Experimental Determination of Laws of Color Harmony. Part 5: The Harmony Content of the Various Hue Triads

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Abstract: We, in 1956 the Department of Architecture at the Budapest University of Technology and Economics, decided to start an extensive color harmony experiment. The experimental work, the collation, and processing of the collected data, lasting 50 years, was completed in 2006. The experiments described in this article are based on earlier experimental results obtained from investigation into the harmony content of hue pairs. We then decided to search for a third hue, which in association with an existing pair, with high-color harmony, forms a hue triad with high-harmony content too. The compositions prepared for the experiment were composed in each case of three hues of four identical saturation but different brightness, forming a group of 12 colors. The color content of the compositions covered the color space uniformly. That was the first stage in the experiment, carried out with 60 compositions. In the second stage, we investigated the effect of the saturation content of the colors used in the composition, on the harmony content of the hue triads. For this experiment, we prepared 48 compositions. In these experiments, we applied the method of grading. We concluded that the level of the harmony content of the hue triads depends on the inclination between the hue planes in the Coloroid color space. We also concluded that to every hue, selected for starting point, six well-definable groups of hues can be ordered from the Coloroid color space, from which color triads with high harmony content, can be selected. It showed conclusively that the saturation level of the individual members of the triads has a significant influence on their harmony content. © 2010 Wiley Periodicals, Inc. Col Res Appl, 00, 000–000, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/col.20590

Key words: color harmony; color composition; color science; color theory; coloroid color system; experimental color harmony; theory of color harmony

INTRODUCTION

Color triads have been the subject of the literature on color harmony, for over 200 years. In spite of that, few papers describing experimental results related specifically to triads can be found. The most cited papers, give recipes for the construction of the color triads. The suggestions, put forward in them, are mostly applicable to the selection of specific colors.[1–16] We decided to start this large volume data collection, specifically because of the complete lack of experimental data related to the definition of the hue triads in the literature.

In our experiments into the harmony content of the hue triads, we were searching for a third hue, which could form a harmonic hue triad with the selected harmonic hue pair. We carried out the first experiments on the harmony content of the hue pairs used in this experiments between 1980 and 1985 and following that between 2002 and 2006.[17–22] The results of these experiments were presented in the color space of the Coloroid system.[23–29] These results showed the angles of inclination between color planes of the selected hue pairs in the Coloroid system.[30–49]

EXPERIMENTS

In our research, we selected a third hue to join a hue pair with high-harmony content in such a way that it formed a high-harmony content hue triad with the selected pair.

The tests in the experiment were based on compositions prepared for the purpose. The compositions formed five categories. The detailed descriptions of the five categories come later. In the compositions for each category, the harmonic hue pair, marking the starting point of the

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TABLE I. The over view of the tables and the figures defining the test compositions in the experiment.

a	b	c	d	e	f	g	h
1.	Table 2^{E1}	Fig. 1	20	Table 3^{E1}	Fig. 2	Fig. 3	Table $4^{Fig.\ 3}$
2.	Table 2^{E2}	Fig. 4	20	Table 3^{E2}	Fig. 5	Fig. 6	Table $4^{Fig.\ 6}$
3.	Table 2^{E3}	Fig. 7	20	Table 3^{E3}	Fig. 8	Fig. 9	Table $4^{Fig.\ 9}$
4.	Table 2^{E4}	Fig. 10	20	Table 3^{E4}	Fig. 11	Fig. 12	Table $4^{Fig.\ 12}$
5.	Table 2^{E4}	Fig. 10	20	Table 3^{E4}	Fig. 11	Fig. 13	Table $4^{Fig.\ 13}$

"a" The serial number of the experimental units (groups). "b" The hue pairs to which the third harmonic color was selected in the experiment. "c" The hue regions in the Coloroid color space, enclosed by the color planes of the hue pairs. "d" The number of the compositions incorporating the hue triads made by extending the hue pairs. "e" The hue triads of the compositions made for the tests of the experiments. "f" The location of the hue triads in the Coloroid color space. "g" CIE XYZ components (CIE tristimulus values), Coloroid coordinates and the Munsell color codes of the presented compositions.

The top indices indicate the line in the tabulation, where the actual data can be found (Table II^{E1}). The $Table^{Fig.\ 3}$ for instance refers to the figure associated with the actual data.

experiment, was selected always from identical viewpoints. There were 20 compositions ordered to every category. Out of this number, five were selected for identical harmonic hue pair. By doing so, the assessment of the color content of the compositions of each category started with the assessment of the colors of the four harmonic hue pairs. Every composition was composed of 12 colors. Out of these colors, eight colors represented the actual hue pairs with high content of harmony, four colors one of each of the third hues under test. The colors associated with one particular hue are used twice in each of the compositions. (see the left-hand side compositions in Figs. A3, 6, 9, and 13).

In the color set of each of the compositions, the colors associated with the same hue, always had the same Coloroid saturation. The Colroid brightness of the colors, associated with the compositions, formed equidistant scales. The compositions were 50 by 50 cm in size and have been produced by collage technique. The total number of the compositions used in the experiment was 100.

During the experiment, each of the tests, carried out with compositions associated with one particular group, formed a self-consistent unit. Out of the individual groups of 20 compositions, five were presented at the same time to the subjects taking part in the experiment. Every composition, associated with different compositions, was presented twice to the subjects of the experiment. Because of this, the assessment of each of the 20 compositions were taken is eight steps. The five compositions presented together were classified by the assessed measure of the personal experience of the harmony. The experiment was carried out first in 1986–1989 by using a group of students, age 18–25, of the Department of Architecture at the Budapest University of Technology and Economics and repeated between 2003 and 2006 by using artists aged between 30 and 50 as experimental subjects. During data compilation, the answers of the female participants were not separated from that of the male subjects, although information on the sexes was included in the questionnaires. The color deficient observers were eliminated from the

TABLE II. The hue pairs with which we combined a third harmonic hue.

E		Coloroid label	Characteristic wavelength
E1	1	A13–A52	576,062–475,449
E1	2	A40–A64	(−504,836)–502,695
E1	3	A52–A13	475,449–576,062
E1	4	A64–A40	502,695–(−504,836)
E2	1	A25–A61	593,981–492,725
E2	2	A43–A72	(−539,174)–555,957
E2	3	A56–A33	487,304–(−493,779)
E2	4	A70–A46	536,295–(−563,846)
E3	1	A54–A10	482,040–570,836
E3	2	A65–A35	509,193–(−500,049)
E3	3	A20–A51	582,640–468,715
E3	4	A41–A63	(−512,077)–498,450
E4	1	A44–A71	(−548,11)–548,11
E4	2	A71–A44	548.11–(−548.11)
E4	3	A33–A54	(−492,79)–482,04
E4	4	A54–A33	482,04–(−492,79)

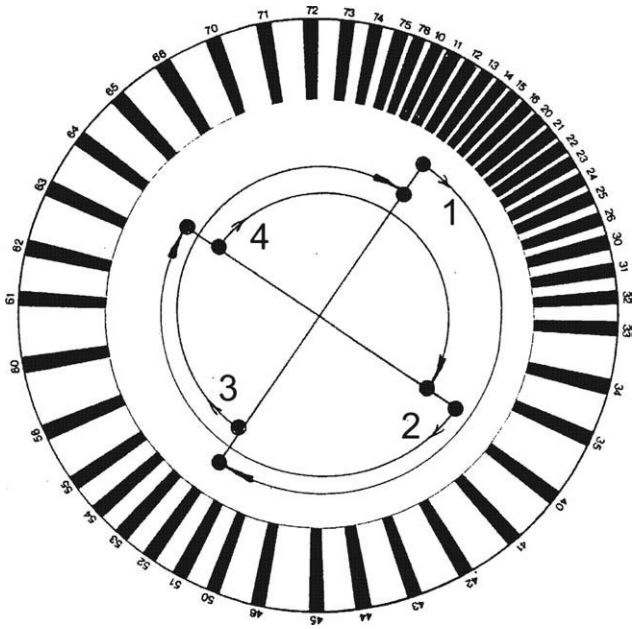

FIG. 1. The color regions, enclosed by the planes of the hue pairs, used as the starting point of the creation of the hue triads, as part of the first category of the experiment.

TABLE III. The hue triads of the test compositions in the experiment.

E		Φ_1	Φ_2	Φ_3	Coloroid label	Characteristic wavelength
E1	1	180 $\Phi_{A13–A52}$	34 $\Phi_{A13–A25,3}$	146 $\Phi_{A13–A25,3}$	A25,3	595,1 nm
E1	2	180 $\Phi_{A13–A52}$	67 $\Phi_{A13–A33,8}$	113 $\Phi_{A13–A33,8}$	A33,8	(−496,1) nm
E1	3	180 $\Phi_{A13–A52}$	90 $\Phi_{A13–A35,7}$	90 $\Phi_{A13–A35,7}$	A35,7	(−502,5) nm
E1	4	180 $\Phi_{A13–A52}$	130 $\Phi_{A13–A43,5}$	50 $\Phi_{A13–A43,5}$	A43,5	(−545,2) nm
E1	5	180 $\Phi_{A13–A52}$	150 $\Phi_{A13–A45,5}$	30 $\Phi_{A13–A45,5}$	A45,5	(−561,1) nm
E2	1	148 $\Phi_{A70–A46}$	45,1 $\Phi_{A70–A10}$	166,2 $\Phi_{A10–A46}$	A10	570,836 nm
E2	2	148 $\Phi_{A70–A46}$	74,5 $\Phi_{A70–A21}$	137,5 $\Phi_{A21–A46}$	A21	584,453 nm
E2	3	148 $\Phi_{A70–A46}$	103,2 $\Phi_{A70–A31}$	108,8 $\Phi_{A31–A46}$	A31	610,141 nm
E2	4	148 $\Phi_{A70–A46}$	137,8 $\Phi_{A70–A35}$	74,2 $\Phi_{A35–A46}$	A35	(−500,049) nm
E2	5	148 $\Phi_{A70–A46}$	171,8 $\Phi_{A70–A42}$	40,2 $\Phi_{A42–A46}$	A42	(−524,590) nm
E3	1	198,9 $\Phi_{A65–A35}$	22,6 $\Phi_{A65–A70}$	138,5 $\Phi_{A70–A35}$	A70	536,295
E3	2	198,9 $\Phi_{A65–A35}$	49,2 $\Phi_{A65–A73}$	111,9 $\Phi_{A73–A35}$	A73	560,739
E3	3	198,9 $\Phi_{A65–A35}$	83,3 $\Phi_{A65–A14}$	77,8 $\Phi_{A14–A35}$	A14	577,699
E3	4	198,9 $\Phi_{A65–A35}$	112,1 $\Phi_{A65–A30}$	49,0 $\Phi_{A30–A35}$	A30	602,72
E3	5	198,9 $\Phi_{A65–A35}$	137,2 $\Phi_{A65–A33}$	23,9 $\Phi_{A33–A35}$	A33	(−493,779)
E4	1	227 $\Phi_{A33–A54}$	24 $\Phi_{A33–A35}$	109 $\Phi_{A35–A54}$	A35	(−498,45)
E4	2	227 $\Phi_{A33–A54}$	47 $\Phi_{A33–A41}$	86 $\Phi_{A41–A54}$	A41	(−509,12)
E4	3	227 $\Phi_{A33–A54}$	68 $\Phi_{A33–A43}$	65 $\Phi_{A43–A54}$	A43	(−536,31)
E4	4	227 $\Phi_{A33–A54}$	98 $\Phi_{A33–A46}$	35 $\Phi_{A46–A54}$	A46	(−564,18)
E4	5	227 $\Phi_{A33–A54}$	113 $\Phi_{A33–A51}$	20 $\Phi_{A51–A54}$	A51	468,71

experiment by using the Ishiara test. The tests were carried out in a room illuminated by light reflected from the northerly sky, near to a window at illumination levels between 1600 and 1800 lux. The compositions were fixed to a vertical surface. The surroundings consisted of gray surfaces of $Y = 30$. The angle of illumination was 45° and the viewing angle of the observation was 90°, from a distance of 150 cm. The leader of the experiment presented the compositions to the experimental subjects before the start of the experiment and described their tasks for them. The subjects were divided into groups of 10 for the experiment. As a general rule, the categories consisting of five compositions were assessed, earlier and in a later time as well by about 100 to 120 people. The number of elementary observations in the experiment was over 80,000.

In the experiments, carried out between 2003 and 2006, we used the so-called kaleido compositions, (see right-hand side compositions in Figs. A3, 6, 9, 12, and 13), generated by a computer, from the colors of the original compositions, by pseudo-random spot recognition. The reason for the selection of the kaleidoscope-like color arrangement for the new compositions was our interest in the possible influence on the judgments of the subjects of the scale-like orderly relation between the dominant colors in the earlier compositions. The kaleidó compositions formed always an identical patch-like network. The colors of the compositions differed only by their hue content. The colors of identical brightness and saturation were always in the same place in the compositions. The compositions were surrounded uniformly by a mid-gray color (A51, T0.5, V55) of $Y = 30.25$ CIE color components (CIE tristimulus value). The kaleido compositions were printed in 28 by 28 cm size. The size of the kaleido compositions was different from that of the earlier ones made by collage technique, because we only had facilities to print them in A3 format. The number of these kaleido compositions was identical to that of the original compositions. We carried out spectrophotometric checks, to make it sure that colors of the compositions made by collage technique are the same as the original colors, made by the method of painting. In case of a discrepancy between the colors, we applied correction before reprinting. The circumstances and the method of execution of the experiments were basically identical to that of the ear-

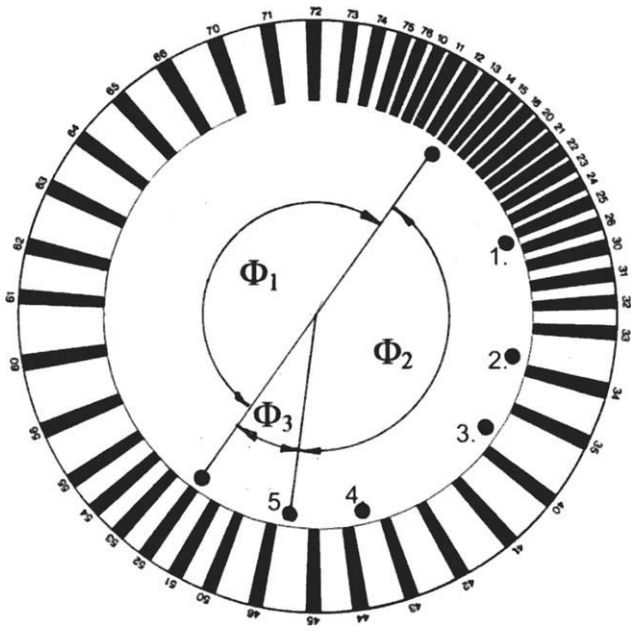

FIG. 2. The locations in the Coloroid circle of the hues in the five-color compositions created by the extension of the *A12-A52* hue pair which forms part of the 20 compositions of the first category of the experiment.

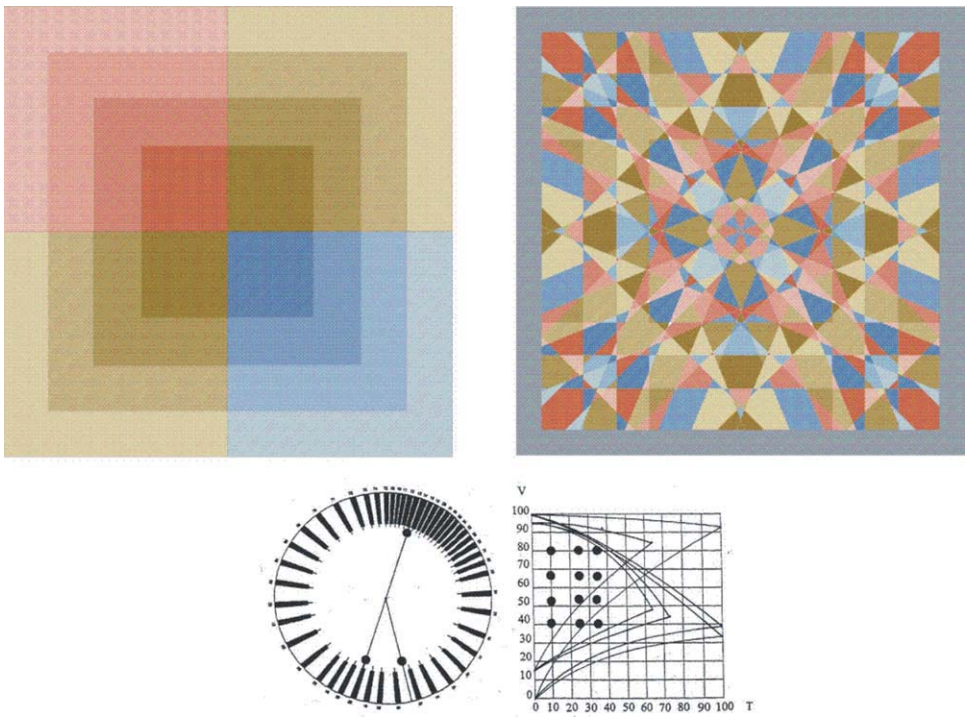

FIG. 3. The fifth composition in order of presentation from the first category of the experiment. The illustration shown on the left is composed from the four colors of each of the colors of *A12-A52-A25* hue triad. Altogether 12 colors are used. The picture on the right were generated from the colors of the one on the right, by computer generated, pseudo-random spot recognition technique and it is a so-called kaleido composition. The Coloroid diagram under the illustrations shows the relation between the saturation and the illumination of the colors in the compositions.

lier experiments. The only difference, worth mentioning, was that the observations were made from a distance of 100 cm and not from 150 cm as earlier with the larger compositions. The subjects of the experiment were recruited from a group of artist aged between 30 and 50.

Before we turn to the description of the experiment, an overview of the content of the figures and tables, with different serial numbers, associated with the experimental units discussed in the presentation will be given. Table I provides the key.

In the first category of the experiment, we ordered a third hue to the four complementing hue pairs as a fifth hue. (Table II[E1]). The hue pairs, with the associated hues, represented the whole of the Coloroid color space. Figure 1 depicts the position of the four color domains in the Coloroid color space, bordered by the planes of the hue pairs, forming the starting points of the created hue triads of the compositions in the first category of the experiment. Table III[E1] shows the first hue pair of the first category, extended by the one additional hue making it into a triad, forming a group of five. Columns 1, 2, and 3 show the Φ angles enclosed by the hue planes of the hue triad. Columns 4 and 5 show the label of the color plane in the Coloroid of the added third color and its characteristic wavelength.

By using the colors out of each of the 12 colors of the hue pairs, extended now to triads, 20 compositions were prepared for the first experiment (Fig. 2). Out of these, one is pictured in Fig. 3. Table III shows the CIE XYZ color components (CIE XYZ tristimulus values) in the color measuring system and the A, T, V color coordinates of the Coloroid color system. The H V/C codes of the Munsell system are shown in Table IV[Fig. 3]. The Munsell codes included in the publication indicate the color available in the Munsell color chart, nearest to the actual color used. In the column, marked "Deviation" following the Munsell codes are the deviations between the colors defined by the Coloroid coordinates and the relevant Munsell color samples, in percentage. These can be found in the Munsell chart. The picture on the left of Fig. 3 depicts the 5th composition of the first category of the experiment in the order of the presentation. The composition is made of all the four color of the hue triad labeled *A12-A52-A25*. The one on the right, a so-called kaleido composition, is a composition, computer generated from the colors of the composition on the left by pseudo-random spot recognition. The Coloroid diagram, under the compositions, shows the relation between the color saturation and the brightness of the colors in the compositions.

The first group was followed by another four. In every group, similarly to the first experimental group, we presented 20 compositions to the experimental subjects. The size, construction, and presentation were the same as that of the first group as described earlier. The only difference between the compositions of the various groups was the selection of the hues defining their color content. All other conditions and the way of execution were exactly the same for all five experimental groups.

TABLE IV. CIE XYZ colour components (CIE XYZ tristimulus values), Coloroid ATV coordinates, and the Munsel colour system H, V/C codes for the colors of the compositions rewarded the highest score during the experiment.

		CIE			Coloroid			Munsell			
Fig.	Color	X	Y	Z	A	T	V	H	V	C	Deviation %
Fig. 3	Color 01	60.80	64.00	59.83	13.00	10.00	80.00	5.0Y	8.00	2.00	4.45
Fig. 3	Color 02	42.22	44.44	38.54	13.00	10.00	66.67	7.5Y	7.00	2.00	1.21
Fig. 3	Color 03	27.01	28.44	21.12	13.00	10.00	53.33	7.5Y	6.00	2.00	4.15
Fig. 3	Color 04	15.18	16.00	7.57	13.00	10.00	40.00	7.5Y	5.00	4.00	4.89
Fig. 3	Color 05	60.91	64.00	97.94	52.42	35.29	80.00	2.5PB	8.00	4.00	3.00
Fig. 3	Color 06	42.32	44.44	76.65	52.42	35.29	66.67	2.5PB	7.00	6.00	2.15
Fig. 3	Color 07	27.12	28.44	59.22	52.42	35.29	53.33	2.5PB	6.00	8.00	4.29
Fig. 3	Color 08	15.29	16.00	45.67	52.42	35.29	40.00	2.5PB	5.00	10.00	5.67
Fig. 3	Color 09	64.51	64.00	62.80	25.38	9.17	80.00	5.0YR	8.00	2.00	2.74
Fig. 3	Color 10	45.92	44.44	41.,50	25.38	9.17	66.67	5.0YR	7.00	2.00	2.46
Fig. 3	Color 11	30.71	28.44	24.08	25.38	9.17	53.33	2.5YR	6.00	4.00	4.11
Fig. 3	Color 12	18.88	16.00	10.53	25.38	9.17	40.00	2.5YR	5.00	4.00	6.43
Fig. 6	Color 01	66.95	64.00	91.65	45.83	18.18	80.00	5.0P	8.00	4.00	2.64
Fig. 6	Color 02	48.37	44.44	70.36	45.83	18.18	66.67	5.0P	7.00	6.00	3.42
Fig. 6	Color 03	33.16	28.44	52.94	45.83	18.18	53.33	5.0P	6.00	6.00	4.29
Fig. 6	Color 04	21.33	16.00	39.39	45.83	18.18	40.00	5.0P	5.00	10.00	5.11
Fig. 6	Color 05	68.92	64.00	71.46	34.86	19.47	80.00	10.0RP	8.00	4.00	2.94
Fig. 6	Color 06	50.33	44.44	50.17	34.86	19.47	66.67	10.0RP	7.00	4.00	4.15
Fig. 6	Color 07	35.12	28.44	32.75	34.86	19.47	53.33	7.5RP	6.00	6.00	2.00
Fig. 6	Color 08	23.29	16.00	19.20	34.86	19.47	40.00	7.5RP	5.00	8.00	5.92
Fig. 6	Color 09	55.68	64.00	61.77	70.00	8.06	80.00	10.0GY	8.00	4.00	6.09
Fig. 6	Color 10	37.10	44.44	40.48	70.00	8.06	66.67	2.5G	7.00	4.00	2.17
Fig. 6	Color 11	21.89	28.44	23.06	70.00	8.06	53.33	2.5G	6.00	4.00	6.02
Fig. 6	Color 12	10.06	16.00	9.51	70.00	8.06	40.00	2.5G	5.00	8.00	6.42
Fig. 9	Color 01	69.50	64.00	58.23	30.01	17.70	80.00	10.0R	8.00	4.00	2.87
Fig. 9	Color 02	50.92	44.44	36.93	30.01	17.70	66.67	7.5R	7.00	6.00	2.26
Fig. 9	Color 03	35.71	28.44	19.51	30.01	17.70	53.33	7.5R	6.00	8.00	3.04
Fig. 9	Color 04	23.88	16.00	5.96	30.01	17.70	40.00	10.0R	5.00	10.00	7.12
Fig. 9	Color 05	68.63	64.00	70.29	34.46	18.59	80.00	10.0P	8.00	4.00	3.22
Fig. 9	Color 06	50.04	44.44	49.00	34.46	18.59	66.67	10.0P	7.00	4.00	2.98
Fig. 9	Color 07	34.83	28.44	31.58	34.46	18.59	53.33	10.0P	6.00	6.00	1.71
Fig. 9	Color 08	23.00	16.00	18.03	34.46	18.59	40.00	10.0P	5.00	8.00	5.39
Fig. 9	Color 09	56.62	64.00	65.76	65.40	8.18	80.00	2.5G	8.00	2.00	3.48
Fig. 9	Color 10	38.03	44.44	44.46	65.40	8.18	66.67	5.0G	7.00	4.00	5.40
Fig. 9	Color 11	22.82	28.44	27.04	65.40	8.18	53.33	5.0G	6.00	4.00	2.17
Fig. 9	Color 12	11.00	16.00	13.49	65.40	8.18	40.00	5.0G	5.00	6.00	4.89
Fig. 12	Color 01	60.92	49.00	45.97	33.00	32.79	70.00	2.5R	7.00	8.00	4.03
Fig. 12	Color 02	48.56	36.00	31.81	33.00	32.79	60.00	2.5R	6.00	10.00	5.47
Fig. 12	Color 03	38.11	25.00	19.84	33.00	32.79	50.00	2.5R	6.00	12.00	5.19
Fig. 12	Color 04	29.55	16.00	10.04	33.00	32.79	40.00	2.5R	5.00	14.00	6.39
Fig. 12	Color 05	58.38	64.00	99.82	53.58	49.08	80.00	7.5B	8.00	4.00	4.89
Fig. 12	Color 06	44.12	49.00	83.48	53.58	49.08	70.00	10.0B	7.00	6.00	4.16
Fig. 12	Color 07	31.77	36.00	69.33	53.58	49.08	60.00	10.0B	6.00	6.00	6.77
Fig. 12	Color 08	21.31	25.00	57.35	53.58	49.08	50.00	7.5B	6.00	8.00	5.79
Fig. 12	Color 09	49.51	49.00	96.16	51.48	40.58	70.00	5.0PB	7.00	8.00	5.52
Fig. 12	Color 10	37.15	36.00	82.01	51.48	40.58	60.00	7.5PB	7.00	8.00	6.83
Fig. 12	Color 11	26.70	25.00	70.03	51.48	40.58	50.00	7.5PB	6.00	10.00	6.99
Fig. 12	Color 12	18.14	16.00	60.23	51.48	40.58	40.00	7.5PB	5.00	12.00	7.90
Fig. 13	Color 01	53.75	49.00	49.66	33.00	16.39	70.00	5.0R	7.00	4.00	3.88
Fig. 13	Color 02	41.39	36.00	35.51	33.00	16.39	60.00	5.0R	6.00	4.00	6.15
Fig. 13	Color 03	30.94	25.00	23.53	33.00	16.39	50.00	2.5R	6.00	6.00	4.64
Fig. 13	Color 04	22.38	16.00	13.73	33.00	16.39	40.00	2.5R	5.00	8.00	4.70
Fig. 13	Color 05	59.60	64.00	84.75	53.58	24.54	80.00	5.0B	8.00	2.00	3.43
Fig. 13	Color 06	45.35	49.00	68.42	53.58	24.54	70.00	5.0B	7.00	2.00	5.59
Fig. 13	Color 07	32.99	36.00	54.26	53.58	24.54	60.00	7.5B	6.00	4.00	5.13
Fig. 13	Color 08	22.54	25.00	42.29	53.58	24.54	50.00	7.5B	6.00	4.00	5.3
Fig. 13	Color 09	48.04	49.00	74.76	51.48	20.29	70.00	5.0PB	7.00	4.00	3.87
Fig. 13	Color 10	35.68	36.00	60.60	51.48	20.29	60.00	5.0PB	6.00	4.00	6.02
Fig. 13	Color 11	25.23	25.00	48.63	51.48	20.29	50.00	5.0PB	6.00	6.00	5.02
Fig. 13	Color 12	16.67	16.00	38.83	51.48	20.29	40.00	5.0PB	5.00	8.00	6.21

The choice of the hues, which determined the set of colors forming the hue triads, was made on the following considerations.

In the second group, in each of the 20 compositions, a different third hue has been added to the starting hue pair in every case to form the a new hue triad. The Coloroid plane of the third hue was located on the concave part of the Coloroid color space bordered by the Coloroid color planes of the starting hue pair, in every composition. This is tabulated in Tables II[E3] and III[E2] and shown in

Figs. 4 and 5. In this experimental category, Fig. 6 received the highest score. In this series of experiments, this composition was the 19th. The set of colors of this composition was formed by the four hues of the *A70-A46-A35* hue triad. The CIE XYZ, Coloroid ATV and the Munsell HVC data of the color of the compositions are given in Table IV[Fig. 9].

In the third group, the Coloroid plane of the third hue was located on the convex part of the Coloroid space bordered by the Coloroid planes of the starting hue pair, in each of the 20 compositions as shown in Table II[E3], Figs. 7, 8, and Table III[E3]. In this experimental group, Fig. 9 the 7th one presented received the highest score. The set of colors of this composition was formed by the four hues of the *A65-A35-A30* hue triad. The CIE XYZ, Coloroid ATV, and the Munsell HVC data of the color of the compositions are given in Table IV[Fig. 9].

In the fourth and fifth group of the experiment, the investigation was focussed on the influence of the saturation level of the colors in the hue triads on the harmony content of the compositions. The color set of the compositions in the fourth experimental group are more saturated than those of the same set in the fifth group. We designated the hue triads, defining the set of colors of the 20 compositions in each experimental group, in the following way. To start with, we selected a complementing hue pair (*A44-A71*) and a noncomplementing pair (*A33-A54*). The selected number was 5 from either side of the Coloroid color space divided by the Coloroid planes of the hue pairs. The selected colors were combined with the hue pairs, forming 20 hue triads as shown in Table II[E4], Figs. 10, 11 and Table III[E4]. From every one of the hue triads,

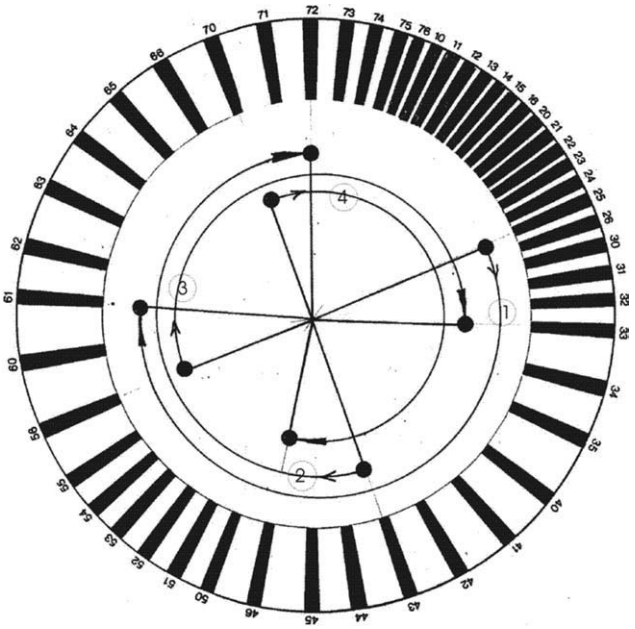

FIG. 4. The color areas, enclosed by the color planes of the hue planes, used as starters for generating the hue triads in the in the compositions as part of the second category of the experiment.

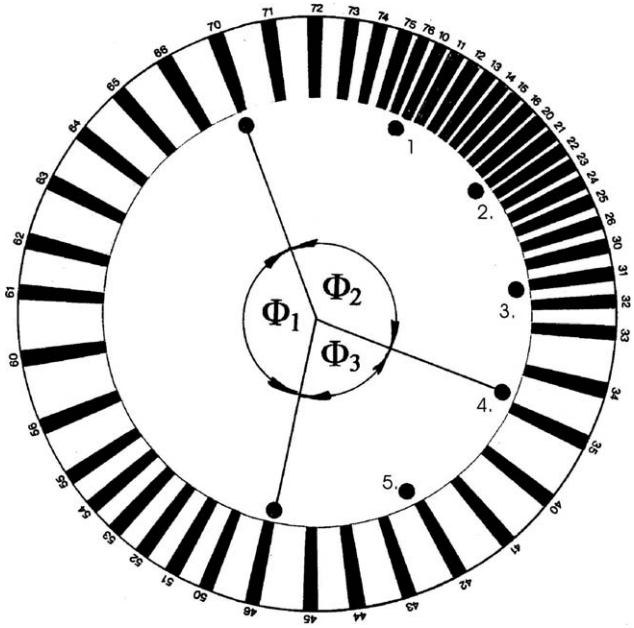

FIG. 5. The hues of the fifth composition, in the Coloroid circle, created by the extension of the *A70-A46* hue pair, as part of the 20 compositions in the second experiment.

we created 12 more saturated color sets for the compositions in the fourth experiment and 12 less saturated color sets for the compositions in the fifth experiment. In the fourth group, Fig. 12 scored the highest, whilst in the in the fifth, one Fig. 13 received the highest score. Both of these compositions were made up from the four colors of the *A33-A54-A51* hue triad. The CIE XYZ, Coloroid ATV, and the Munsell HVC data of the color of these compositions are given in Tables IV[Fig. 12] and IV[Fig. 13].

RESULTS

The results of the experiment are summarized in the graphs shown in Figs. 14–17. The radii of the orbital diagrams symbolize the color planes of the same Coloroid colors, with 5° inclination from each other, within the color space of the Coloroid system. During the experiment, in each of the experiments, we selected a harmonic hue pair, as a starting point, from which one chosen hue represented the plane of "0°". When the experimental subjects assessed the harmony content of the compositions, they judged the degree of inclination of the planes from the "0°" reference. The number of votes given to the hues, looking as the percentage of the total number of voters symbolized by the radii shows a uniform increase, progressing from the center (0%) toward the circumference (100%).

The diagrams in Figs. 14 and 16 show the view of the student population, not associated professionally with colors, representing the judgements of the average population. Figures 15 and 17 depict the judgement of people from the art world, professionally associated with colors.

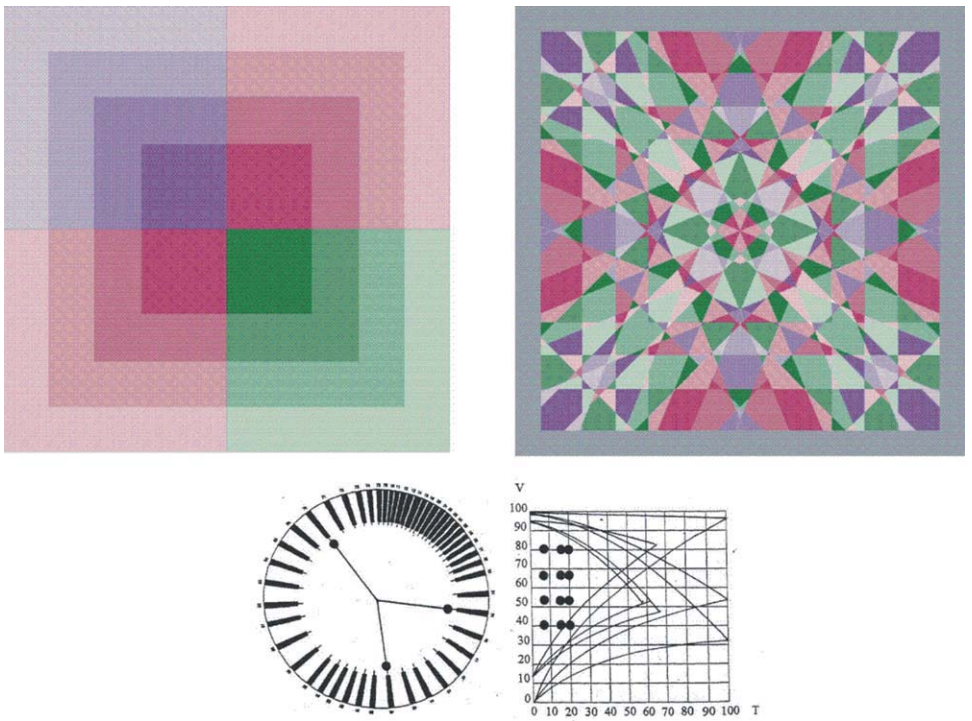

FIG. 6. The 19th composition, in order of presentation, from the second category of the experiment. The picture, shown on the left, is composed from each of the four hues of the *A70-A46-A35* hue triad. Altogether 12 colors are used.

Figures 14 and 15 show three sets of three closed curves. The red color curves show the results from the first category of the experiment. These represent the view of the experimental subjects on the harmony content of the composition, which contained the actual hue triad, when the two colors in the triad are complementing each other. Here, the sum of the angles of the color planes is 180°. The curves in blue show the results of the second experimental category. In this experiment, the experimental subjects judged the compositions, whose hues' color planes had deviation from each other larger than 180°. The brown curves are related to the results of the third

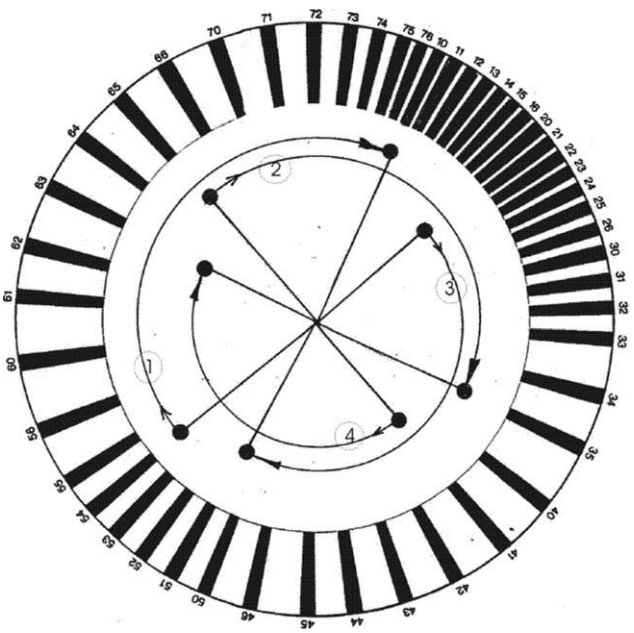

FIG. 7. The color regions, enclosed by the color planes of the hue pairs, used as starters for generating the hue triads in the compositions as part for the third category of the experiment.

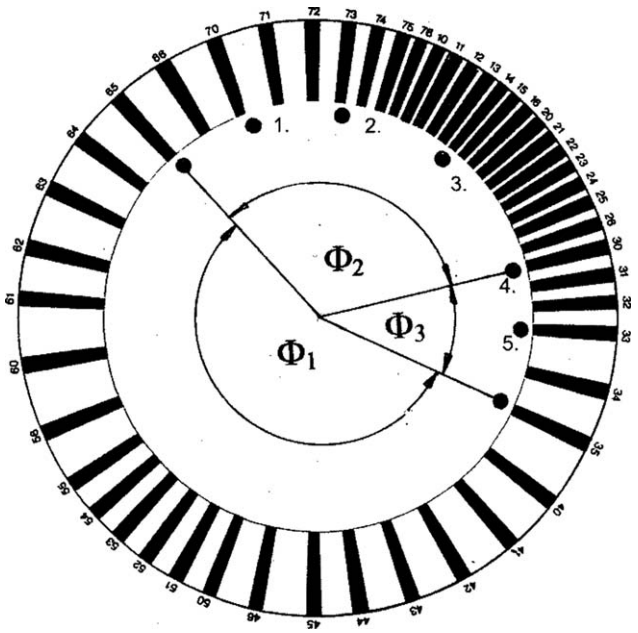

FIG. 8. The positions in the Coloroid color circle, of the hues of the five compositions, created by the extension of the *A65-A35* hue pair, as part of the 20 compositions in the second experiment.

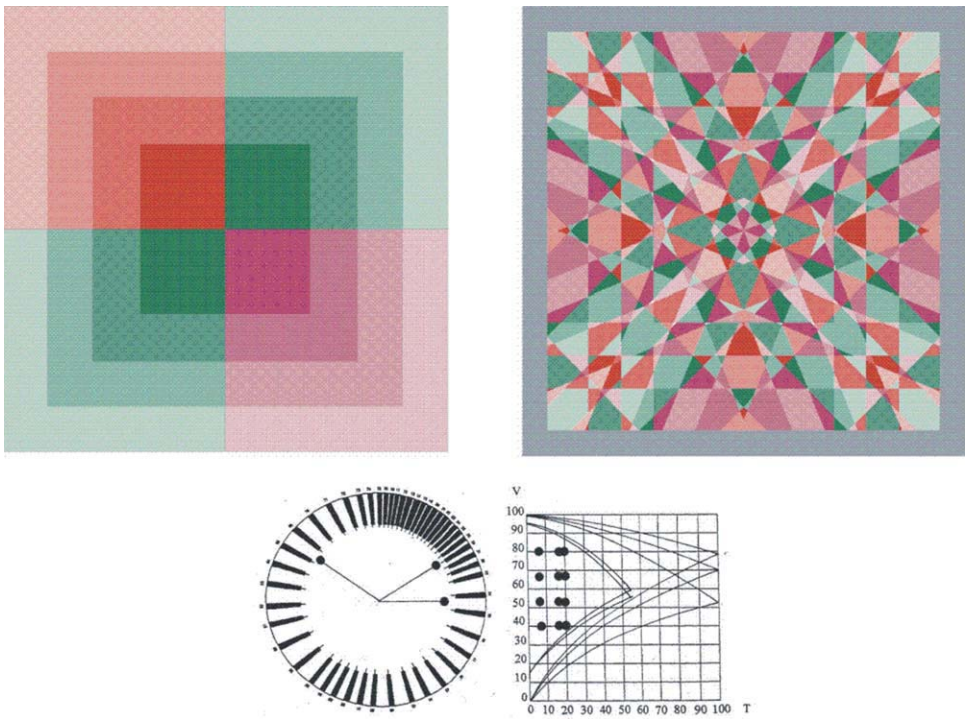

FIG. 9. The 5th composition, in order of presentation, from the third category of the experiment. The picture, shown on the left, is composed from each of the four hues of the *A65-A35-A30* hue triad. Altogether 12 colors are used.

category. They represent judgements on the compositions, in which the color planes of the colors in it show a sum of deviation from each other less than 180°.

Figures 16 and 17 show two sets of two closed curves. The curves in red show the results from the fourth category. In these experiments, the subjects judged compositions with colors of high Coloroid saturation. The blue curves show the results from the fifth category. In this experiment, the subjects gave their assessments on those compositions having color saturations less than the ones in the fourth experiment.

These graphs show that the number of votes cast on even the least harmonic compositions can reach nearly 50%. Because of the great care taken at the design of the

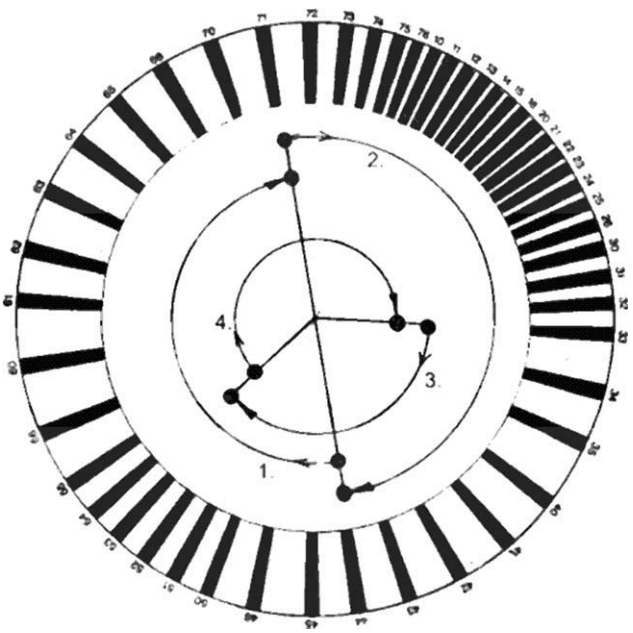

FIG. 10. The color regions, enclosed by the color planes of the hue pairs, used as starters for generating the hue triads in the compositions as part for the 4th and 5th categories of the experiment.

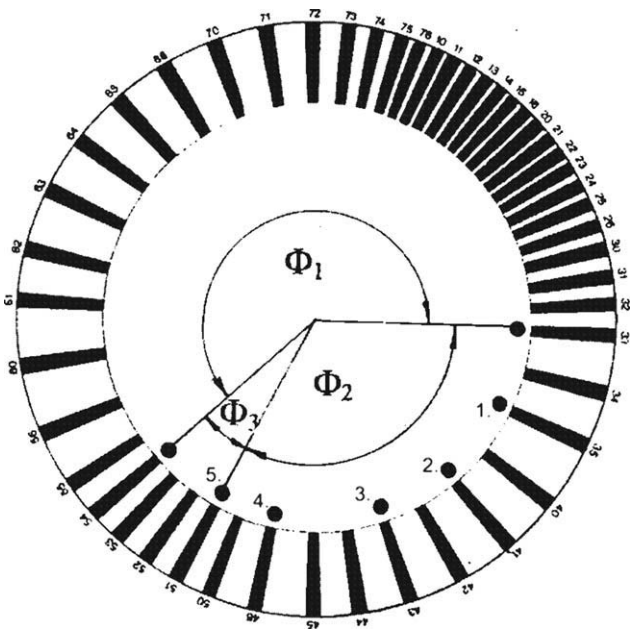

FIG. 11. The positions in the Coloroid color circle, of the hues of the five compositions, created by the extension of the *A33-A54* hue pair, as part of the 20 compositions in the 4th and 5th experiments.

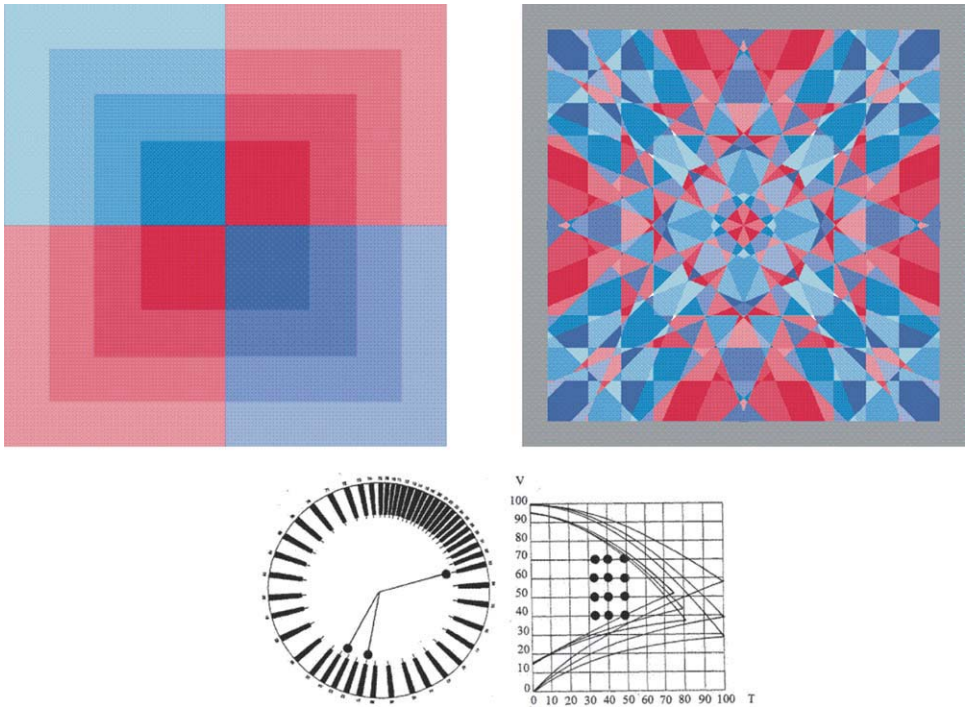

FIG. 12. It is the 18th composition, in order of presentation, of the 4th category of the experiment. The picture, shown on the left, is composed from each of the four hues of the *A33-A54-A51* hue triad. Altogether 12 colors are used.

compositions, this can happen only when the relation between the saturation and the illumination of the colors in the compositions follows the same rule of harmony same as the one established in the earlier experiments. We found this was a necessary requirement, so that the difference between the harmony content of the compositions was made dependent only on the relation between the hues in the compositions.

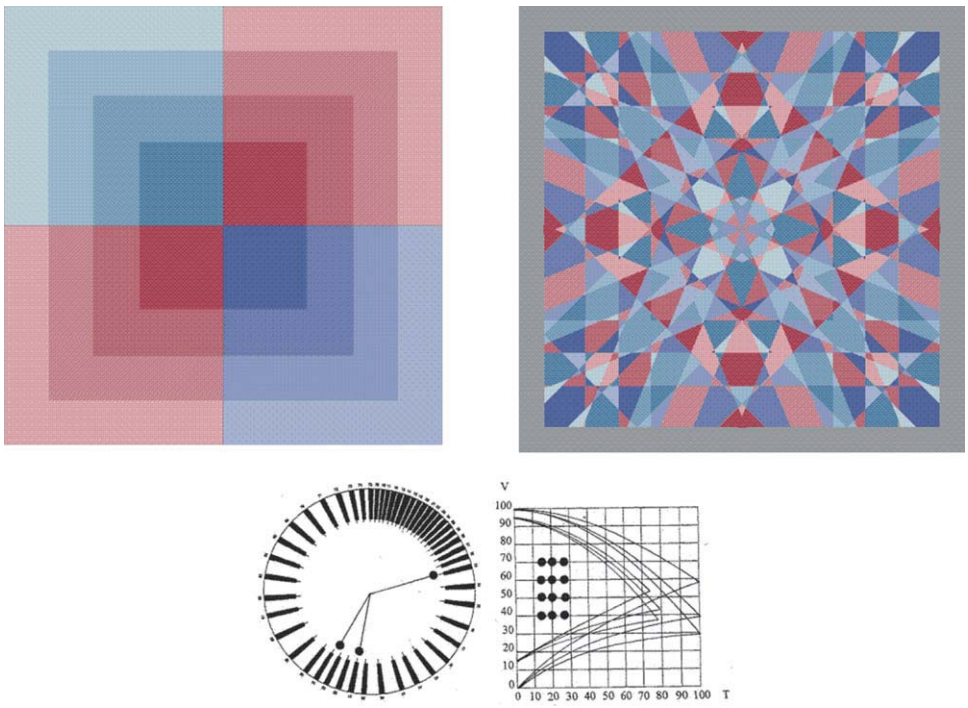

FIG. 13. The 18th composition, in order of presentation, from the 5th category of the experiments. The picture, shown on the left, is composed from each of the four hues of the *A33-A54-A51* hue triad. Altogether 12 colors are used. The saturation levels of the colors in the composition are different, from that of the composition shown in Fig. 12.

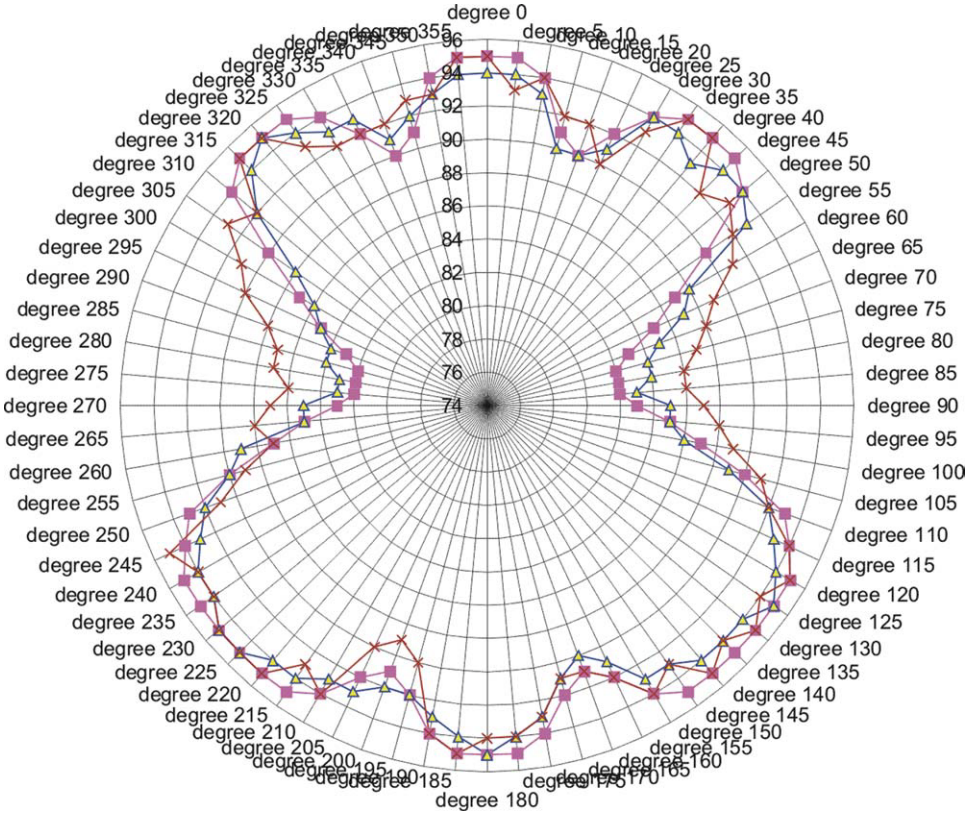

FIG. 14. The results from the first three categories as part of the experiment carried out in 1986–1989. For the explanation of the diagram see the text.

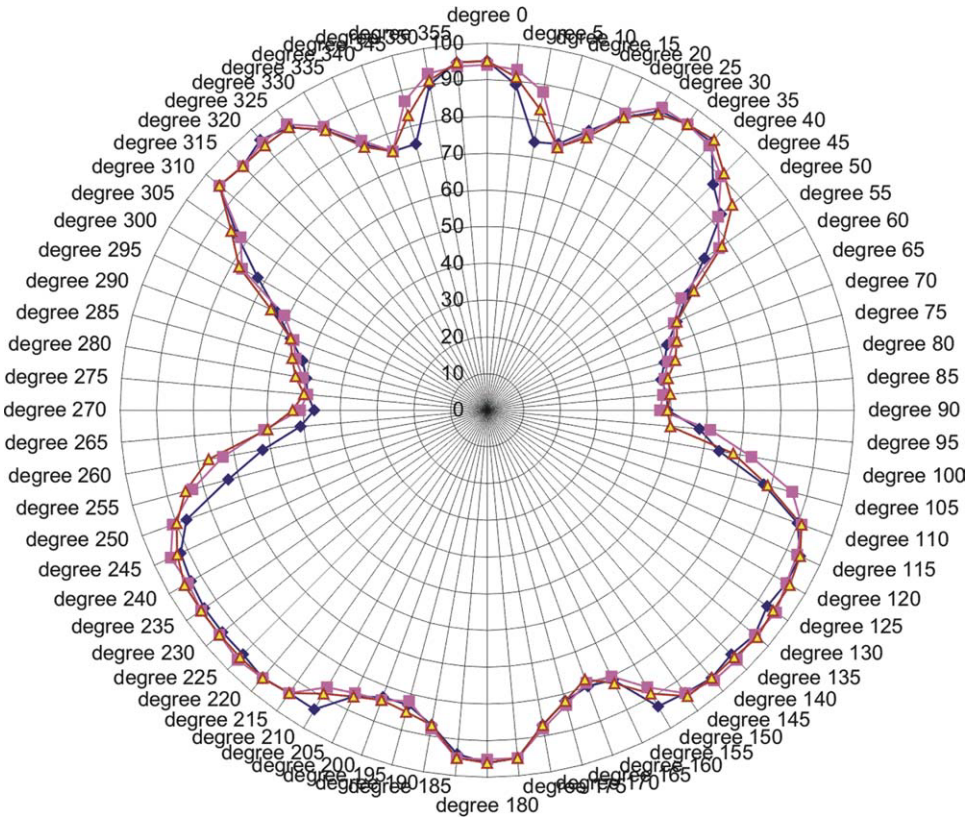

FIG. 15. The results from the first three categories as part of the experiment carried out in 2003–2006. For the explanation of the diagram see the text.

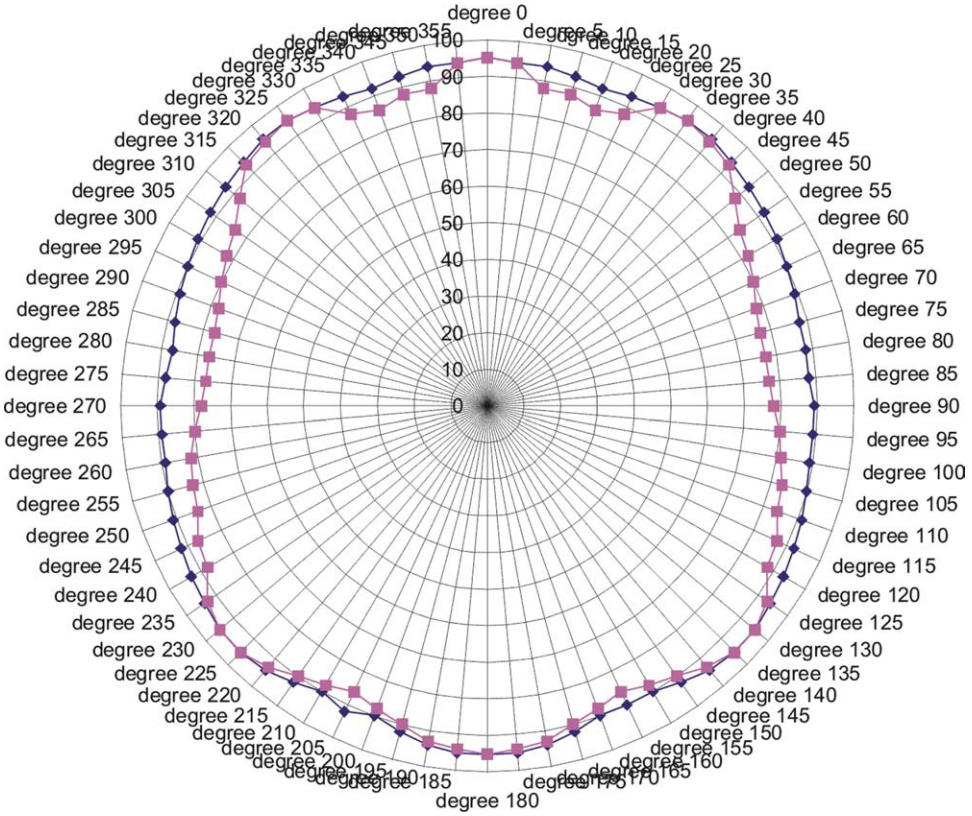

FIG. 16. The results from the 4th and 5th categories as part of the experiment carried out in 1986–1989. For the explanation of the diagram see the text.

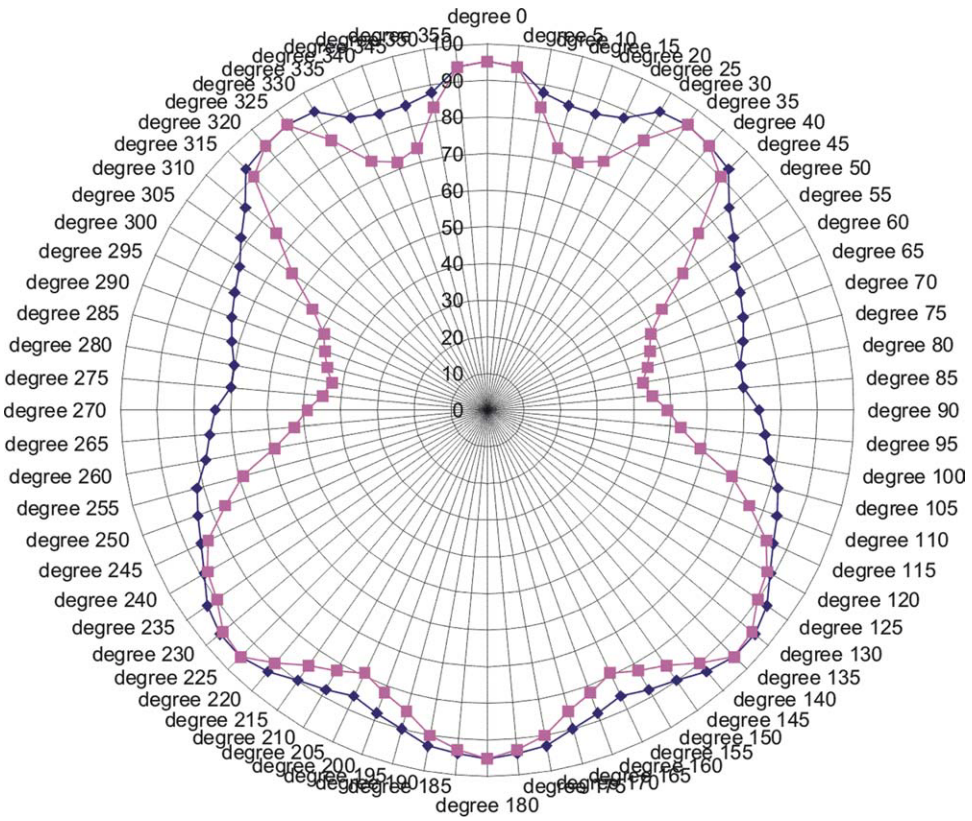

FIG. 17. The results from the 4th and 5th groups as part of the experiment carried out in 2003–2006. For the explanation of the diagram see the text.

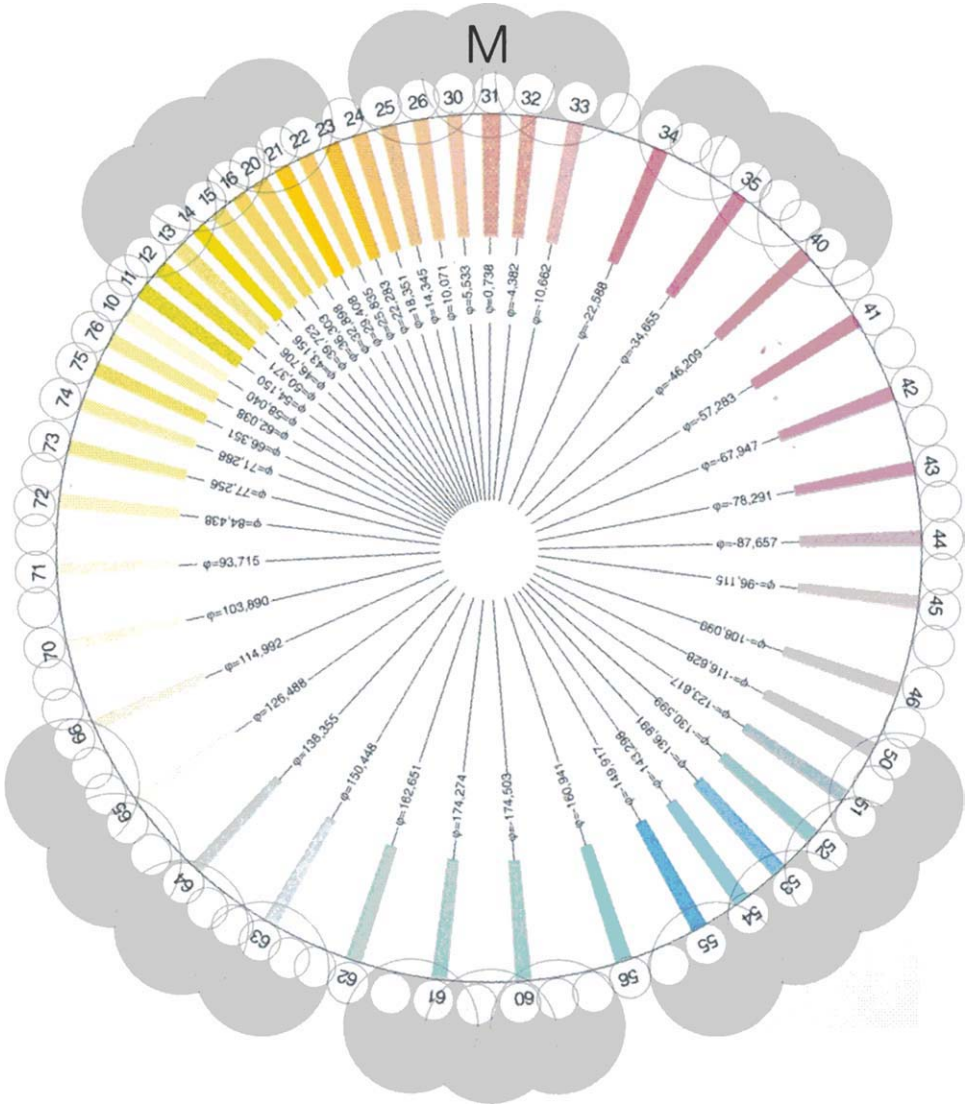

FIG. 18. Color regions in the Coloroid circle, for the creation of harmonic hue triads with the *A31* Coloroid hues.

One can read well-defined rules from the graphs. These rules, however, are only applicable to the whole sampled population on statistical ground. According to the judgements of the student group, shown in the graphs of Figs. 14 and 16, the number of votes cast for the compositions with the least harmony content was very high. The number of votes cast on the compositions with the least harmony content, differed only by 13% from that of the most harmonic compositions. In the case of the artist group, this ratio was 47% as shown in Figs. 15 and 17. We concluded from these results, that for an average person, judging the harmony content of the hue triads is rather difficult, further to that, even people, experienced with colors, may find it difficult to make this judgement with great confidence.

Let us suppose for instance, that we order "0°" angle, to one of the hues of the observed hue triad, during the experiment, then the other two hues, judged with high-harmony content, will fall always into well-defined intervals between two angles. We can call the hue triads high-harmony triads, when the hues of their elements coming from the hues from the 30°–50°, 110°–145°, 175°–185°, 215°–250°, 310°–315°, and 355°–005° angular intervals. We call less harmonic or unharmonic those sets, whose other two hues fall between 10°–25°, 55°–105°, 155°–170°, 190°–210°, 255°–305°, and 320°–350°. These hue regions can shrink or expand depending on whether the numerical values of the Coloroid saturation of the compositions are smaller or larger (Figs. 16 and 17).

CONCLUSIONS

The results of our experiments indicated that the angular regions of the other two hues making up the triads with high-harmony content are symmetrically positioned on the right and left of the selected starting "0°" angle, when depicted in the Coloroid color circle. We ordered "0°"

angle to *A31* Coloroid hue, as shown in Fig. 18, whose λ is 610.14 nm and marked this as a starting point with the letter "M." Gray areas are representing the hue regions, from which the selection of the two other hues and adding to the one at the letter "M" results in a hue triad with high harmonic content. For the "0°" angle marked with "M" can be chosen from any of the hues in the Coloroid circle. In that case, the gray areas will follow the letter "M" like a movable stencil. This means, that depending on the choice of the starting hue triad, the angular regions, on the right and on the left will contain more or less Coloroid hues, depending on the properties of the Coloroid color circle.

Summarizing what we said earlier, we can conclude the judgment of the harmony content of hue triads is not an easy task even for professionals. The measure of the harmony content of the hue triads is a function of the angular deviation between the color planes, in the Coloroid color space. For every hue, selected for a starting point, six well-definable color groups can be ordered, whose elements can be used for the selection of hue triads with high-harmony content. The saturation level of the elements in the hue triads, influences significantly their harmony content. The experimental data also show way how to interpret the conclusions in other color systems.

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