shown below the image. Participants wrote a Japanese word to express the emotion that the stimulus color made them feel or that they associated with the stimulus color. Participants were permitted to report emotion words other than those that the experimenter initially read aloud and to report the same emotion word for different colors. Stimuli were presented in random order; participants evaluated each stimulus once, resulting in 40 trials. After the experiment, the participants responded to a personality inventory (results not reported).

3 | RESULTS

Three types of Japanese characters exist (*hiragana*, *katakana*, and *kanji*—Chinese characters).* Therefore, given words may be written in different ways. To manage this variation, different versions of the same word were grouped together under a common label. Additionally, expressions that use an identical Chinese character and almost share a meaning were grouped and transformed into a representative expression. Responses considered not to represent an emotion (e.g., wide, cold, strong) in Japanese were excluded. We obtained 167 emotional words in this manner and, accordingly, created a preliminary contingency (cross-tabulation)

*Kana is a phonetic writing system in Japanese, and kanji are Chinese characters, which are ideograms. Japanese documents are generally written using mixtures of kana and kanji. There are two types of kana: hiragana and katakana. Hiragana is generally used for Japanese writings, but some words, such as words imported from foreign languages and some onomatopoeic words, are written preferentially in katakana. Chinese characters that are difficult to write or are not easily remembered are often written by kana.

TABLE 2 Emotion words used for correspondence analysis and their frequency

Japanese	English	Frequency	Japanese	English	Frequency
安堵	Relief	135	絶望	Despair	4
好奇心	Curiosity	103	やらしい	Eros	4
退屈	Being bored	83	純粋	Purity	4
心配	Worry	78	静けさ	Quietness	4
愛	Love[1]	75	不思議	Wondering	4
皮肉	Sarcasm	71	活発	Activeness	3
喜び	Pleasure	63	和み	Being soothed	3
後悔	Regret	61	暗い	Darkness	3
欲望	Desire	60	無心	Detachment	3
悲しみ	Sadness	56	歓喜	Great joy	3
軽蔑	Contempt	54	幸せ	Happiness	3
不安	Unease	54	恋	Love[2]	3
嫉妬	Jealousy	49	新鮮	Newness	3
嬉しさ	Delight	47	平和	Peace	3
賞賛	Praise	47	きつい	Sternness	3
諦め	Resignation	47	平常心	Usual frame of mind	3
落胆	Dismay	44	注意	Attention	2
誇り	Pride	40	晴れやか	Brightness[2]	2
苛立ち	Irritation	38	清潔	Cleanness	2
嫌悪	Disgust	36	包容	Comprehension	2
非難	Condemnation	29	敗北	Defeat	2
恥	Shame	28	憂鬱	Depression	2
怒り	Anger	26	残念	Disappoint	2
羨望	Envy[1]	26	冷めている	Dispassion	2
憤怒	Fury	23	空虚	Emptiness	2
優しさ	Gentleness	20	熱意	Enthusiasm	2
落ち着き	Composure	19	妬み	Envy[2]	2
楽しい	Merriness	19	激しい	Fierceness	2
興奮	Excitement	18	もやもや	Fogginess	2
恐怖	Fear	17	和やか	Genialness	2
清々しさ	Freshness	17	どんより	Gloominess	2
憎しみ	Hatred[1]	16	憎悪	Hatred[2]	2
爽やか	Invigoration	16	寂しい	Loneliness	2
元気	Liveliness	15	すっきり	Lucidity	2

(Continues)

TABLE 2 (Continued)

Japanese	English	Frequency	Japanese	English	Frequency
穏やか	Placidness	15	やる気	Motivation	2
冷静	Calmeness	13	自然	Naturalness	2
情熱	Passion	13	吐き気	Nausea	2
無感情	Emotionlessness	11	平凡	Ordinary	2
安心	Feeling secure	11	苦しい	Painfulness	2
明るさ	Brightness[1]	9	下心	Secret intention	2
期待	Anticipation	7	誠実	Sincerity	2
安らぎ	Ease	7	滑らか	Smooth	2
癒し	Healing	7	柔らか	Softness	2
驚き	Surprise	7	安定感	Steadiness	2
涼しい	Coolness	6	奇妙	Strangeness	2

table of 40 stimulus colors (rows) × 167 reported emotional words (columns). It was a 40 × 167 matrix whose ith row jth column element was the number of participants who reported the jth emotion word to the ith color stimulus. Seventy-seven emotion words that appeared only once were eliminated; 90 words subsequently remained, reducing the contingency table to 40 colors × 90 words. Table 2 presents the retained emotion words and their English translations; all emotion words were nominalized in their English translation (e.g., "angry" was converted to "anger"). A chi-square test conducted on the table showed high significance ($\chi^2(3471) = 5992.5$, $p < 2.2 \times 10^{-16}$), though the chi-squared approximation might not be so good because of the low frequency of many cells. Further, correspondence analysis was conducted using that table.[59,60] Figure 2 presents the resulting inertia values (eigenvalues). Fairly clear gaps were found between components four and five and between components eight and nine. We decided to extract eight components to avoid a loss of useful information. The eight dimensions explained 61.7% of the total inertia. Figure 3 presents the resulting eight-dimensional biplot.

Figure 3A presents the projection of configurations to dimensions 1 and 2. The U-shaped pattern of hue variations is clearly visible. Red colors were located in the upper left, and the color changed from reddish hues to pink and orange and then to yellowish hues from the upper left to the center bottom. From there to the upper right, the color changed from yellow to green and then to bluish hues and, finally, to dark colors, such as violet and black. Several purplish or brown colors were present between the upper right and the upper left; however, the item density was lower than in other regions. The U-shaped pattern resembles the CIE xy color space rotated by 180°, or the spectral trajectory in the rotated CIELAB color space, though the order of hues in the biplot is not fully consistent with that space along the wavelength trajectory. For example, bright cyan colors were located at the bottom center, preceding greenish colors, which was inconsistent with the spectral color order. Nonetheless, the hue order along the curve generally conformed to the spectral hue order (red–orange–yellow–green–blue–violet). White and black were located not in the center but outside the U-shaped region (achromatic colors were represented in other dimensions, as described below).

Emotion words were also positioned along the U-shaped trajectory. "Passion," "anger," "enthusiasm," "motivation,"

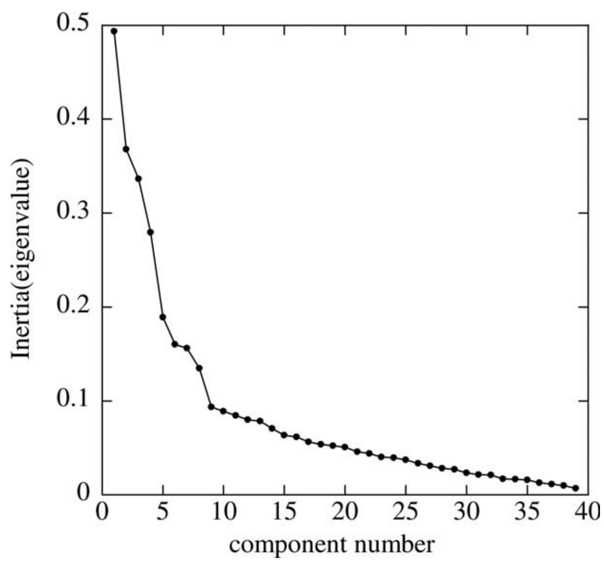

FIGURE 2 Inertias (eigenvalues) obtained by correspondence analysis as a function of the component number

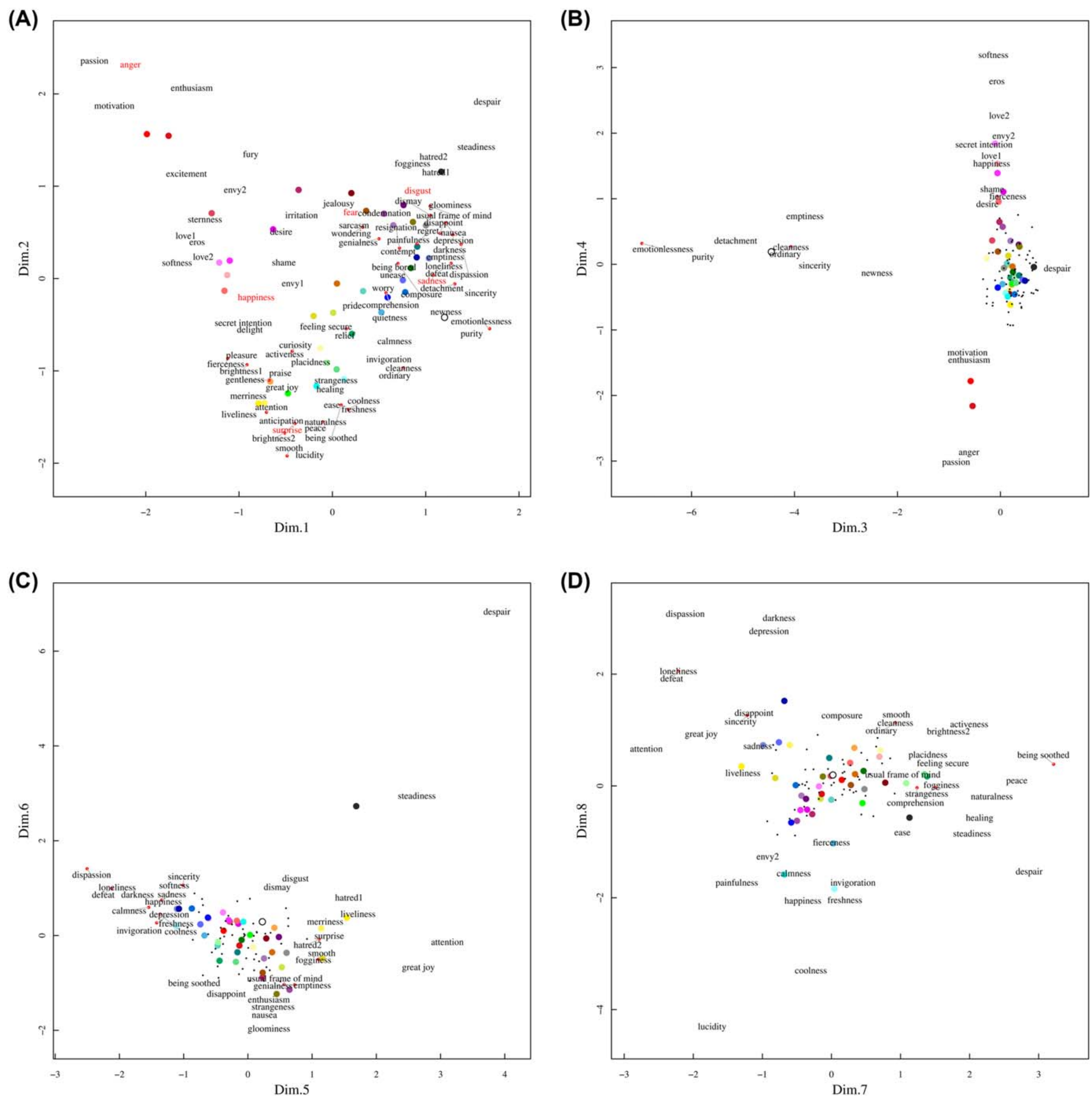

FIGURE 3 Biplot obtained by correspondence analysis. Plots (A)–(D) are projections to the plane of dimensions 1–2, 3–4, 5–6, and 7–8, respectively. In (A), the basic six emotions are written in red. Only the emotion words with absolute coordinates larger than 1.0 on either the horizontal or vertical axis are shown in (B)–(D)

"excitement," and "fury" were located in the upper left, near the red colors. "Love," "softness," and "eros" were located near the pinkish colors. Positive words such as "happiness," "pleasure," "brightness," and "joy" as well as "surprise" and "anticipation" were located from the upper left to the center bottom, near orange and yellow colors. "Calmness," "quietness," "feeling secure," and "relief" were located near the greenish colors. Negative emotion words such as "sadness," "worry," "regret," and "depression" were located in the upper right near the blue and violet colors. "Fear" and "jealousy" were located in the upper center near the purplish colors. The order of basic emotions along the U-shape trajectory was "anger"–"happiness"–"surprise"–"sadness"– "disgust"–"fear"; this does not match Russell's circumplex model (Figure 1). In summary, the hue circle (presented in two dimensions) was roughly consistent with the spectral order, but the emotion order along the hue circle did not correspond to the circumplex model's emotion order. This does not support the hypothesis that the hue circle corresponds to the emotion circle.

To examine the similarity in the color configurations in Figure 3A and the a^*b^* color coordinates of the stimulus colors in the CIELAB color space, each of the coordinates in Figure 3A were linearly regressed to the CIE a^*b^* color coordinates. (The regressors a^* and b^* were divided by 100 to avoid too-small regression coefficients.) The results are summarized in Table 3. These regressions were highly significant, and all partial regression coefficients, except that of b^* for dimension 2, were significant. Thus, the configurations in Figure 3A were strongly related to the a^*b^* color coordinates. However, the coefficients of determination (R^2) were not remarkably high (0.43 and 0.40 for dimensions 1 and 2, respectively). Further, using the CIE xy coordinates instead of CIELAB a^*b^* coordinates, the same regression analyses were conducted. However, the coefficients of determination were about as large as those for the CIELAB a^*b^* coordinates (0.36 and 0.44 for dimensions 1 and 2, respectively). This suggests that the configurations of the stimulus colors in Figure 3A were not entirely determined by the a^*b^* or xy color coordinates.

To analyze further the deviations in the color coordinates in the biplot from the a^*b^* color coordinates, we performed another analysis. The a^*b^* coordinates were fitted to the color configurations in Figure 3A. The color coordinates (a^*b^*) were scaled, rotated, and translated so that the sum of square distances between the coordinates of each color in Figure 3A and the transformed a^*b^* coordinates of that color should be minimized. (This procedure is called a Procrustes transformation in psychometrics.) The transformed a^*b^* coordinates and the coordinates of the colors in Figure 3A are shown in Figure 4A. The biplot point for each of the colors was connected to the transformed a^*b^* color coordinates by a line, the length of which represented the deviation in the biplot configurations from the transformed CIE a^*b^* coordinates. Some of the colors were systematically displaced from the transformed a^*b^* coordinates; although saturated red colors were displaced to the upper region, these deviations were quantitative (the positions were exaggerated) but not qualitative. Although achromatic colors (white, gray, and black) should be in the center of the a^*b^* color space, they were in the periphery in the biplot. Light violet was placed near red in the biplot, whereas dark colors, such as brown, dark green, and unsaturated orange, were placed near blue in Figure 3A. These findings suggest that luminance/lightness was related to the color configurations in Figure 3A; dark colors were displaced to the blue regions from the positions predicted from the a^*b^* color coordinates. Although there were considerable deviations from the a^*b^* color coordinates, we can observe from Figure 4 that the overall spectral order of the color configurations in Figure 3A was fairly preserved.

Because the U-shaped color configurations of colors in Figure 3A appears to be more similar to the CIE xy color space, the configuration of colors in Figure 3A was fitted to the xy color coordinates in the same way as to the a^*b^* coordinates. The results are shown in Figure 4B. The fit results were quite similar to those for a^*b^* in Figure 4A, and the use of xy did not improve the fit.

Figure 3B presents the configurations of the third and fourth dimensions. The following words had a large absolute coordinate value in the third dimension: "emotionlessness," "pureness," "detachment," "emptiness," "clearness," "sincerity," and "newness." Only white had a large absolute coordinate value. Hence, this dimension represents white and emotions associated with white. Deep red colors and associated emotions ("motivation" and "enthusiasm") were located on the negative side of the fourth dimension, and light reddish colors such as pink and magenta and "softness," "eros," and "love" were located on the positive side. Hence, this dimension represents the deepness/lightness of reddish colors and the variation in their associated emotions.

Figure 3C presents dimensions 5 and 6 of the biplot. The L-shaped configuration indicates the two tilted axes. Blue colors were arranged along the axis from the bottom-center to the left-center. Emotion words such as "dispassion," "defeat," "calmness," and "loneliness" were located near these colors. This axis seems to represent emotions associated with blue that are not represented entirely in the first and second dimensions. The other oblique axis in Figure 3C was strongly related to black and the emotion words "steadiness" and "despair," apparently describing emotions specifically associated with black.

Figure 3D presents dimensions 7 and 8. Green colors and emotions associated with green (e.g., "being soothed," "peace," and "naturalness") were gathered in the right-center. Bluish colors varied from light to dark along the eighth dimension. "Lucidity," "coolness," "happiness," and "freshness" were located near light bluish colors on this dimension's negative side; "dispassion," "darkness," and "depression" were located near the dark bluish colors on the positive side. This dimension appeared to describe variation in the emotions associated with bluish colors from light to dark tones.

To obtain the biplot in Figure 3, some of the responses were eliminated. To evaluate the impact of that elimination, correspondence analysis was applied to the whole table, which included all the original uncorrected responses. The first four dimensions were very similar to those reported in Figure 3A,B. In the remaining four-dimensional space (dimensions 4–8), the same axial structure composed of the four associations (black–despair, blue–depression, green–being soothed, and light blue–freshness) were also observed, though the axes were oriented differently from those reported here. Thus, the dimensional structure reported in the results did not depend on that elimination procedure.

TABLE 3 Regression of the biplot's coordinates of colors to CIE a^*b^* coordinates

Dimension		Coefficient[a]	$t(37)$	$p(t)$
1	(Intercept)	0.22		
		(0.11)		
	$a^*/100$	−0.99	−3.99	<0.001
		(0.25)		
	$b^*/100$	−1.01	−4.65	<0.001
		(0.22)		
$R^2 = 0.43$, $F(2, 37) = 14.01$ ($p < 0.0001$)				
2	(Intercept)	−0.16		
		(0.11)		
	$a^*/100$	1.13	4.79	<0.001
		(0.24)		
	$b^*/100$	0.05	0.26	0.80
		(0.21)		
$R^2 = 0.40$, $F(2, 37) = 12.59$ ($p < 0.001$)				

[a]The inside of the parenthesis indicates the standard error.

4 | DISCUSSION

This study examined associations between colors and emotions. Participants viewed 40 colors and reported a word that expressed the emotion they associated with or felt in response to each color. Participants' responses were aggregated into a contingency table of colors and emotion words. Some emotion words were removed, and, subsequently, correspondence analysis was performed to generate an eight-dimensional biplot. The first and second dimensions were related to hue; hue configuration resembled spectral trajectory in the CIELAB a^*b^* or CIE xy color space. The third dimension was related to white and emotions associated with it. The fourth dimension represented tone variation in the color red and accompanying emotional variation. The fifth and sixth dimensions had tilted axes representing black and blue and emotions related to those colors. The seventh dimension represented green colors, and the eighth dimension represented tone variation in bluish colors.

The biplot's U-shaped hue representation in the first and second dimensions was particularly significant as it resembled the spectral trajectory from long-wavelength (red) to short-wavelength (blue) light in the CIE xy color space. Emotion words also varied along a similar trajectory, including active emotions associated with reddish colors (e.g., anger, passion, and excitement); steadier, more positive emotions associated with orange and yellow (e.g., pleasantness and happiness); and inactive and negative emotions associated with dark blue and violet (e.g., disgust, hatred, depression, and fear). This curvilinear trajectory represented a transition from hot to cold colors and from high- to low-activity emotions. Thus, the curve appeared to reflect the apparent temperature of colors and activeness of emotions. Although emotional variation along the curve roughly corresponded to relative emotional arousal, some deviation was clearly present; anger and fear were both high-arousal emotions but were located at opposite ends of the curve.

Hues are usually represented using a circular figure in the relevant color model (e.g., the Munsell color system). In addition, several models of emotion have been proposed; the circumplex model[41] is among the most popular of these. This model uses orthogonal axes of pleasantness and arousal, and emotions are arrayed on a circle in the resulting two-dimensional space. We examined emotions' hypothesized association with colors by comparing circles plotting colors and emotions. We obtained a hue circle roughly consistent with representative color models. However, the ordering of emotion words in the biplot was anger–happiness–surprise–sadness–disgust–fear (–anger) (Figure 3A), which contradicts the ordering of basic emotions in the circumplex model (anger–fear–surprise–happiness–sadness–disgust(–anger); Figure 1). The respective emotion circles could be made equivalent by exchanging the positions of anger and fear and of happiness and surprise. However, these exchanges are unnatural and irrational considering the conceptualization of the relevant emotional dimensions (i.e., pleasantness and arousal). Sadness, disgust, and fear were clustered in the biplot. However, anger was distant from them (Figure 3A). This result also contradicts the circumplex model, which locates anger near fear (Figure 1). Thus, the ordering of emotions in the circumplex model does not match the ordering of emotions in Figure 3A, and the hypothesis that the hue circle corresponds to the circumplex model of emotion was not supported.

Plutchik presented a different circular model of emotions,[50,51] and some researchers argue that his emotion circle matches the color circle.[52,57,58] However, the ordering of emotions in Figure 3A was not also consistent with that in Plutchik's emotion circle: anger–anticipation–joy–trust–fear–surprise–sadness–disgust(–anger). Thus, the results did not support the claim that the hue circle corresponds to Plutchik's emotion circle.

Odbert et al.[7] and Ross[48] represented color–mood associations by arranging a hue circle following Hevner's mood circle,[49] which consists of circular arrangement of eight types of moods: gay–playful–leisurely–tender–sad–solemn–vigorous–exciting(–gay). Because Hevner's mood model was intended to model mood induced by music and does not include strong emotions such as anger, fear, surprise, or

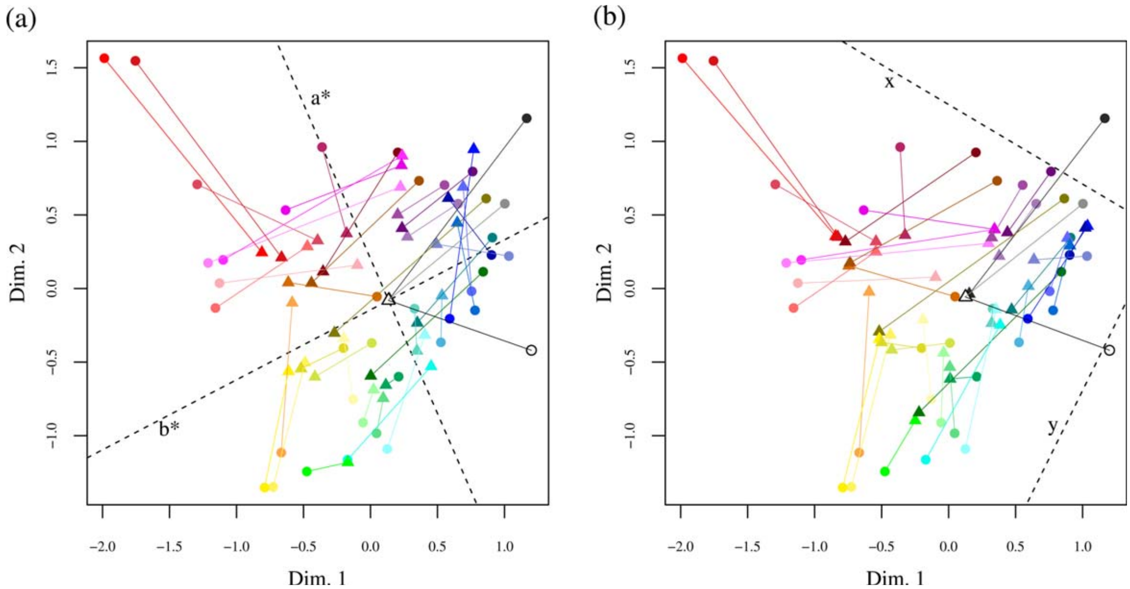

FIGURE 4 Configurations of colors in Figure 3A are replotted with circles, and the transformed a^*b^* coordinates in CIELAB or CIE xy coordinates are plotted with triangles. (A) Results of a^*b^*. (B) Results of xy. The corresponding symbols are connected with lines. The transformed CIE a^*b^* or xy coordinates were obtained by scaling, rotating and translating the original coordinates so that the sum of square distances between each color in Figure 3A and the transformed a^*b^* or xy coordinates of that color should be minimized

disgust, direct comparison of our results with those of Odbert et al.[7] and Ross[48] was not feasible. However, the correspondences, such as exciting to red, sad to purple (or blue and black), gay to yellow-orange, and awe-inspiring (which should be related to fear, which was grouped into solemn mood in Hevner's mood circle) to violet were consistent with those observed in biplot dimensions 1 and 2. Notably, Ross also suggested that the correspondence between the hue circle and Hevner's mood circle was mediated by temperature.[48] Thus, the configurations of emotions in Figure 3A, which seem also to be mediated by temperature or activeness, were more similar to Hevner's mood circle than the circumplex model of emotions. Colors induce perceptions of relative temperature. Similarly, emotions involve excitement/calmness, which is often associated with temperature, as suggested by the partial synonymy of "hot" and "cold" with "angry" and "calm" in some English expressions (e.g., "hot-headed," "cold-hearted"). Thus, emotions seem to be associated with colors through the mediation of a concept of temperature. It should be noted, however, that the configurations of colors and emotions in Figure 3A are not along a closed circle but, rather, U-shaped, whereas Hevner arranged moods along a circle. Thus, it cannot be concluded with certainty that the configuration of emotions in Figure 3A is entirely consistent with the Hevner's mood circle. Further studies are required to conclude that the emotion configuration in color–emotion associations is circular (or U-shaped) and consistent with Hevner's mood circle.

The associations between colors and emotions presented in Figure 3A may reflect the physiological inducement of emotion by colors during the experiment. Reddish colors may induce high arousal, yellowish and greenish colors partial arousal, and bluish colors low arousal. However, the effect of small-size colored stimuli on emotion or physiological variables appears small. Additionally, this study's participants viewed stimuli for a relatively short period. Previous research has suggested that short-duration exposure may not induce emotion or mood reliably.[31,33] Therefore, the U-shaped trajectory obtained does not reflect participants' emotional states during the experiment, although participants reported the emotions they associated with the stimuli or that the stimuli made them feel. However, physiological effects of colors may have been previously learned—probably unconsciously—by participants, which might be reflected in their color–emotion associations.

The remaining biplot dimensions described white, black, red, green blue, and the emotions associated with these colors, although some of these dimensions were tilted relative to their coordinate axes. Colors along each axis of dimensions 3–8 have a similar hue. Hence, these higher dimensions were not related to the hue circle, and correspondence between the hue and emotion circles would not be represented in these dimensions. The color–emotion associations presented in these higher dimensions did not appear based on any underlying principle (e.g., temperature) and, therefore, may be more likely candidates for cultural or cognitive determination. Emotion words related to the "white" dimension (the third biplot dimension) were "emotionlessness," "purity," and "emptiness." This association may reflect the fact that any color may partially cover white without being altered to another color; if so, this association would be cognitively determined. The "pink" dimension (the fourth biplot dimension) was related to "eros" and "love." In Japanese culture, pink is associated with eros (e.g., in Japanese, the expression "pink film" refers to adult erotic movies). Hence, the observed association between pink and eros or love may be cultural in origin. In dimensions 5 and 6, black was observed to be associated with despair, and in the seventh, green was associated with peace, soothing, and healing; previous research findings indicate these associations are cognitively determined.[9,10] Plants are generally green, and this may underlie the association between green and feelings of peace. Black is not easily painted over by other colors, and this may underlie its association with feelings of helplessness. In dimensions five and six, as well as the positive side of the eighth dimension, dark blue was associated with negative feelings such as depression, defeat, and loneliness. English expressions such as "blue Monday" and "maternity blues" may reflect this association. (Interestingly, in Japanese traditional culture, blue is not associated with depression. However, many young Japanese are now familiar with the English expressions "blue Monday" and "maternity blues," and some use such expressions regularly.) In contrast, the eighth dimension represented an association between light blues and coolness, lucidity, and freshness. These associations may arise from clear skies and clean water. Thus, dimensions 3–8 of the biplot seem to be more dependent on cultural or conventional associations of colors with emotions than dimensions 1–2, though it is still possible that hidden universal principles for the color–emotion associations are present in these dimensions. It should be also noted that these associations probably dependent on cultural and conventional influences were also separated into these interpretable dimensions by correspondence analysis. This also suggests the usefulness of correspondence analysis, even for cultural and conventional color–emotion associations.

Colors are often associated symbolically with some meanings; danger is often represented by red in human–machine interfaces; the ionizing radiation hazard symbol is drawn with red-purple on a yellow background in Japanese Industrial Standard (JIS Z 9103).[62] Thus, color associations consist of emotional (color emotions) as well as symbolic associations (color meanings). Color meanings can be thought of as associations by conventions or regulation, and people do not necessarily feel some emotion when they see a color representing a symbolic meaning. This study focused on color emotions (emotional associations with colors) but not on color meaning. However, participants' responses might be affected by color meanings. In fact, configurations in dimensions 3–8 of the biplot (Figure 3B-D) seemed to be influenced by color meanings to some degree. However, color meanings should be reflected by color–emotion associations in the process of determination; green would be inappropriate for the symbol of danger or radioactive substances. Thus, color emotions are interconnected with color meanings, though they are conceptually different. Reciprocal influences of color meanings and color–emotions should be further investigated in future studies.

Many color–emotion associations vary between cultures while others appear consistently from one culture to the next. For example, red is typically associated with anger and excitement, yellow with happiness, and blue with calmness and comfort.[3–10] These universal associations appeared in the first and second biplot dimensions. Additionally, the first and second dimensions possessed the largest and second-largest inertia values (eigenvalues), suggesting that these dimensions explained color–emotion associations more than the other dimensions did. Thus, these dimensions' color–emotion associations should be primary. The plane spanning these dimensions predominantly represented hue, and emotions were ordered along the spectral color trajectory. The primary associations appeared based on the perceived temperature of colors and emotions, suggesting that perceived temperature may explain cross-cultural color–emotion associations. In contrast, the higher dimensions appeared to represent culturally contingent or cognitively mediated minor associations.

There are some limitations regarding the generalization of the results in this study. All participants were Japanese university students, and it is unknown whether the results can be generalized to other populations with different cultural backgrounds. In addition, there were many more male than female participants. Although sex differences in color preferences have been reported,[14,15] insignificant sex differences in color–emotion associations for adults have been reported[3] (except for the weak effect of sex also involving nationality[8]), and the influence of sex was not large for children.[16–19] Although it is expected that an imbalance in sex would not affect the results as much, we cannot reject that possibility. Further studies will be needed to clarify these issues by conducting similar experiments on a wider range of populations with different cultural backgrounds.

5 | CONCLUSION

Correspondence analysis has rarely been used to analyze color–emotion associations. This study analyzed a contingency table of colors and emotions using correspondence analysis, and several associations were identified in the resulting biplot: in dimensions 1 and 2, universally observed color–emotion associations appeared, whereas secondary associations were observed in the other dimensions. Using color and emotion configurations in dimensions 1 and 2 of the biplot, the hypothesis that the hue circle corresponds to the circumplex model of emotion was tested. Although this hypothesis was not supported, a new hypothesis that the primary association of colors and emotions is mediated by perceived temperature was proposed. Importantly, this new hypothesis is consistent with the representation of color–mood associations in music and theatre in earlier studies with cultural backgrounds different from Japanese, suggesting that these primary associations were observed widely across different cultures. Thus, it would be worth investigating further. Although correspondence analysis will not necessarily decompose associations into distinct components, this study's results suggest that correspondence analysis facilitates the study of color–emotion associations through its ability to reveal associations' underlying statistical structure. Notably, this capability was also revealed in a study of material perception, where correspondence analysis was also used for decomposing responses in visual material perception into several perceptual dimensions.[63] There should be cultural differences in color–emotion associations, and there might be also differences in sex and age. It is highly expected that universal color–emotion associations are observed in the low-dimensional biplot space, as in this study. Future research should further elucidate color–emotion associations, particularly regarding their cross-cultural universality and cultural uniqueness and the effects of sex and age. Correspondence analyses would facilitate such research.

ORCID

Mitsuhiko Hanada http://orcid.org/0000-0001-9002-2059

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AUTHOR BIOGRAPHY

Mitsuhiko Hanada received B. A. in education psychology from Faculty of Education, Kyoto University in 1995. He received M. A. degree and Ph. D. in human and environmental studies from Graduate School of Human and Environmental Studies, Kyoto University in 1997 and 2000, respectively. He was a research assistant in Department of Information and Cognitive Sciences from 2000 to 2004, Faculty of Letters, Chiba University. In 2004, he joined Future University Hakodate as an assistant professor, and he is currently an associate professor at Department of Complex and Intelligent Systems, Future University Hakodate. His research interests include visual information processing, human personality, and, statistical analysis of psychological data.

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