Experimental Determination of Laws of Color Harmony Part 8: Harmony Content Versus Relative Surface Coverage

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Received 26 September 2012; revised 31 December 2012; accepted 7 January 2013

Abstract: It is a recognized fact, that the relative surface coverage of the colors has a great influence on the harmony content. It is an open question that, in a composition, what is the optimum ratio between the surface area coverage of the colors, for maximum harmony content of the color pairs, selected for the composition. Various theories on color harmony already tried to answer this question, based on two substantially different principles. One is built on the mechanism of color vision, while the other one founded on statistical test results. The first approach was already proven not valid; but the second one was not proven right either due to the lack of available data. Our experiments aim is to fill this gap by using 324 compositions with different color coverage, to investigate its relation to harmony content. The statistical results were summarized in graphs as well as formulated in mathematical equations. The results show that the prime factor in the measure of harmony content is the relative surface coverage of the highly saturated colors. In most cases however the 50–50% ratio of color coverage leads to maximum harmony content in a composition. Col Res Appl, 39, 387–398, 2014; Published Online 25 February 2013 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.21797

Key words: color harmony; color composition; color science; color theory; Coloroid Color System; experimental color harmony; theory of color harmony

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INTRODUCTION

It has long been known, that harmony content of compositions, made up from different colors, (i.e., in paintings) is fundamentally influenced by the relative size of the surfaces occupied by the colors in the composition. The explanations given by various color harmony theories are based on two fundamentally different principles.

According to the first theory on color harmony the rules of producing color harmony experiences are determined by the mechanics of color vision. The trigger of the theory has been the phenomenon of successive contrast: longer observation of green results in a red afterimage. Investigating this phenomenon Rumford[1] has established that colors of successive color contrast mixed in an 'appropriate proportion' in the Maxwell disk are resulting in a medium grey color. Goethe[2] has built his theory of color harmony based on this observation. He thought the colors of successive contrast and that of simultaneous contrast are identical. Therefore he stated: the 'appropriate proportion' established by Rumford expresses the magnitude of color surfaces creating harmony experiences.

Goethe's theory has appeared with the mediation of Hoelzel[3] in the works on the theory of art written by Kandinsky,[4] Klee,[5] Itten,[6] Albers,[7] Moholy-Nagy,[8] Itten, in his book written to the students of the school of arts Bauhaus has fixed this proportion in relation of main colors. He established that the appropriate mutual proportion of the colors yellow, orange, red, violet, blue and green is as follows: 9 : 8 : 6 : 4 : 6.

Krawkow[9,10] has demonstrated by experiments that the colors of successive contrast are not identical to the colors of simultaneous contrast. This experimental result has refuted the conclusions of harmony theories originated from Rumford. Successive contrast is a physiological phenomenon the simultaneous color contrast is an aesthetic influence.

According to the second theory on color harmony the recognition of rules sought for is only possible by statistical assessment of a multitude of experiences. It has been recognized that color harmonies are different for national costumes of different folks and on pictures of different artists. It has been realized that young people and elder people prefer different color compositions. The rules of creation of color harmony experiences have been investigated using statistical assessments by researchers Moon and Spencer,[11–13] Poppe,[14] Granger,[15,16] Mori,[17] Morris,[18–20] Linett,[21] Feisner[22] among others. Many important statements were made for the relation between the mutual proportion of surface magnitude of color appearing in the compositions and the harmony content of the composition. We considered that further statistical assessments are necessary.

Our experiments are aimed at the fulfilment of this requirement. Our assessments complemented the investigations of former researchers by two new aspects. They are the following: the harmony content appearing in case of 1:1 density relation of colors of the composition, and the preference of color of the composition.

EXPERIMENT DESCRIPTION

General

All colors were defined and the experimental results are interpreted here by using the Coloroid system as the most suitable one for this purpose. For details of the Coloroid system we refer the reader to the literature[23–25] and we only give a brief system description in the following.

The Coloroid color space is in a cylinder containing all visible colors. The identification of the colors is by the following Coloroid coordinates. (A) hue angle, (T) the radial coordinate and the coordinate on the vertical axis (V) of Coloroid lightness (Fig. 1).

The half planes bordered by the achromatic axis are called Coloroid color planes. On these, the colors have the same Coloroid hues with identical dominant wavelengths and the colors are bordered by the neutral axis and two curves, called Cloroid border curves. On the vertical lines the saturation, on the horizontal axis the lightness is constant. The complementing hues, in the color space, are on planes with 180° inclination between them; therefore the complementing colors are opposite to each other.

In our experiment, we have used 12 hue pairs from these Coloroid planes. The angle of inclination between them was: 28°, 41°, 46°, 54°, 116°, 130°, 131°, 138°, 160°, 179°, 180°, and 181°, respectively. The saturation of the color pairs was the same every time, so was their lightness. Out of the 3 color pairs' saturations, the first one was the highest. The second had medium and in every case the third one was T = 10. The details of the 72 colors of the 36 color pairs are tabulated in Table I. For those who are more familiar with CIELAB, the CIELAB data are also given in 2 to 8 columns for the first pair, whilst for the second one; the data are shown in columns 9 to 15.

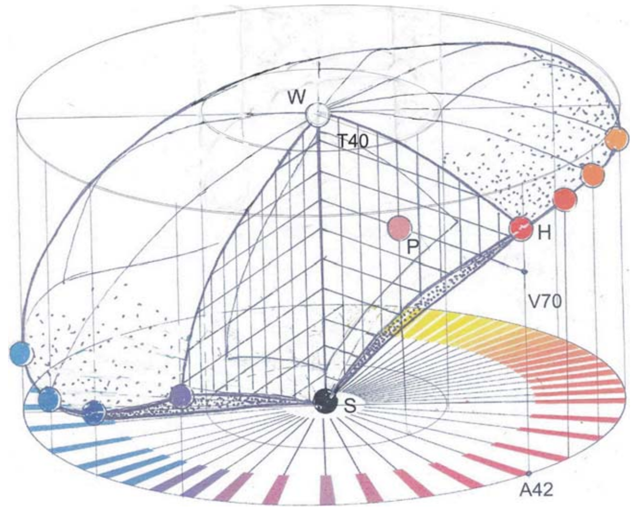


FIG. 1. Schematic presentation of the Coloroid Color System.

Experimental Objects

The 36 sets of boards were made of 9 compositions each in, a 3 × 3 matrix configuration, totaling 324 compositions of 18 × 18 cm in size on 74 × 74 cm birch backings. Only three of these are shown in Figs. 2–4 for brevity. Their details are shown in line 1–3 of Table I.

The surface coverage of the colors in the compositions is given in percentage below.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	
First color	100	87.5	75.0	62.5	50.0	37.5	25.0	12.5	0.0	%
Second color	0.0	12.5	25.0	37.5	50.0	62.5	75.0	87.5	100	%

In each composition, the colors are arranged in a 4 × 4 matrix form. The compositions were printed, the colors were checked by spectrophotometer before presentation and in case of discrepancy they were remade.

Experimental subjects

Twelve professional observers were selected from painters, textile designers and printers from the age group of 30–50. Both genders were represented approximately in equal numbers. Daltonians and color- blinds were deselected.

Experimental Conditions

The experiments were set up in a room lit by light reflected from the northern sky, i.e., standard D65 illumination, near to windows. The birch plates were perpendicularly placed, surrounded by grey background of $Y = 30$

TABLE I. Details of the colors used (Experimental Tables) in the compositions.

1 No.	2 A	3 T	4 V	5 L	6 a	7 b	8 nm	9 A	10 T	11 V	12 L	13 a	14 b	15 nm	16 P1	17 H5	18 P9
1	10	50	70	75.45	(−18.30)	105.59	570.83	51	50	40	75.45	17.30	46.77	492.72	43	78	55
2	10	30	70	75.45	(−10.77)	39.44	570.83	51	30	40	75.45	10.55	−30.80	492.72	22	73	29
3	10	10	70	75.45	(−3.52)	10.86	570.83	51	10	40	75.45	3.58	−11.54	492.72	17	35	14
4	12	40	70	75.45	−4.79	58.34	574.38	44	40	40	46.97	68.76	−43.48	(−548.11)	24.2	61	34.3
5	12	25	70	75.45	−2.98	29.97	574.38	44	25	40	46.97	46.40	−30.28	(−548.11)	20.2	21	25.1
6	12	10	70	75.45	−1.19	10.54	574.38	44	10	40	46.97	20.35	−13.94	(−548.11)	16.9	16	11
7	14	40	70	75.45	3.98	55.37	577.50	53	40	50	57.08	−4.81	−33.36	498.45	25.9	18	42.3
8	14	25	70	75.45	2.50	28.82	577.50	53	25	50	57.08	−2.99	−22.57	498.45	21.5	61	27.7
9	14	10	70	75.45	1.00	10.20	577.50	53	10	50	57.08	−1.19	−9.94	498.45	17.5	32	18.3
10	23	40	60	66.52	34.88	68.37	588.59	30	40	50	57.08	69.88	80.43	602.72	43.4	27	59
11	23	25	60	66.52	22.55	32.24	588.59	30	25	50	57.08	46.79	32.81	602.72	30.1	20	36.2
12	23	10	60	66.52	9.36	11.03	588.59	30	10	50	57.08	20.30	10.92	602.72	19.9	9	18.3
13	25	30	50	57.08	43.92	58.77	594.00	51	30	40	46.97	21.17	(−50.89)	492.72	33.8	66	46.3
14	25	20	50	57.08	30.50	30.56	594.00	51	20	40	46.97	14.46	(−37.70)	492.72	24.5	73	34.4
15	25	10	50	57.08	15.96	13.21	594.00	51	10	40	46.97	7.42	(−21.58)	492.72	17,5	71	18.4
16	32	30	50	57.08	50.60	18.85	625.00	62	30	60	66.52	(−26.32)	(−2.25)	495.28	39.7	48	27.6
17	32	20	50	57.08	35.33	11.86	625.00	62	20	60	66.52	(−17.09)	(−1.51)	495.28	25.4	45	17.2
18	32	10	50	57.08	18.60	5.64	625.00	62	10	60	66.52	(−8.33)	(−0.76)	495.28	13.4	23	10.4
19	42	30	50	57.08	44.76	(−19.22)	(−520.4)	34	30	60	66.52	39.57	1.46	(−495.28)	35.2	54	32.5
20	42	20	50	57.08	31.10	(−13.39)	(−520.4)	34	20	60	66.52	27.28	0.97	(−495.28)	21.4	61	18.1
21	42	10	50	57.08	16.28	(−7.03)	(−520.4)	34	10	60	66.52	14.14	0.48	(−495.28)	9.1	36	10.2
22	51	40	50	57.08	21.18	(−52.64)	492.72	16	40	70	75.45	12.18	52.26	580.95	56.4	51	34.3
23	51	25	50	57.08	13.56	(−36.78)	492.72	16	25	70	75.45	7.70	27.57	580.95	39.7	32	24.2
24	51	10	50	57.08	5.56	(−17.02)	492.72	16	10	70	75.45	3.12	9.81	580.95	20.2	30	18.3
25	53	40	50	57.08	(−4.81)	(−33.36)	594.00	64	40	70	75.45	(−43.68)	6.60	502.69	42.3	46	28.5
26	53	25	50	57.08	(−2.99)	(−22.57)	594.00	64	25	70	75.45	(−26.07)	4.06	502.69	27.7	34	21.4
27	53	10	50	57.08	(−1.19)	(−9.94)	594.00	64	10	70	75.45	(−10.01)	1.60	502.69	18.3	27	13.1
28	55	40	60	57.08	(−17.08)	(−23.76)	484.29	75	40	70	75.45	(−25.78)	63.98	566.78	43.6	78	31.6
29	55	25	60	57.08	(−10.05)	(−15.11)	484.29	75	25	70	75.45	(−15.70)	32.02	520.40	27	68	19.3
30	55	10	60	57.08	(−3.29)	(−5.38)	484.29	75	10	70	75.45	(−6.13)	11.15	520.40	14.8	47	15
31	60	50	50	57.08	(−43.87)	(−15.42)	490.40	10	50	70	75.45	(−18.30)	105.59	570.83	34.5	83	28.7
32	60	30	50	57.08	(−24.45)	(−9.67)	490.40	10	30	70	75.45	(−10.77)	39.44	570.83	26.4	82	21.2
33	60	10	60	57.08	(−7.72)	2(−3.39)	6.490.40	10	10	70	75.45	(−3.52)	10.86	570.83	10.5	45	16.8
34	73	40	70	75.45	(−42.46)	66.72	(−495.28)	16	40	60	66.52	14.81	91.42	580.95	68	56	35
35	73	25	70	75.45	(−25.28)	32.95	(−495.28)	16	25	60	66.52	9.39	37.14	580.95	25.3	52	24.2
36	73	10	70	75.45	(−9.75)	11.42	(−495.28)	16	10	60	66.52	3.82	12.36	580.95	13.5	29	18.3

Column 1. The order number of the color pairs.
Column 2 The Coloroid hue of the first color of the pair.
Column 3 The Coloroid saturation of the first color of the pair.
Column 4 The Coloroid lightness of the first color of the pair.
Column 5 – 7 CIELAB details of the of the first color pair.
Column 8 Characteristic wave length of the first color of the pair.
Column 9 The Coloroid hue of the second color of the pair.
Column 10 Coloroid saturation of the second color of the pair.
Column 11 Coloroid lightness of the second color of the pair.
Column 12 – 14 CIELAB details of the second color of the pair.
Column 15 Characteristic wave length of the second color of the pair.
Column 16 Color preference of the first color of the pair.
Column 17 Harmony content of the color pair.
Column 18 Color preference of the second color of the pair.

light density. They were illuminated at 45° and observed at 90° from a distance of 100 cm.

The compositions were judged at three different occasions, days apart. One of the compositions served as a reference. In this composition the whole surface was covered by the first color. Its Coloroid reference served as a preference number (see column 16 of Table I), resulted from a large scale (50,000 observer), long-term experiment.[26–28]

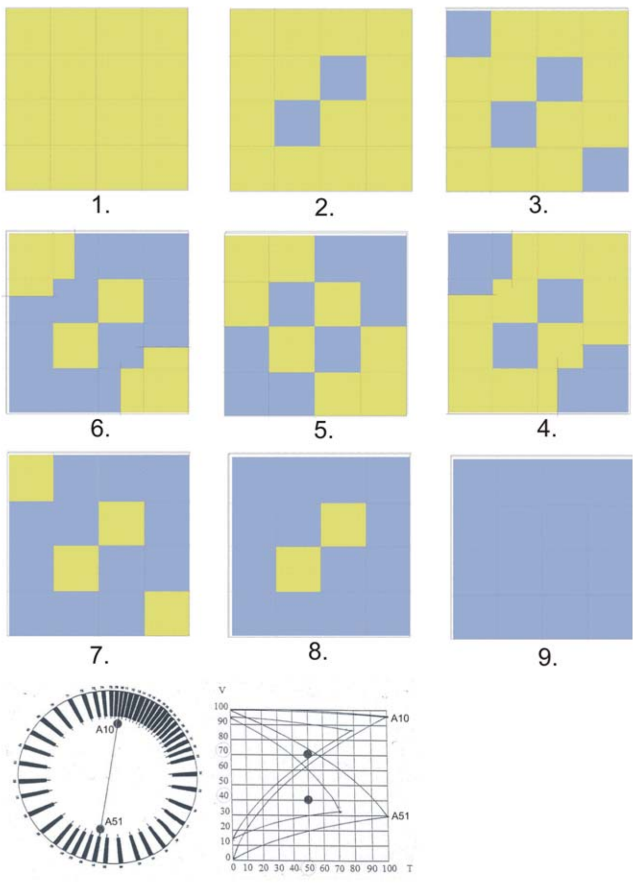
In the second experiment the reference composition was 5th in the order of the compositions, showing equal coverage of both colors of the color pair. The reference this time was the harmony content, generated from another long-term large scale experiment.

In the third experiment the reference composition was 9th in the order of the plates and the total area was covered by the second color of the color pair. Its Coloroid reference also served as the preference number of this color (see 18th column in Table I), according to the color preference indexing system.

Before these experiments, the leader introduced the experimental plates and informed the observers about their tasks. The observers had 2–3 min for making their decisions on the harmony content, relative to the reference. The overall deviation from the reference was ±15 units. The observed harmony values were recorded. The subjects participated singularly in the experiment.

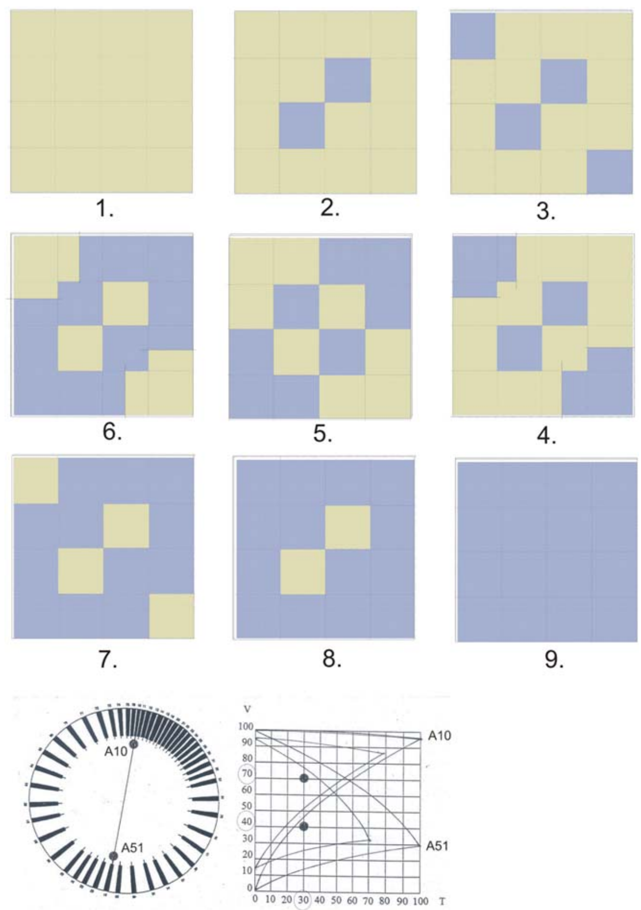
Data Processing

Before the data were processed their validity was tested by applying the RMS (Root Mean Square) method for



	1.	2.	3.	4.	5.	6.	7.	8.	9.	
10-50-70	100	87.5	75.0	62.5	50.0	37.5	25.0	12.5	0.0	%
51-50-40	0.0	12.5	25.0	37.5	50.0	62.5	75.0	87.5	100	%

FIG. 2. Compositions on the first experimental plate. The compositions are made with the following relative surface coverage. The diagram under the compositions show the numerical positions of the composition colours in the Coloroid Color System.



	1.	2.	3.	4.	5.	6.	7.	8.	9.	
10-30-70	100	87.5	75.0	62.5	50.0	37.5	25.0	12.5	0.0	%
51-30-40	0.0	12.5	25.0	37.5	50.0	62.5	75.0	87.5	100	%

FIG. 3. Same as Fig. 2 except on second experimental plate.

spread or deviation from the mean. With the exception of very few points the spread was within 7%.

We compiled the distribution diagrams of votes related to the harmony content of each composition. On the horizontal axis of the distribution diagram, as the measure of distribution, the harmony content has been drawn as a scale with a precision of one decimal. It has been established that the maximum standard deviation does not exceed the harmony content of 3.3 units, for the majority of compositions. Within that the maximum standard deviation did not exceed 1.6 units for the 90% of the votes. The magnitude of standard deviation of votes given for the compositions of different experimental tables has been approximately the same, the variation coefficient did not reach 4%. The density function of the standard deviation has shown a slight difference for votes given to compositions containing colors of higher saturation and that of lower saturation.

We averaged the results, obtained on the 3 × 3 color matrix, created from the 12 pairs. Instead of averaging point by point, we made the best fit to the experimental data and used the formulae for further data processing. The data are presented in graphs as well as in mathematical formulae as the best fit to the curves, for the benefit of those who wish to use these results. Although these curves show some difference in shape, nevertheless all described by cubic equations, showing similar basic laws for various dependence.

Figure 5 depicts the 10–50–70 and the 51–50–40 Coloroid color pairs' harmony content, for various ratios of surface area coverage. The first experiment is shown in red [Eq. (1)], the second is in green [Eq. (2)], the third is in blue [Eq. (3)] and the average is in black color [Eq. (4)].

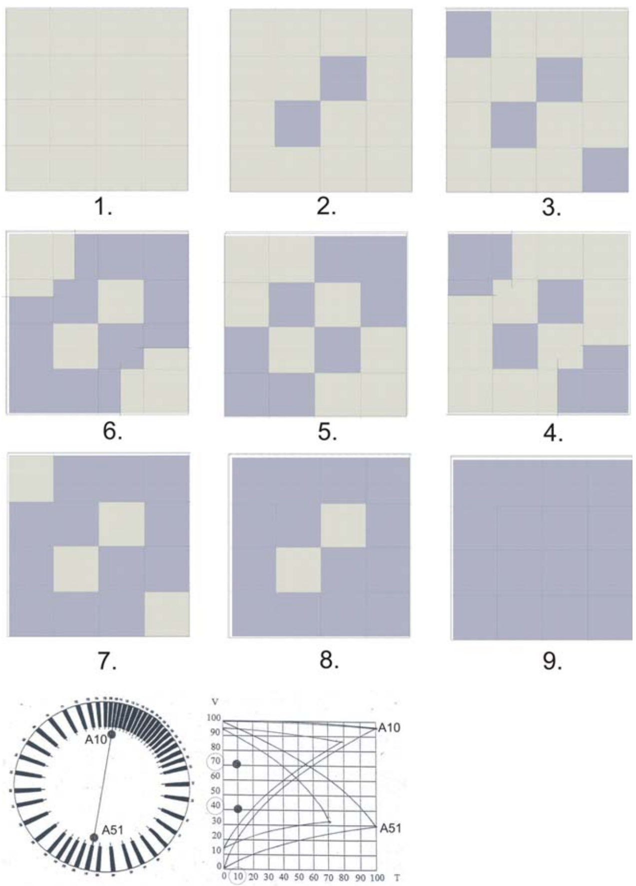
$$y_A = 27.7698 + 17.7223x - 1.9863x^2 + 0.0294x^3 \quad (1)$$

$$y_B = 1.1508 + 34.911x - 4.8716x^2 + 0.1936x^3 \quad (2)$$

$$y_C = 34.4603 + 22.1765x - 2.6335x^2 + 0.0471x^3 \quad (3)$$

$$y_D = 21.127 + 24.9366x - 3.1637x^2 + 0.09x^3 \quad (4)$$

Figure 6 shows the compositions of the 10–30–70 and the 51–30–40 Coloroid color pairs' harmony content, for various ratios in surface coverage. The first experiment is



	1.	2.	3.	4.	5.	6.	7.	8.	9.	
10-10-70	100	87.5	75.0	62.5	50.0	37.5	25.0	12.5	0.0	%
51-10-40	0.0	12.5	25.0	37.5	50.0	62.5	75.0	87.5	100	%

FIG. 4. Same as Fig. 2 except on third experimental plate.

red [Eq. (5)], the second is green [Eq. (6)], the third is blue [Eq. (7)] and the average is black [Eq. (8)].

$$y_A = 1.992 + 22.5893x - 1.7161x^2 - 0.0673x^3 \quad (5)$$

$$y_B = -20.4206 + 36.5333x - 3.8542x^2 + 0.0648x^3 \quad (6)$$

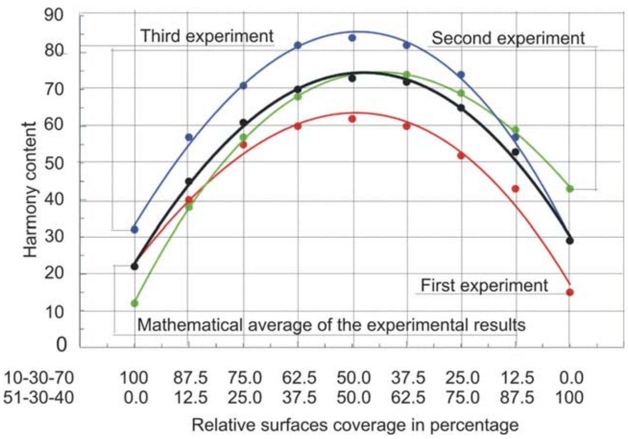


FIG. 6. Graphs showing the results of the judgments made on the harmony content of the compositions in Fig. 3.

$$y_C = 6.1666 + 29.3788x - 2.356x^2 - 0.0682x^3 \quad (7)$$

$$y_D = -4.0873 + 29.5005x - 2.6421x^2 - 0.0235x^3 \quad (8)$$

Figure 6 presents the harmony content of the 10–30–70 and the 51–30–40 Coloroid color pairs, for various ratios of surface coverage. The first experiment is red [Eq. (9)], the second is green [Eq. (10)], the third is blue [Eq. (11)] and the average is black [Eq. (12)].

$$y_A = 3.637 + 16.5528x - 2.088x^2 + 0.0496x^3 \quad (9)$$

$$y_B = 13.2302 + 9.4847x - 0.9607x^2 - 0.0168x^3 \quad (10)$$

$$y_C = 2.0238 + 10.871x - 1.079x^2 + 0.0025x^3 \quad (11)$$

$$y_D = 6.2936 + 12.3028x - 1.3759x^2 + 0.0118x^3 \quad (12)$$

All averages of the harmony contents, resulted from the experiment for various ratios in surface coverage will be compared.

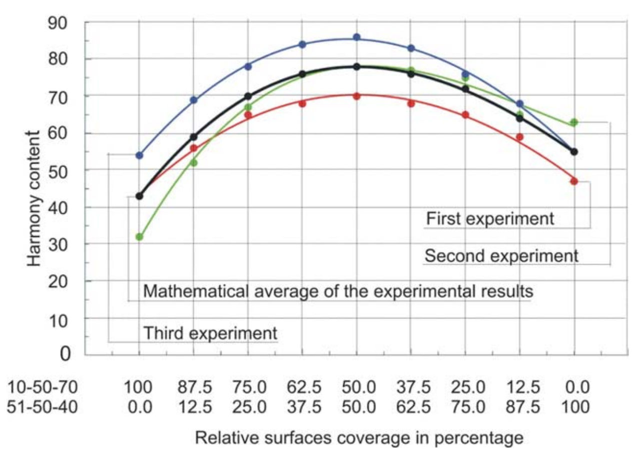


FIG. 5. Graphs showing the results of the judgments made on the harmony content of the compositions in Fig. 2.

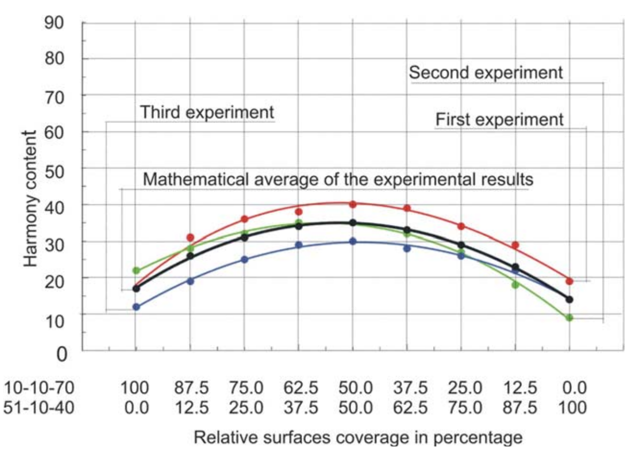


FIG. 7. Graphs showing the results of the judgments made on the harmony content of the compositions in Fig. 4.

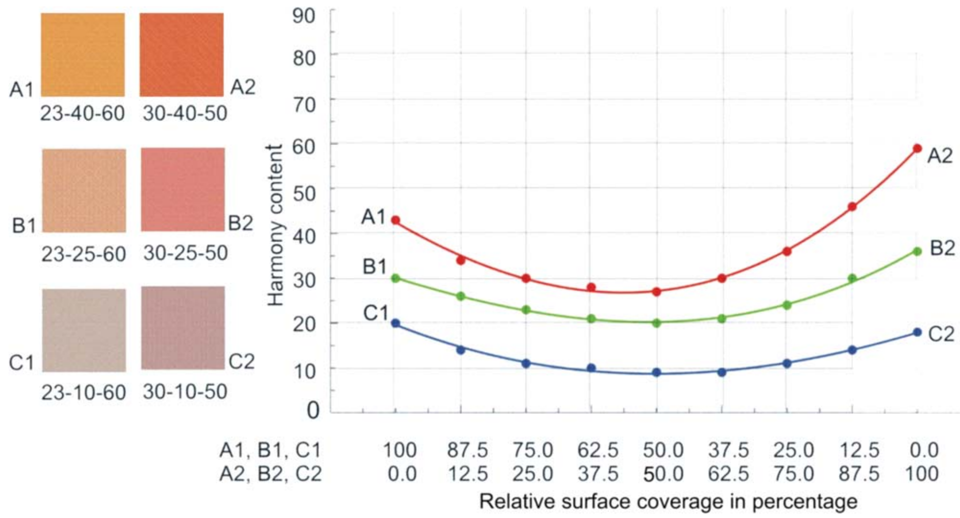


FIG. 8. Graphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 10, 11, and 12.

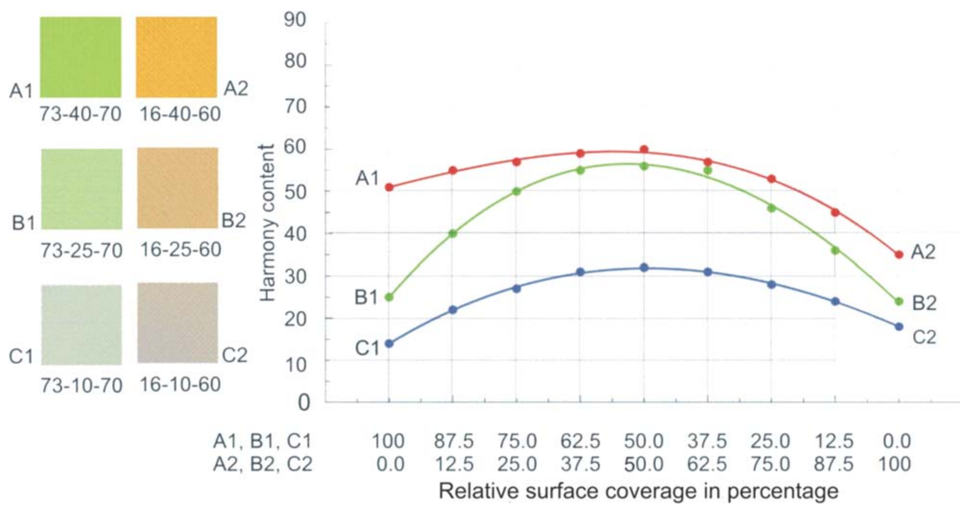


FIG. 9. Graphs showing the results of the judgments made on the harmony content of the compositions in the experimental plates 34, 35, and 36.

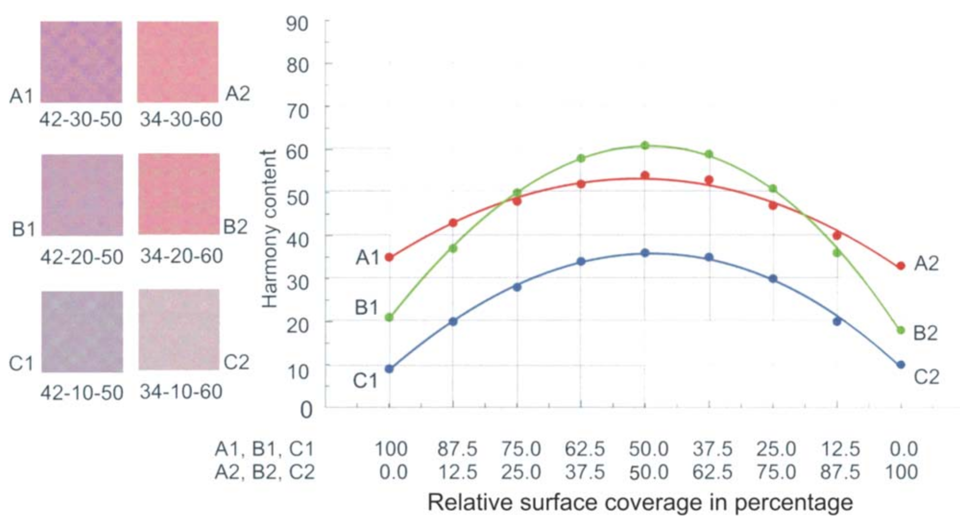


FIG. 10. Graphs showing the results of the judgments made on the harmony content of the compositions in the experimental plates 19, 20, and 21.

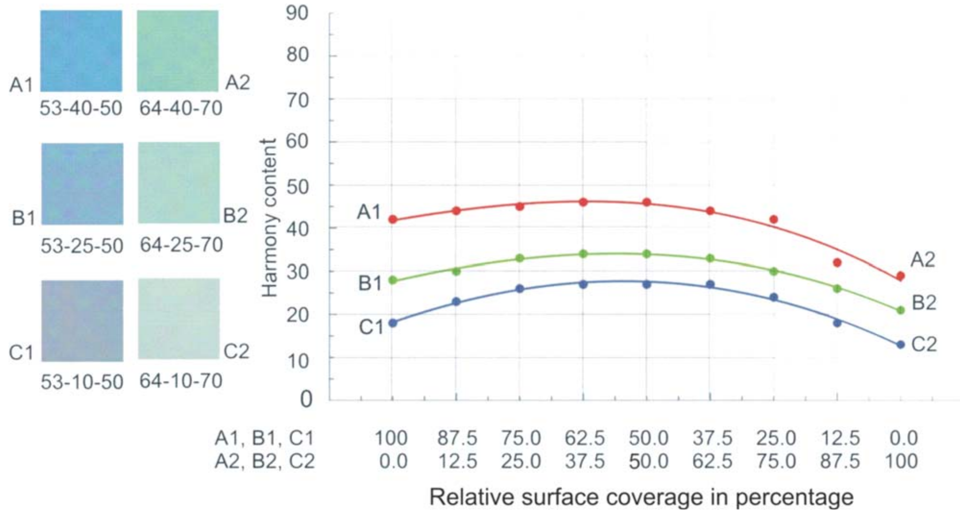


FIG. 11. Graphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 25, 26, and 27.

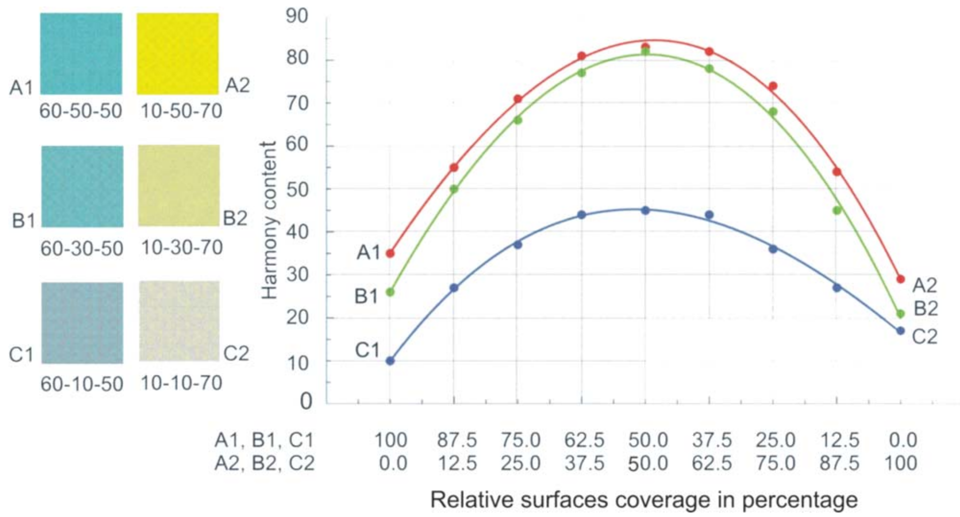


FIG. 12. raphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 31, 32, and 33.

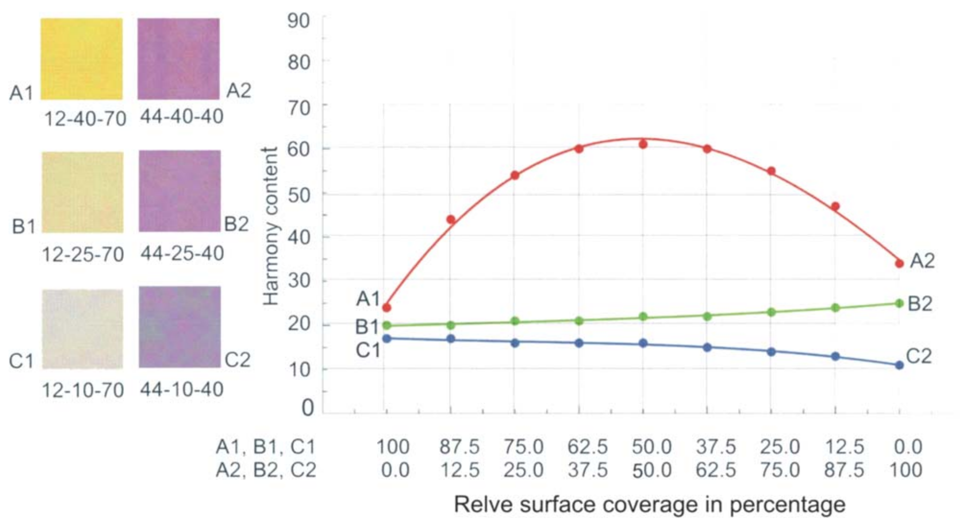


FIG. 13. Graphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 4, 5, and 6.

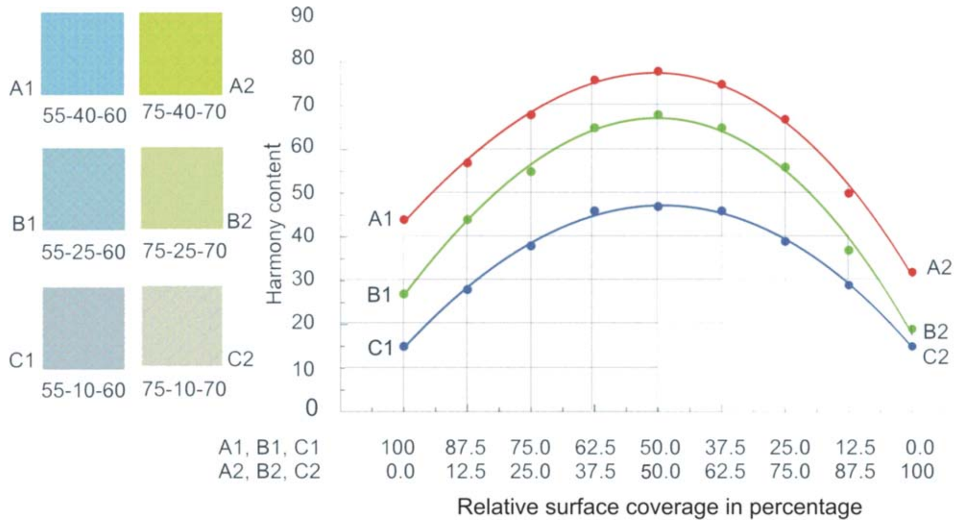


FIG. 14. Graphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 28, 29, and 30.

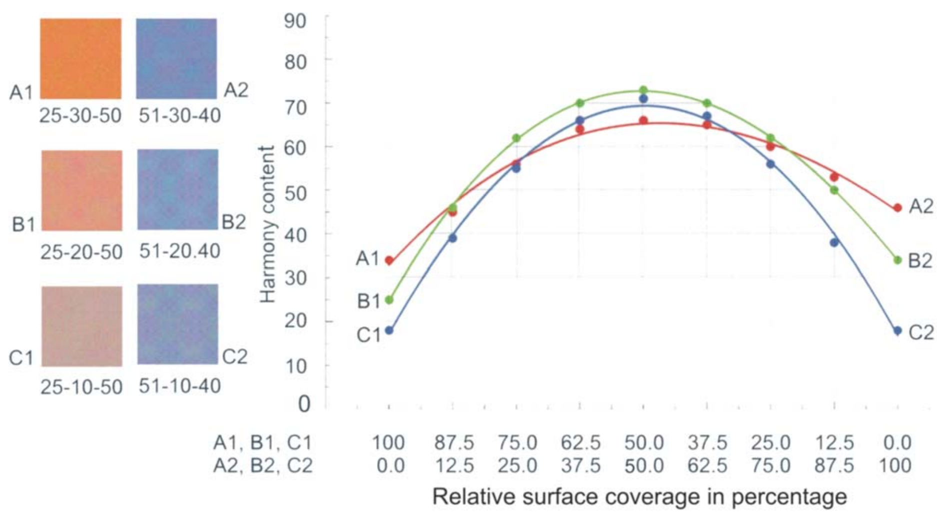


FIG. 15. Graphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 13, 14, and 15.

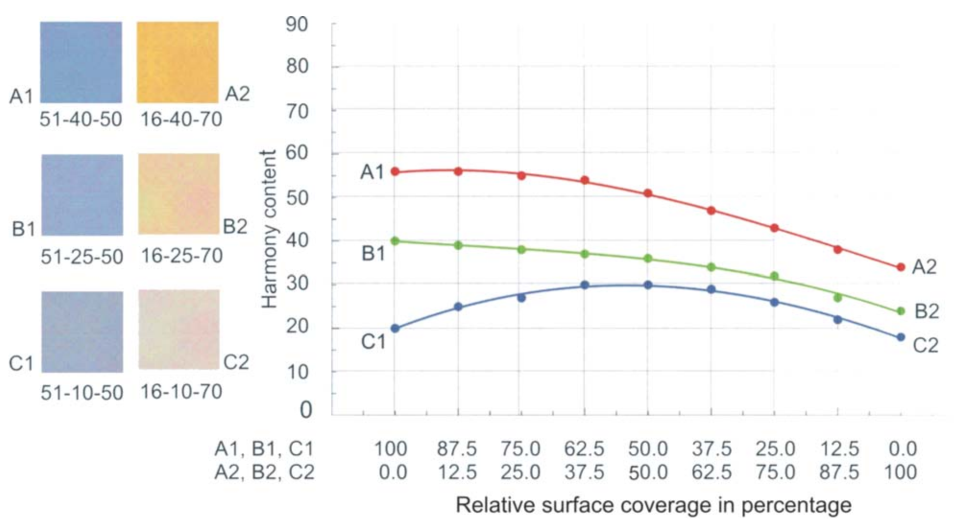


FIG. 16. Graphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 22, 23, and 24.

RESULTS

The final results are presented against the angle of inclination between the individual members of the color planes, used in the experiment. The selected colors always formed a color pair. Results were shown in graphs and the best fits were described in mathematical formulae, to establish the degree of dependence on the various factors. All distributions show cubic character shown in a form ready to be used by those engaged in similar or further research in the subject. The formulae show the slight but unavoidable, differences in the conditions during the three experiments (A, B, C) carried out at different times.

Figure 8 shows the colors from two planes with 28° angle of inclination between them. Earlier experiments[28,29] show that when the inclination fell between 25° and 38° the harmony content was smaller than the individual preference of the constituent colors,[30] irrespective of their saturation levels. In Fig. 8 A line (red) is modeled by Eq. (13), line B (green) is by Eq. (14) and line C (blue) is by Eq. (15).

$$y_A = 52.0794 - 10.4995x + 0.9184x^2 + 0.037x^3 \tag{13}$$

$$y_B = 34.9921 - 5.196x + 0.2687x^2 + 0.0361x^3 \tag{14}$$

$$y_C = 26.2222 - 7.4486x + 0.8686x^2 - 0.016x^3 \tag{15}$$

Figure 9 shows two colors of a color pair 42° hue units apart. Based on earlier experiments[30,31] the harmony content of color pairs on color planes with angular deviation between 40° and 50° is always bigger than the individual preference of the constituent colors.[27,29–31] Line A (red) is modelled by (16), line B (green) is by (17) and line C (blue) is by (18).

$$y_A = 47.0476 + 4.0144x + 0.0389x^2 - 0.0707x^3 \tag{16}$$

$$y_B = 4.5476 + 23.176x - 2.8398x^2 + 0.0555x^3 \tag{17}$$

$$y_C = 3.4365 + 11.8562x - 1.3575x^2 + 0.0244x^3 \tag{18}$$

Colors in Fig. 10 are in 46° hue units from each other. Based on earlier experiments,[31–33] the harmony content of the compositions made of color pairs from color planes, with angles between 40° and 50° is always bigger than the individual preference of the constituent colors.[34] These earlier experiments showed also, that the medium saturated colors in the magenta region have higher harmony content than the highly saturated ones.[31–33] Line A (red) is modelled by (19), line B (green) is by (20) and line C (blue) is by (21).

$$y_A = 24.0476 + 11.8781x - 1.1959x^2 - 0.0025x^3 \tag{19}$$

$$y_B = -0.2857 + 22.8932x - 1.8928x^2 - 0.0479x^3 \tag{20}$$

$$y_C = -5.5714 + 15.7536x - 1.4069x^2 - 0.0176x^3 \tag{21}$$

Colors, shown in Fig. 11, are 54° hue units from each other. Based on earlier experiments[28,32] the harmony content of the compositions made from color planes with angles 52° to 55° between them is only slightly bigger than the individual preference of the constituent colors.[30] Line A (red) is modelled by Eq. (22), line B (green) is by Eq. (23) and line C (blue) is by Eq. (24).

$$y_A = 38.9683 + 3.9937x - 0.1598x^2 - 0.0345x^3 \tag{22}$$

$$y_B = 23.9365 + 4.096x - 0.3272x^2 - 0.0185x^3 \tag{23}$$

$$y_C = 12.3571 + 6.4794x - 0.6471x^2 - 0.0075x^3 \tag{24}$$

Colors, shown in Fig. 12, have 116° hue units between them. Based on earlier experiments[31,33] the harmony content of the compositions made of color pairs from color planes with angles between 110° and 140°, is always bigger than the individual preference of the constituent colors.[30] Our present experiment shows, that in this region, the preference of the high and the medium saturated colors, as well as the harmony content of the compositions, using the same colors, differ only slightly. In the illustration A line (red) is modelled by Eq. (25), line B (green) by Eq. (26) and line C (blue) by Eq. (27).

$$y_A = 11.0397 + 25.874x - 1.7074x^2 - 0.1052x^3 \tag{25}$$

$$y_B = -3.3968 + 32.2047x - 2.759x^2 - 0.0589x^3 \tag{26}$$

$$y_C = -13.0714 + 26.3167x - 3.3993x^2 + 0.0934x^3 \tag{27}$$

Colors in Fig. 13 are on two Coloroid color planes with 130° inclination angle between them. When the hue separation is that great, according to our earlier experiments[28,30] the harmony content of the color pair of high and medium saturation is similar to the magnitude of the color preference of the constituent colors of the color pair. In the illustration line A (red) is modelled by Eq. (28), line B (green) is by Eq. (29) and line C (blue) is by Eq. (30).

$$y_A = 1.5158 + 26.738x - 3.3632x^2 + 0.08922x^3 \tag{28}$$

$$y_B = 19.4206 + 0.5020x - 0.03968x^2 + 0.0059x^3 \tag{29}$$

$$y_C = 17.7381 - 0.7940x + 0.1645x^2 - 0.0176x^3 \tag{30}$$

Colors in Fig. 14 are also from two color planes with 130° inclination angle, similarly to Fig. 13. This hue pair is from the cool side of the color circle. In this color region the harmony content of the color pairs of broken colors is always greater than the preference of the constituent colors of the color pair. In the illustration line A (red) is modelled by Eq. (31), line B (green) is by Eq. (32) and line C (blue) is by Eq. (33).

$$y_A = 25.9365 + 18.8562x - 1.2969x^2 - 0.0816x^3 \tag{31}$$

$$y_B = 5.2698 + 23.2779x - 1.8575x^2 - 0.064x^3 \tag{32}$$

$$y_C = -2.9603 + 19.3765x - 1.7832x^2 - 0.0168x^3 \tag{33}$$

The angle of inclination between color planes of the color pairs shown in Fig. 15 is 138°. Considering that this angle is between 110° and 140°, the harmony content of the compositions is higher than preference of the constituent colors in the compositions. In significant number of cases, the harmony content of the compositions, made of

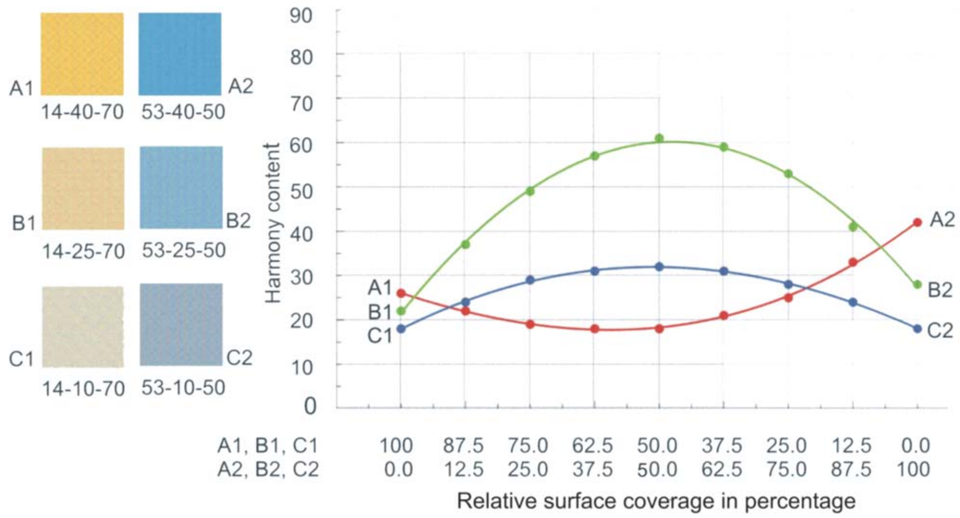


FIG. 17. Graphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 7, 8, and 9.

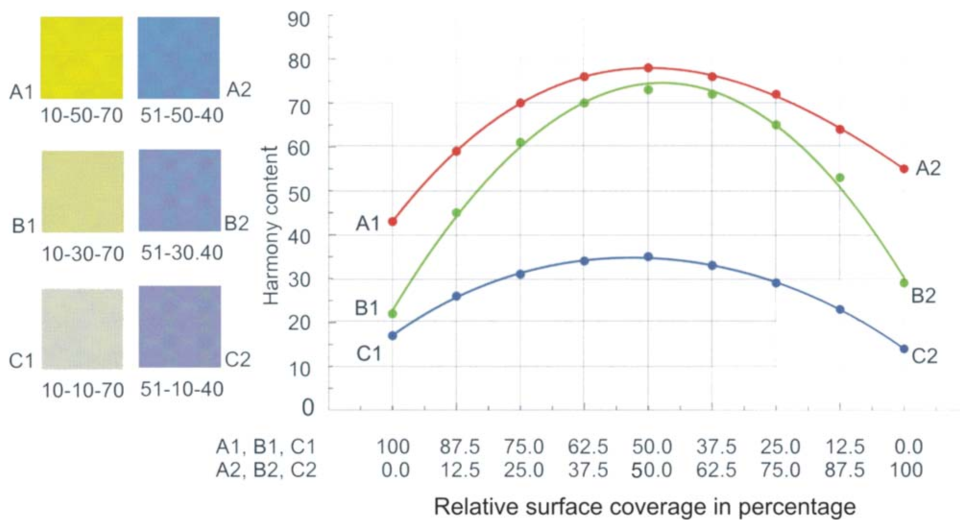


FIG. 18. Graphs showing the results of the judgments made on the harmony content of the compositions on the experimental plates 1, 2, and 3.

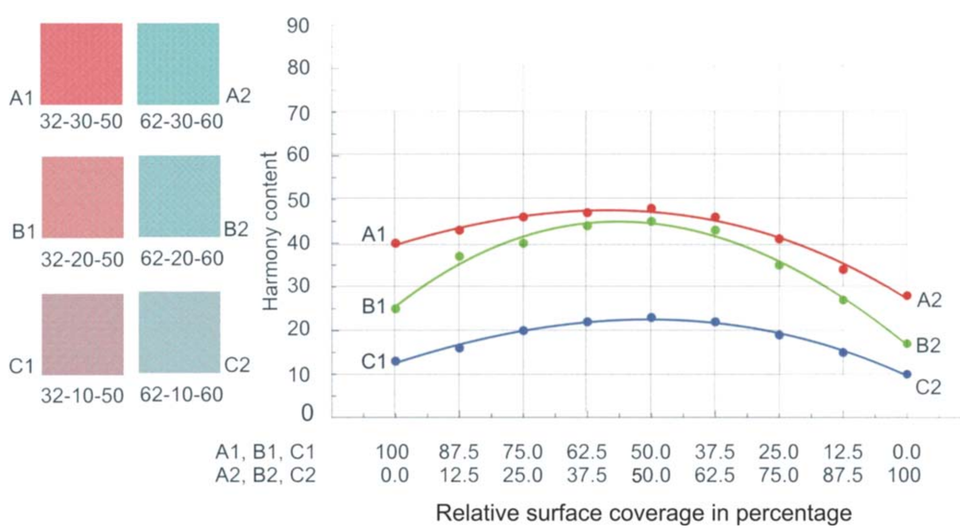


FIG. 19. Graphs showing the results of the judgments made on the harmony content of the compositions in the experimental plates 16, 17, and 18.

stronger, high saturated colors is less than the ones with broken tints. In the illustration line A (red) is modelled by Eq. (34), line B (green) is by Eq. (35) and line C (blue) is by Eq. (36).

$$y_A=14.6905+20.4592x-2.2835x^2+0.0429x^3 \quad (34)$$

$$y_B=-4.5396+33.1463x-3.9516x^2+0.0825x^3 \quad (35)$$

$$y_C=-11.5714+31.9076x-3.0818x^2-0.0126x^3 \quad (36)$$

The separation between colors in Fig. 16, in the color space is 116° hue units. Based on earlier experiments[26] the harmony content of the compositions made of color pairs from color planes with angles 150° to 165° is always smaller than the individual preference of the constituent colors.[35] In the illustration line A (red) is modelled by Eq. (37), line B (green) is by Eq. (38) and line C (blue) is by Eq. (39).

$$y_A=53.7778+2.79721x-0.8383x^2+0.0311x^3 \quad (37)$$

$$y_B=41.0159-1.2569x+0.1897x^2-0.0429x^3 \quad (38)$$

$$y_C=13.4762+7.3261x-0.8755x^2+0.0126x^3 \quad (39)$$

The colors in the compositions in Figs. 17–19 are complementing each other. The angular deviation of the color planes, containing these colors is 180° in the color space. In case of complementing colors, the harmony content of the composition is set by a relation between the harmony content and the color preference of the colors of the color pair.

Graphs in Fig. 17 show, that when a pair composed of orangey yellow and cobalt blue, the relation of the harmony content and the preference of the involved colors follow the rules of the theory of harmony only, when broken tints are involved. In the illustration line A (red) is modelled by (40), line B (green) is by (41) and line C (blue) is by (42).

$$y_A=31.3571-5.7907x+0.4588x^2+0.03535x^3 \quad (40)$$

$$y_B=1.2539+22.3379x-2.0548x^2-0.0118x^3 \quad (41)$$

$$y_C=9.5635+9.3812x-1.0364x^2+0.011x^3 \quad (42)$$

Graphs in Fig. 18 are the best fits to the compositions harmony content predicted for complementing colors. This shows up also in the closeness between the harmony content of compositions made of middle and high saturation colors. Furthermore, it shows that the harmony content of compositions made of low saturation colors are very much legging behind expectations. In the illustration line A (red) is modelled by Eq. (43), line B (green) is by Eq. (44) and line C (blue) is by Eq. (45).

$$y_A=21.127+24.9366x-3.1637x^2+0.09x^3 \quad (43)$$

$$y_B=-4.0873+29.5005x-2.6421x^2-0.0235x^3 \quad (44)$$

$$y_C=4.7222+14.4548x-2.2321x^2+0.1399x^3 \quad (45)$$

The relationship between graphs in Fig. 19 is similar to that of Fig. 18. A notable difference is that they show lower harmony content. In the illustration line A (red) is modelled by Eq. (46), line B (green) is by Eq. (47) and line C (blue) is by Eq. (48).

$$y_A=34.5794+5.5106x-0.4679x^2-0.0261x^3 \quad (46)$$

$$y_B=12.1984+15.1502x-1.8705x^2+0.027x^3 \quad (47)$$

$$y_C=7.3412+5.6783x-0.4354x^2-0.0185x^3 \quad (48)$$

The illustration's red, green, blue and black lines always represent the first second and third experimental result with the black as an average of the tree.

CONCLUSIONS

Harmony content of a composition depends, amongst other factors (i.e., hue angle, saturation, lightness, etc.) on the relative surface coverage of the colors, present. This finding looks significant for highly saturated colors; while at low saturation is negligible. This relation for medium saturation (i.e., A34-A43, A14-A53, A25-A51 color pairs) still needs further investigation. We have found that in most cases equal ratio of color coverage leads to maximum harmony content. In some cases however, for some color pairs (i.e., A23-A30, A14-A53) the equal coverage of saturated colors in a composition results minimal harmony content. We also found, that the preference of the constituent colors has considerable effect on the harmony content of the compositions. Our experimental findings are presented in graphical form and fitted with optimum mathematical expressions for the benefit of researchers working in this field.

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BOOK REVIEWS

(Continued from page 346)

lighting is acceptable and where it is not, would enhance the value of this chapter. Also some discussion on chromatic adaptation would have been relevant in the section, where the tint of an off-white source is described.

When it comes into the domain of temporal phenomena your reviewer gets worried if the term energy is used instead of power, even if in colloquial English little care is taken for their use.

In Chapter 4 Rea suggests possible new concepts and measures some of which he warns are not precise, but are more accurate than the old terms and quantities. This reviewer could certainly debate some of the terms recommended, such as "bright illuminance" or "circadian illuminance." Would it then be not necessary to rename illuminance into, for example, "task-performance illuminance"?

Your reviewer has problem with the concept of "unified illuminance" as well, as the metrics is really underpinned only for luminance. Professor Rea suggests four $V(\lambda)$ curves to be used at different illuminance levels. The use of these would provide difficulties when one has to change from one to another. If one designs, for example, a street lighting to provide approximately 1 lux, as here the recommendation changes from one $V(\lambda)$ function to another, two sources might provide different results for 0.99 lux and 1.01 lux.

It should be pointed out that this book was certainly not written as a compendium of final recommendations, but rather to provoke interest and discussion. Therefore, it can be recommended for everybody interested in promoting light and lighting. The questions discussed (and there are much more as brought here as examples) should be further analyzed and definitely new concepts for an added value of lighting should be elaborated.

J. SCHANDA

Published Online 17 March 2014 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.21880

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