Human Color Impression for Color Sequence with Minimum Distance

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Abstract—*We examine how a row of fundamental six-color (cyclic) sequence affects human color impression. In order to investigate the different effects of two spatial sequences, we consider a hexagonal diagram that is a projection of RGB color space from white to black. The hexagonal diagram corresponds roughly to the hue circle indicated by both hue and saturation in the HLS system. The projected route area indicates the magnitude of naturalness (as in rainbows) for color sequences. The minimum sequence is similar to the order of colors in rainbows, whereas the non-minimum sequence is completely different. Therefore, we proposed a human color impression model using the projected route area indicated by both hue and saturation. We clarified that subjects of nearly all ages have natural impressions when the route area is large and unnatural impressions when the route area is small, and compared the human color impression to the human color impression model.*

Keywords: *Spatial color sequence, minimum distance, human color impression, natural-unnatural, RGB color space, hexagonal diagram, route area, HLS (hue, lightness, saturation) system, human color impression model*

1 Introduction

The different effects of temporal color sequences of several colors on human color impression were examined in a previous study [5], [8]. In these studies, the possibility of a several-color cyclic sequence having a minimum distance in RGB color space was investigated for subjects in an analysis of color sensations. Several words are commonly used to describe the character and associative meanings of colors [3]. The degrees of pairs of terms that are applied to color sequences, such as natural-unnatural, are investigated herein. The word "natural" as a human color impression invokes expressions such as calm, flowing, and relaxed, whereas the word "unnatural" invokes expressions such as intense, tight, and unpleasant. Well-ordered color signal sequences having a minimum distance (minimum sequences) were found to elicit responses of a degree of naturalness. In contrast, random-ordered color signal sequences having no minimum distance (non-minimum sequences) were found to elicit responses of a degree of unnaturalness. We therefore adopted the words, natural and unnatural, based on a questionnaire that was given to 31 subjects. The two words *natural* and *complex* (or *unnatural*), were also described in ref. [1].

In the present study, we describe the results of experiments to examine human color impression and compare human color impression and the human color impression model using the projected route area based on these experiments. This model will provide spatial color sequences for managing emotions, coordination and similar applications.

2 Methods

2.1 Color sequences

A system of the three primary colors, red, green, and blue (RGB) presented in a cubic color space (Fig.1) was used in this study. In this space, we selected six fundamental color coordinates: (r_1,g_1,b_1), (r_2,g_2,b_2),…, (r_6,g_6,b_6), and prepared non-minimum sequences as six-color (cyclic) sequences (see Fig.1 (a)). The minimum distance of the coordinates could be computed. The minimum sequences made up of the same colors were also prepared as six-color (cyclic) sequences (see Fig.1 (b)). Table 2 (Type A) shows that RGB values ranged from 0 to 255. The sum of the distances is 2295 in the non-minimum sequences (Fig.1 (a)) and 1530 in the minimum sequences (Fig.1 (b)). The distance of the minimum sequences is clearly smaller than that of non-minimum sequences. The letters in Fig.1 denote the following: B; blue, C; cyan, G; green, Y; yellow, R; red, M; magenta, W; white, and S; black.

2.2 Experiments

For each experiment, either 60 (Type A and B in Table 1) or 121 (Type C and D in Table 1) undergraduate students, graduate students, and participants in a

Table 1. Number of subjects in the human color impression experiment

Type	Colors	No. of subjects	male	female	age	year
A	six fundamental colors	60	34	26	16-64	2002
B	five fundamental colors & orange	60	34	26	16-64	2002
C	six intermediate colors	121	67	54	4-82	2003
D	six magenta-blue relevant colors	121	67	54	4-82	2003

university festival volunteered to participate as subjects for this study. The subjects were asked to sit in a chair and watch a display continuously. The subjects were shown different sequences of six colors, as listed in Table 2. For example, a six-color sequence is (r_1,g_1,b_1),..., (r_6,g_6,b_6). The experiments were performed in an isolated area in order to restrict visual cues with regard to the display.

2.3 Equipment

A Sharp 11.3” Liquid Crystal Display was used to present the stimulus pattern. The display resolution was 1024×768 pixels/60 Hz.

3 Experimental Results

We examined whether the color impression for such a spatial color sequence could be expressed using simple adjectives (or adverbs). Figures 1 (a) and (b) show two of sixty possible tours in the three-dimensional RGB color space. One (circuitous) route is selected randomly (as a complimentary colors in Fig.1 (a)), and the other route is selected based on the minimum distance (Fig.1 (b)) [5], [8]. The two six-city TSP tours are obviously different. A complex route in (a) and a simple route in (b) are visually recognizable. Therefore, one suitable color sequence for which the subject has natural impressions is selected (is made) by the subject using the graphical user interface (GUI), as shown in Fig.2 (c). The buttons on the display are pushed in the desired order, as denoted by the numbers. The @ symbols indicate which button was pushed. When each button is pushed, the order of each color is fixed.

Using the schematic GUI in the questionnaire (Fig.2 (c)), we examined whether the subjects associate natural impressions with non-minimum sequences (a) or minimum sequences (b). The non-minimum cyclic route is blue, cyan, red, magenta, green, yellow, and blue again. The minimum cyclic route is blue, cyan, green, yellow, red, magenta, and blue again. Six sets (BCGYRM), (MBCGYR), (RMBCGY), (YRMBCG), (GYRMBC), and (CGYRMB) are treated as the minimum sequence.

The left-hand side of Fig.4 shows the projected minimum cyclic routes for each color sequence type. The

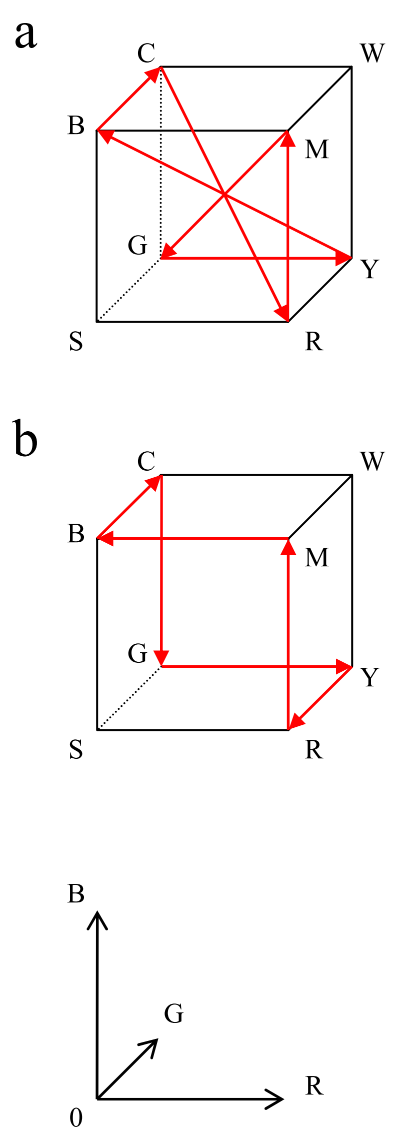

Figure 1. Two typical routes, (a) non-minimum routes and (b) minimum routes, for Type A colors (Table 1) in the RGB color space

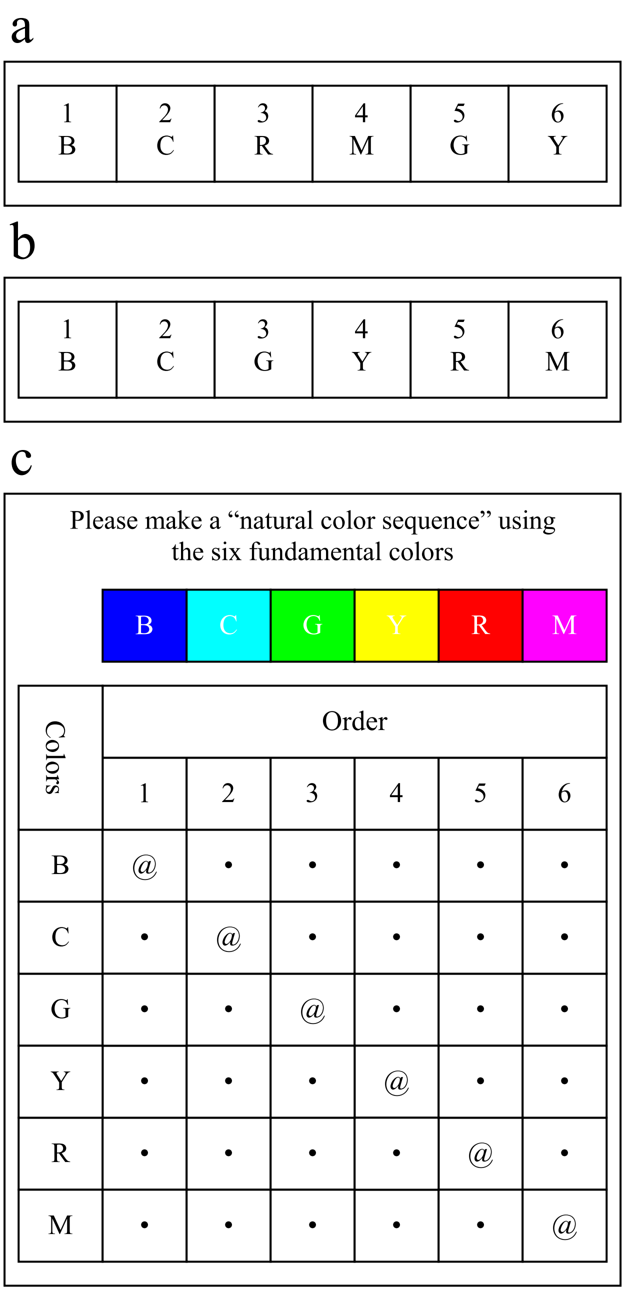

Figure 2. Typical two sequences (a) of non-minimum routes and (b) minimum routes, and (c) the schematic GUI for the questionnaire used for Type A colors

left ordinate shows the direction from yellow (bottom) to blue (top). The abscissa shows the direction from magenta (left) to cyan (right), or from red (left) to green (right). The projected route areas decrease from Type A to Type D. For instance, the projected minimum sequence of Type A is shown in Fig.3 (b). Figure 4 (right) shows the relationship between the number of subjects, the projected route area, and the order of the projected route distance. The majority of the subjects report a "natural" impression for the minimum sequence or close to it. This

Table 2. List of colors and RGB values for each type

		RGB values		
Type A colors	Order	*r*	*g*	*b*
blue	No.1	0	0	255
cyan	No.2	0	255	255
green	No.3	0	255	0
yellow	No.4	255	255	0
red	No.5	255	0	0
magenta	No.6	255	0	255
		RGB values		
Type B colors	Order	*r*	*g*	*b*
blue	No.1	0	0	255
cyan	No.2	0	255	255
green	No.3	0	255	0
yellow	No.4	255	255	0
orange	No.5	255	127	0
magenta	No.6	255	0	255
		RGB values		
Type C colors	Order	*r*	*g*	*b*
greenish blue	No.1	0	127	255
bluish green	No.2	0	255	127
green yellow	No.3	127	255	0
orange	No.4	255	127	0
magenta (rose)	No.5	255	0	127
violet	No.6	127	0	255
		RGB values		
Type D colors	Order	*r*	*g*	*b*
reddish purple	No.1	255	0	204
bluish purple	No.2	204	0	255
violet[1]	No.3	153	0	255
violet[2]	No.4	102	0	255
purplish blue	No.5	51	0	255
blue	No.6	0	51	255

cyan: blue green, orange: yellow red, magenta: red purple, violet: purple blue

is similar to the order of colors in rainbows, which are composed of colors having the following wavelengths [2]: violet (400-430nm), indigo (440-460nm), blue (470nm), green (505nm), yellow (575nm), orange

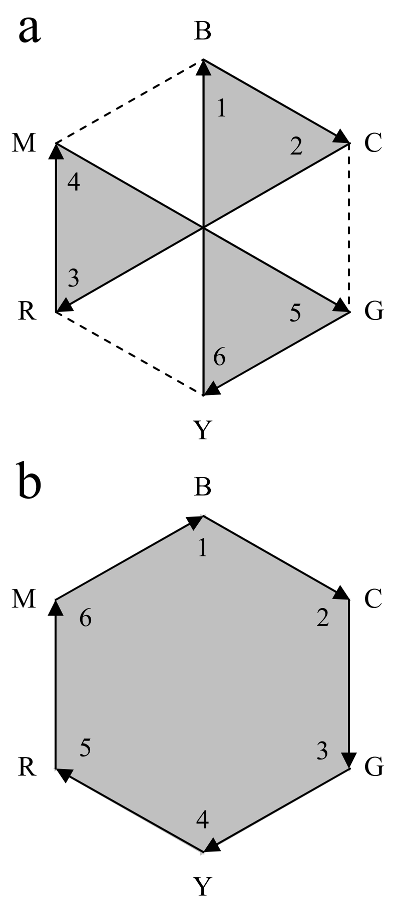

Figure 3. Two projected routes and projected route areas (shaded areas) for six fundamental colors (Type A)

(590-620nm), red (>630nm), where orange is yellow red, indigo is dull blue, and violet is purple blue.

4 Human Color Impression Model

Here, we examine how a six-color sequence affects human color impression. In order to investigate the different effects of two sequences, we consider a hexagonal diagram that is a projection of RGB color space from white (black) to black (white). The hexagonal diagram in Figs.3 (a) and (b) (see Fig.1) corresponds roughly to the hue circle (top view) indicated by both hue and saturation (except for lightness) in the HLS system. The numbers in the figure denote the order of each color corresponding to the arrows from the previous color to the present (target) color in Fig.2.

If *i)* the projected route distance is near the minimum, *ii)* each saturation is large (each point is far away from the center), and *iii)* neighboring colors are not too close to each other (on the hexagon), then the projected route area is assumed to be large. The route area indicates the magnitude of naturalness (as a rainbow effect) for color sequences. The minimum sequence is similar to the order of rainbow colors. On the other hand, the non-minimum sequence is completely different from the order of rainbow colors. Although the seven colors used in the previous study are not distributed as rainbow colors (violet, indigo, blue, green, yellow, orange, and red), and the six-color cyclic sequences are not continuous sequences having gradation, we propose a human color impression model using the route area indicated by both hue and saturation. This model [6], [7], [9] invokes natural impressions when the route area is large (Fig.3 (b)) and unnatural impressions when the route area is small (Fig.3 (a)).

5 Modeling Results

In the hexagonal diagram (Fig.3), we consider two projected routes and projected route areas of the human color impression model using six fundamental colors (at the six corners). Each color has maximum saturation, and the projected neighboring colors are widely spread in this case. For instance, the non-minimum route (blue, cyan, red, magenta, green, yellow, and blue again), shown in Fig.3 (a), includes the order of complimentary colors. However, this is not so for the maximum route. The minimum route (blue, cyan, green, yellow, red, magenta, and blue again), shown in Fig.3 (b), runs clockwise around the hexagon. The shaded regions show the projected route areas. If the sides are of unit length, the ratio R_d of the non-minimum projected route distance d_n to the minimum projected route distance d_m is 1.5, and the ratio R_a of the non-minimum route area a_n to the minimum route area a_m is 0.5.

The distances are only calculated in RGB color space, and not in HLS color space, because hue represents the angle in degrees. However, hue, lightness, and saturation in the HLS system are available for analysis of color sensation. In the present study, hue and saturation, rather than lightness, are important. No difference exists between the projected routes in the RGB system and those in the HLS system.

In the simulation results for the six fundamental colors of Type A (Fig.4 right), the relationship between the order of projected routes and the route areas shows a fluctuating, decreasing trend. This trend indicates a logarithmic approximation from the minimum route (1^{st} order of projected distance) to the maximum route (60^{th} order of projected distance). These fluctuations become larger as the order of the projected distance increases. Ignoring small fluctuations, the distances of the three-dimensional route are directly proportional to those of the projected route.

The simulation results for six colors (Fig.4, right) indicate that as route distance increases, route area diminishes, and numerous fluctuations occur. The result for six magenta-blue relevant colors (Type D) is not equal to that for six fundamental colors (Type A). Although the results for six fundamental colors and those for six

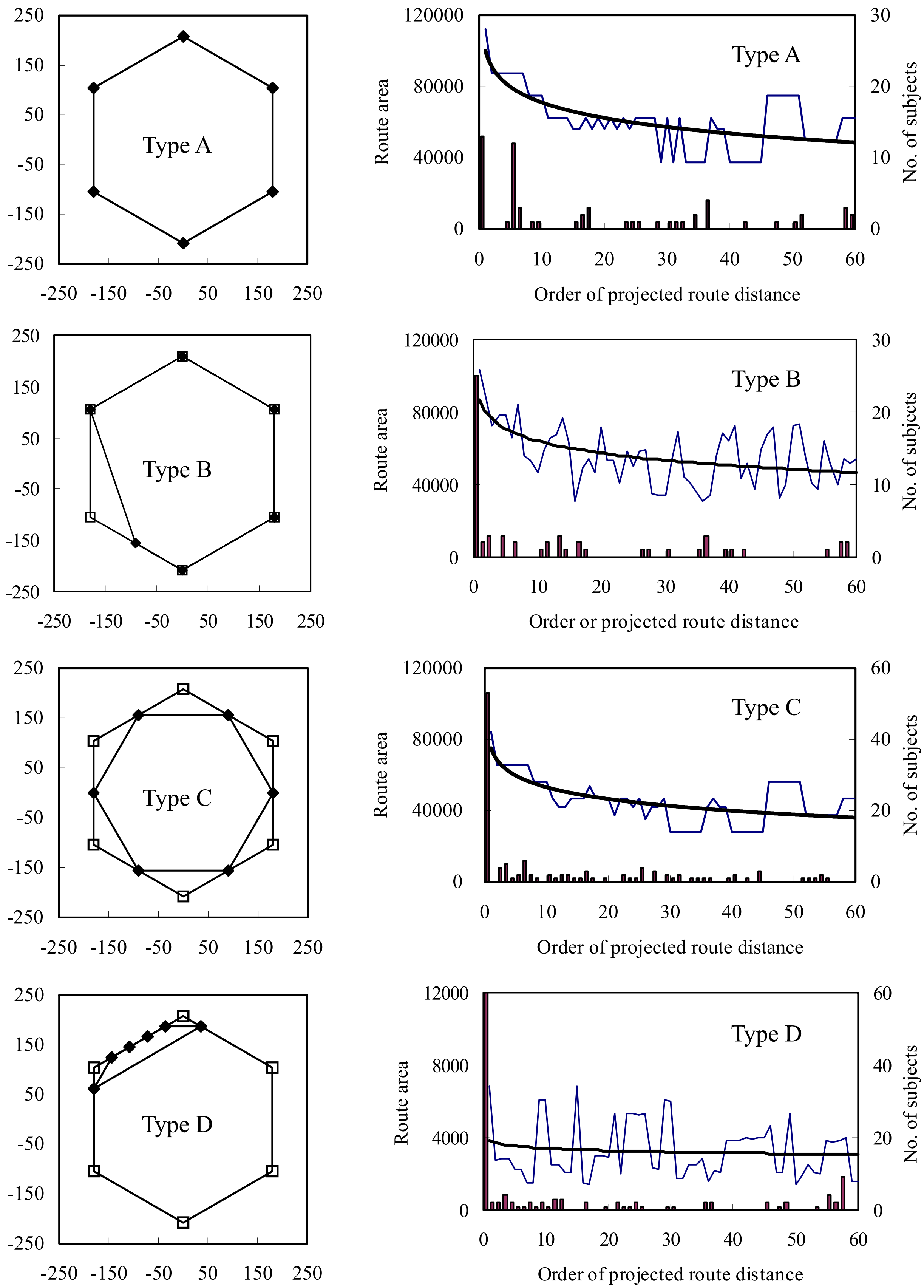

Figure 4. Relationship between order of projected route distance, route area, and number of subjects

Table 3. Characteristics of each color sequence type and responses

Type	Route distance i)	Saturation ii)	S.D. iii)	Route area iv)	Response (%) v)
A	1247.6	1247.6	0.0	112320	21.7 (13/60)
B	1210.7	1219.8	55.0	102960	41.7 (25/60)
C	1080.4	1080.4	0.0	84240	43.8 (53/121)
D	518.8	1125.4	81.3	6822	49.6 (60/121)

i) minimum projected route distance, *ii)* summation of each distance from the center, *iii)* standard deviation of distances between neighboring colors, *iv)* maximum projected route area, and *v)* number of subjects who selected the minimum sequence of each type as a natural color sequence

magenta-blue relevant colors differ, the respective trends of the questionnaire results are similar with respect to the histogram (right ordinate).

As shown in Fig.4, subjects preferring the minimum sequence make up the largest group (approximately 20-50%), although the six magenta-blue relevant colors present the most confusing task.

Table 3 summarizes the characteristics of each sequence type along with the responses of 181 subjects. The projected route distances are directly proportional to the projected route areas. In each case, the saturation changes only slightly. The standard deviations of distances between neighboring colors differ depending on whether the area for each type is hexagonal (Type A and Type C) or non-hexagonal (Type B and Type D).

Although the route area was thought to indicate the magnitude of naturalness for color sequences in our model, the route area is not proportional to the response of subjects in this case. For the similar colors of Type D, subjects might have a high-level human color impression recognized the most confusing task. Although we have not yet investigated the response of subjects who are allowed to compare the four sequence types, we believe that the majority of subjects will select the minimum sequence of Type A, rather than Type D, when selecting a “natural color sequence”.

6 Conclusions

In the present paper, we proposed a human color impression model that indicates the degree of perceived naturalness using the projected route area. These simulation results suggest that if the projected route distance is minimum, or nearly minimum, human color impression is “natural”, and is otherwise “unnatural”. The projected route distances are directly proportional to the projected route areas. However, the route area is not proportional to the response of subjects in this case.

In addition, this model will enable the management of feelings and emotions through the design of a row of suitable colors (as spatial information) for use in signboards, tiled floors, or gardening, for example, and through the use of color signal sequences (as temporal information) [5], [8] based on single color effects [4].

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