Experimental Determination of Laws of Color Harmony. Part 3: Harmony Content of Different Hue Pairs

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Abstract: At the Budapest University of Technology and Economics in 1956, we decided to start large-scale experiments on color harmony. The experiments and the processing of the experimental data were completed in 2006. The experiments described in this article were based on a long established experience that harmony content of different hue pairs greatly differ from each other. The vast majority of former research activities on the subject of color harmony narrowed down mostly to investigations of saturated color pairs. Color samples of our experiments have been defined within the color space of the Coloroid color system, built on harmony thresholds. The compositions, prepared for the experiments, always consisted of two saturated hues and three low saturation colors of each hue at varying brightness, making it a total of eight colors. Within the framework of the experiments, 48 hues were used. Out of these, each of the 24 was formed into composition pairs with the remaining 48 hues, forming a total of 852 compositions. The paired-comparison experiments were conducted with the use of the compositions prepared by collage technique. Color samples made of painted paper, between 1980 and 1985, have been repeated between 2002 and 2006 with the same color selection but with computer-generated pseudorandom patch system compositions. It has been established that harmony content of hue pairs can be expressed by the relative angle of their hue planes in the Coloroid color space. The harmony content of hue pairs exceeds that of other pairs, when this angle is below 10°, between 30° and 40°, between 130° and 140° or near to 180°. Those color pairs of which hue planes are between 60° and 90° to each other in Coloroid color space, exhibit the least harmony content. © 2008 Wiley Periodicals, Inc. Col Res Appl, 34, 33–44, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/col.20457

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

INTRODUCTION

Experience shows that the harmony content of different hue pairs greatly differ from each other. As far back as the second half of the 18th century, there have been some attempts to explain the greater harmony content observed with complementary color pairs, which exceeded that of other pairs. It was observed that the viewing of a green surface for a considerable period results in a red after-image. It also was observed that the after-image always appears in the complementary color of the viewed color. These observations have been the starting point of a number of theories on color harmony by saying that the eyes are always automatically trying to reach equilibrium in color impressions. On the basis of that theory, Rumford[1] has formulated and Hering[2] explained further the view that harmony is an equilibrium, specifically equilibrium of psychophysical forces.

This conclusion and its explanation have formed the base of the totality theory of Goethe and the duality theory of harmony by Schopenhauer. Their theories through the interpretation of Hoelzel have survived and in the works of Kandinsky, Klee, Itten, Albers, and Moholy-Nagy on theory of art, kept their influence, on theoretical and practical pursuits related to colors, till today. Chevreul has verified the creating role of the complementarity harmony with the phenomena of simultaneous contrast. The application of his teaching—through Delacroix inter-

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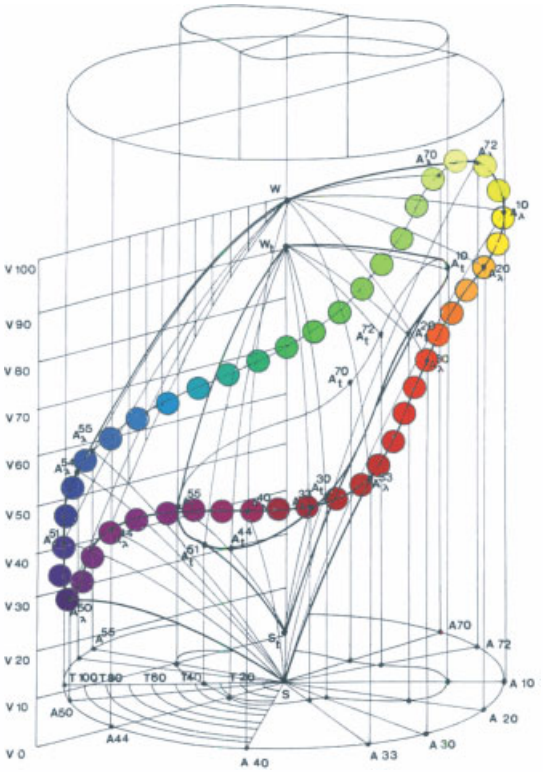

FIG. 1. The color space of the Coloroid color system. The spectral colors and magentas, called boundary colors are located on a self-returning curve, which is placed on the surface of a cylinder, comprising the color space. Out of the boundary colors, there are 48 numbered basic colors, esthetically equidistantly placed with good approximation. The half planes comprising the basic colors are the loci of the Coloroid basic colors. The experiments have been carried out with colors selected from the basic colors of the Coloroid.

pretation—has been put into practice in paintings by Seurat and Signac.[3–11]

Different authors including Ostwald and Munsell have even drawn some conclusions from it regarding the color harmonies of their own color schemes.[12–15]

In the meantime, more and more experiments were conducted, in persuit of the definition of the laws of harmony creation, based on not only theoretical considerations but also practical experience.[16–40] A number of researcher such as Guilford, Moon and Spencer, Pope, Granger, Burchartz, Beaudeneau, Togral, Mori *et al*., Knoop, Pickford, Sivik, Granville, Heddel, Yeh and Chuang, Chuang and Ou, Burchett, Ou *et al*., and Ou and Luo,[16–40] have conducted experiments related to the harmony content of color pairs.

In contrast to the experiments listed earlier, we did not investigate color pairs but hue pairs consisting of two saturated hues and three of the same hues of lower saturation having different brightness levels. These unsaturated colors created low saturation brightness scales for each composition in the experiments. The colors of our experiments have been defined in the color space of the Coloroid system, based on harmony thresholds, with the aim of drawing conclusions from these results relating to the whole color space containing surface colors. This publication is limited only to the description of the experiments and the presentation of the experimental results.

THE COLOROID

Because of the importance of the starting point in our experiment, we have to define Coloroid as a system built on the sensation of harmony color difference as perceived by people with normal color vision, when the surface colors illuminated by daylight. This is aesthetically uniform because the same number of harmony intervals indexed with whole numbers is distributed evenly between the neighboring surface colors. Because of this feature, it can be used to describe harmony relations of surface colors and for creating harmonic color compositions.

The Coloroid locates the three-dimensional multitude of color sensations within the inner space of an upright cylinder in such a way that the change in hues occurs along the perimeter, the saturation changes along the radius, and the brightness varies along the axis. The spectral colors and magentas, as the border colors of the Coloroid, are located on the wall of the cylinder forming a continuous self-returning curve. Out of the border colors, 48 colors are located aesthetically approximately equidistant from each other as basic colors of the Coloroid. The indexes and the wavelengths (in case of the magentas, the negative wavelengths the complementing colors) of the Coloroid basic colors give the coordinates (A) and characteristic wavelengths of the hues of every color on the half plane of the basic colors (Fig. 1).

The Coloroid color body is located within the Coloroid color space. The Coloroid color body contains the surface colors. Its borders are not defined by Coloroid and shape and dimensions vary depending on whether the color samples are created by paint mixing or by printing. The color body shown within the Coloroid color space in Fig. 1, which is similar to the color space, relates to colors of the color samples prepared for the experimental compositions by paint mixing. The most saturated colors are laying on a continuous curve located on a convoluted surface. This curve penetrates all 48 planes of the basic colors.

These 48 colors represent the basic hues of the Coloroid. To represent them on a circle, we projected all 48 of them onto a plane perpendicular to the color planes in such a way that they are located equidistant from the penetration point of the acromatic axis with the plane, but at the same time they stay within their original plane of hues. The Coloroid color circle appears asymmetrical because the distances between its colors are linearly proportional to the inclination between hue planes, established by harmony threshold experiments (Fig. 2).

This property of the Coloroid color circle has a special importance in our experiments, because the harmony content of hue pairs is linked to the inclination between the

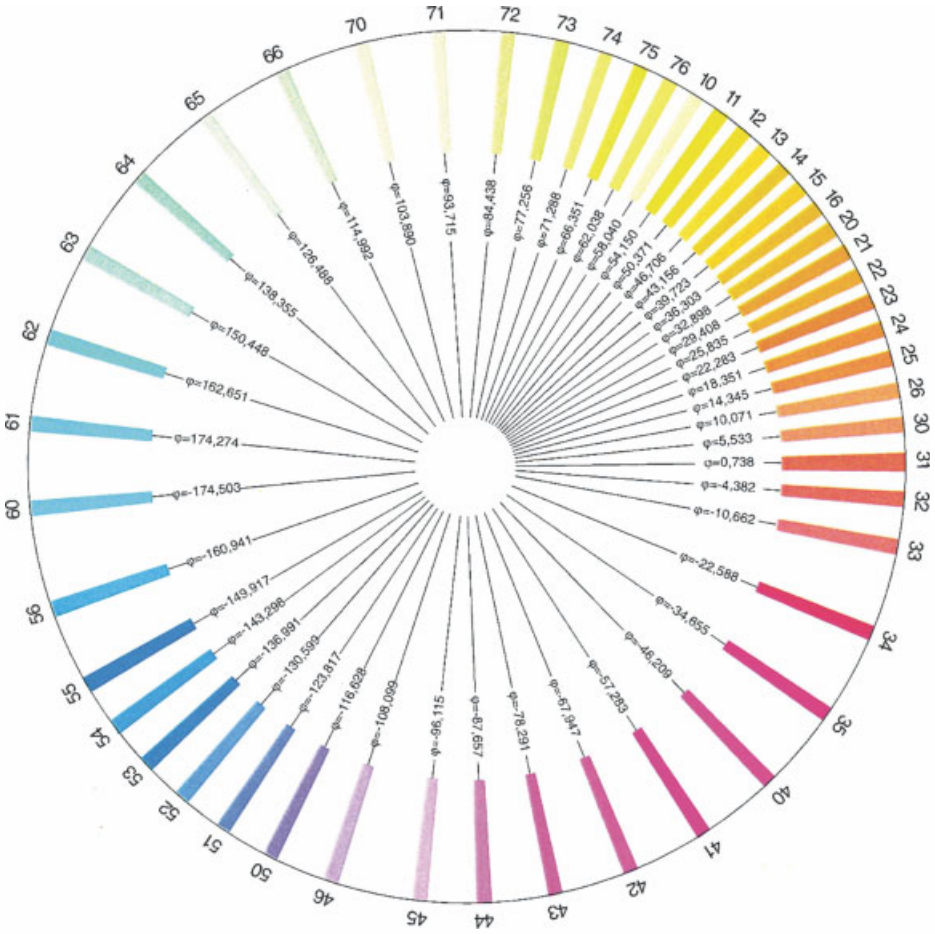

FIG. 2. The Coloroid color circle. The colors of the color circle symbolize the Coloroid hues. Numbers written in the figure outside the circle are the indexes of Coloroid hues. These index numbers are hue coordinates of the colors, belonging to the actual hue (*A* values). The half-planes of the different hues were defined by their declination angle to the half-plane of a randomly chosen boundary color. In case of D65 illumination, the 0,00 declination happened to be at Coloroid hue of *A*31,44. The φ angles, written on the radii of the circle, show the angle of declination of hue planes to the initial plane. It is necessary to demonstrate this, because in our experiments the level of harmony content is always linked to the φ angle of the angle of declination of the hue pair, under investigation.

Coloroid hue planes. Further details and the definitions of the Coloroid color system can be found in other publications.[41–52]

EXPERIMENTS

The experiments conducted between 1980 and 1985 have used compositions prepared between 1978 and 1980. The compositions were based on color pairs consisting of most saturated surface colors, attainable by paint mixing. Each one of the highly saturated color pairs was accompanied with three broken color shades, linked to the Coloroid hues of the same color pairs. In these compositions, which were used in the experiments, it was desirable to complement the color pairs with broken colors because the experiments described in current publication aim to define not only the extent of harmony content of one color pair but also that of the Coloroid hue pairs represented by this color pair. The compositions were assembled by collage technique from color samples, produced with paint and their dimensions were 50 × 50 cm. To each one of the 24 basic hues, selected from the 48 basic hues of the Coloroid, has been assigned a pair from each of the basic hue. The hues, present in the composition, have been characterized with their wavelengths as well by using the rules of the Coloroid (Table I). All compositions used the same patch system having two of the highly saturated colors of the hue pairs in the middle of it. Progressing toward the edge of the compositions, one can find the broken colors, 2 by 2, from the lightest to the darkest color. Within the same composition, as related to the hue, the saturation levels of the broken colors were identical. Their brightness has diminished in all compositions uniformly with d10V Coloroid brightness units from the center to the edge. All together, 852 compositions were assembled out of which 12 are depicted as the left compositions of Figs. 3, 4, 5, 6, 8, 9, 10, 11, 13,

TABLE I. Forty-eight Coloroid basic hues and their characteristic wavelengths of colors linked to these hues, used as color samples in the compositions of testing the experiment. Colors associated with the 24 basic hues shown in bold were used in dichromatic compositions with colors linked to each Coloroid basic hue.

Coloroid basic hues	Wavelength, λ (nm)
A10	**570.83**
A11	572.64
A**12**	**574.38**
A13	576.06
A**14**	**577.50**
A15	579.31
A16	580.95
A**20**	**582.65**
A21	584.46
A22	586.43
A**23**	**588.59**
A24	591.06
A25	594.00
A**26**	**597.74**
A30	602.72
A**31**	**610.14**
A32	625.00
A**33**	−**492.79**
A34	−495.28
A**35**	−**498.45**
A40	−502.69
A**41**	−**509.12**
A42	−520.40
A**43**	−**536.31**
A44	−548.11
A**45**	−**555.96**
A46	−564.18
A**50**	**450.00**
A**51**	**468.71**
A52	475.44
A**53**	**479.29**
A54	482.04
A**55**	**484.29**
A56	487.31
A**60**	**490.40**
A61	492.72
A**62**	**495.28**
A63	498.45
A**64**	**502.69**
A65	509.12
A**66**	**520.40**
A**70**	**536.31**
A71	548.11
A**72**	**555.96**
A73	560.74
A**74**	**564.18**
A75	566.78
A**76**	**568.92**

14, 15, 16. The CIE *XYZ* color components and the Coloroid *ATV* coordinates of the colors present in the compositions are collated in tables. The data of the 12 compositions, included in this article, are tabulated in Tables II–IV.

The subjects in the experiments were students of the Budapest University of Technology and Economics of ages 18 to 25. Color blind subjects were eliminated by Ishihara tests. The experiments were conducted in a room illuminated with light reflected by the Northern sky, next to the window, where the range of illumination level was between 1600 *lx* and 1800 *lx*. The composition pairs were placed on vertical surfaces. The composition was surrounded by a grey colored surface of $Y = 30$ CIE color component (light density factor). Their illumination angle was 45°, the observation was made with a viewing angle of 90° from a distance of 150 cm. The experiments involved comparing pairs. The participants in the experiment had to select always only two compositions, judging by their harmonic content, until all possible composition pairs of the relevant experimental section have been judged. Before the start of the experiment, the supervisor of the experiments has presented the compositions to the participants and explained their task. The experiments were conducted in groups of 10. Each composition pair has been assessed by the average of 100 people. The assembled and presented 852 compositions provided 363,378 pair combinations, out of which we selected and completed 18,048 assessments. This procedure required a highly organized effort and considerable time. In the mornings, under good natural illumination conditions, in five parallel groups of 10 participants, 24 composition pairs were presented for assessment in hourly intervals. This represented the assessments of 600 composition pairs each day, during 5 hours of working session. The data was collated and processed each day by the leaders of the experiments.

A part of the experiments was repeated between 2002 and 2006, by using pseudorandom patch compositions, called caleido compositions, generated from the colors of the original compositions by a computer. The caleidoscopic arrangement of colors in these new compositions were chosen to find out whether the judgments of the participants are influenced by the scale-like order of colors that are well observable in the former compositions. These compositions were uniformly surrounded by medium grey color (*A*51, *T*0.5, *V*55) of $Y = 30.25$ CIE color component (light density factor). The caleido effect were magnified further with the inclusion of the white color of $Y = 81$ CIE color component (light density factor) in the compositions. The caleido compositions were printed out in a dimension of 28 × 28 cm. In total, 308 compositions have been prepared with Coloroid basic hues in pairs of the *A*12, *A*20, *A*31, *A*41, *A*51, *A*60, and *A*70 basic Coloroid colors with all the Coloroid hues, out of those 12 are presented as the right-side compositions of Figs. 3–6, 8–10, 13–16. The color correspondence between the samples and the colors of the original painted composition samples were checked with a spectrophotometer. In case of color difference, we have made modifications and reprinting. The circumstances and the organization of the experiments were mostly the same as that of the former experiments. The only difference was that the composition was observed from a distance of 100 cm instead of 150 cm. A significant number of the subjects of the experiment were artists. Out of the possible 47,586 pair forming combinations, 2379 composition pairs have been assessed.

CONCLUSIONS

The processed experimental results have provided a curve for each of the 48 Coloroid basic hues. The graphs showed which actual Coloroid hue paired up with other hues from the Coloroid has larger or smaller harmony content relative to each other. The similarities and differences between the curves have drawn the attention to the correlations between harmony content of different hue pairs. For the demonstration of the experimental results, the harmony contents of three basic hues, namely *A*12, *A*31, and *A*51, paired up with the other Coloroid basic hues, depicted in three diagrams. These diagrams are demonstrating the assessments of the pair combinations of 138 compositions, assembled by collage technique and 138 computer generated and printed compositions. For the demonstration of the similarities and differences between compositions, 24 samples of the compositions are shown.

Figure 3 shows the compositions of hue pair *A*12-*A*10, assembled with collage technique (left) from color samples and the computer-generated compositions (right). Under the compositions, one can see the standardized (MSZ 7300) Coloroid diagram. The circle on the left of the illustration is the scheme of the Coloroid color circle. The distance between the radially placed small patches is proportional to the angle of declination between the color planes containing the hues. The two radii shown are symbolizing the inclination between the two color planes, signified by *A*12 and *A*10. The round patches on the radii are become increasingly unsaturated near to the center of the circle, whereas they become increasingly saturated

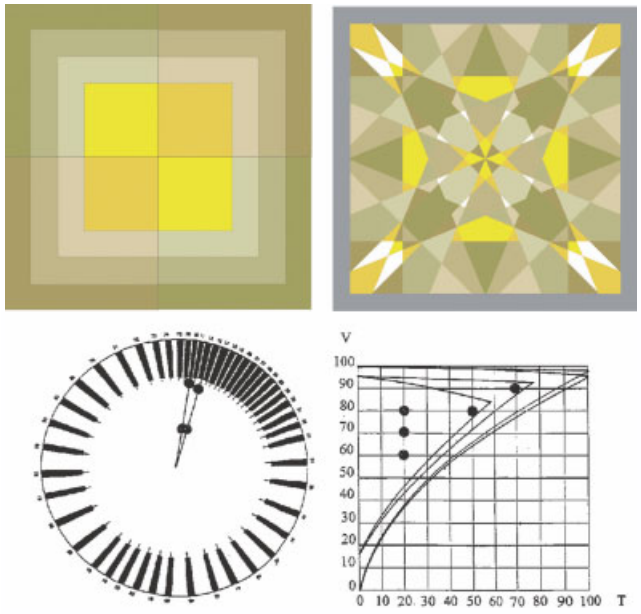

FIG. 3. Two compositions constructed of four colors each of the hue pair *A*12-*A*10, painted on paper (left) and generated by computer (right). The Coloroid diagram, on the left under the compositions, demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

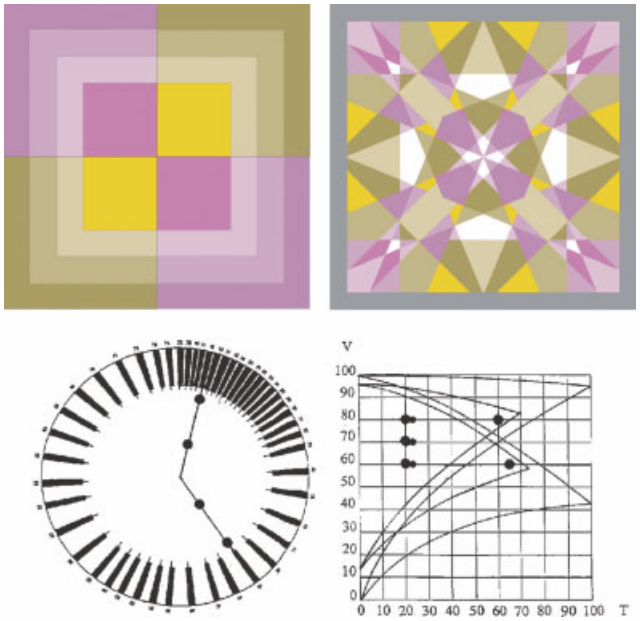

FIG. 4. Two compositions constructed of four colors each of hue pair *A*12-*A*10, painted on paper (left) and generated by computer (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

when the colors move away from it. The picture on the right shows the superimposed view of the two Coloroid color planes. The vertical lines are the loci of identical saturations, whereas the horizontal ones are that of identical brightness. One can read that saturated colors came from the midst of the most saturated colors of the actual hues and that broken colors form brightness scales of similar saturation. It should be noted here that because it is built on the identical product numbers of harmony thresholds, within the Coloroid color space, the brightness scales provide the compositions certain explicit harmony content. In the interest of the experimental subjects not to get influenced in their assessments by the harmony content of the brightness scale, broken shades are included in every composition forming scales of *V*80-*V*70-*V*60 Coloroid brightness.

The saturation of each member of the scale is always identical, their saturation level, however, depends on the limits of *T*8-*T*21, where the level of the most saturated color of the composition falls.

Figs. 4–6 show the compositions made of hue pairs *A*12-*A*13, *A*12-*A*60, and *A*12-*A*72, respectively, demonstrating the location in the color space of colors included in the compositions explained by the use of the Coloroid diagram. CIE color components (*XYZ*) and Coloroid coordinates (*ATV*) of colors, present in the compositions and made with Coloroid basic hue *A*12 are shown in Table II.

During the processing of the experimental data, the answers of the male participants were handled separately from that of the female subjects. In the experiments,

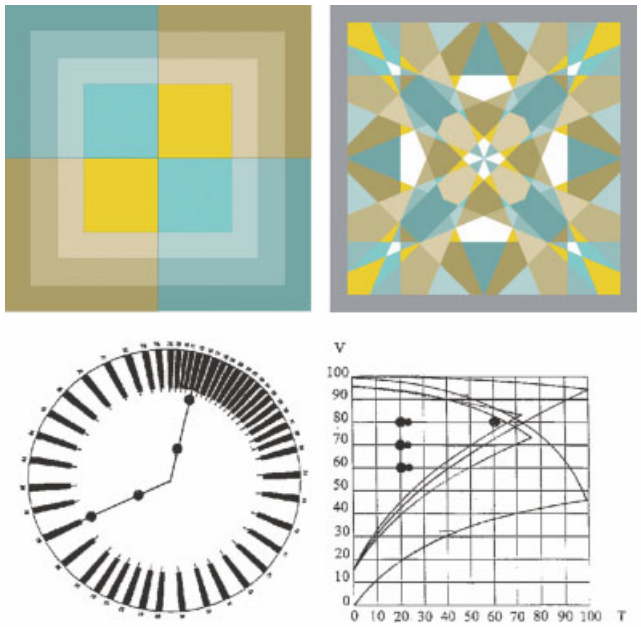

FIG. 5. Two compositions constructed of four colors each of hue pair *A*12-*A*60, painted on paper (left) and generated by computer (right). The coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

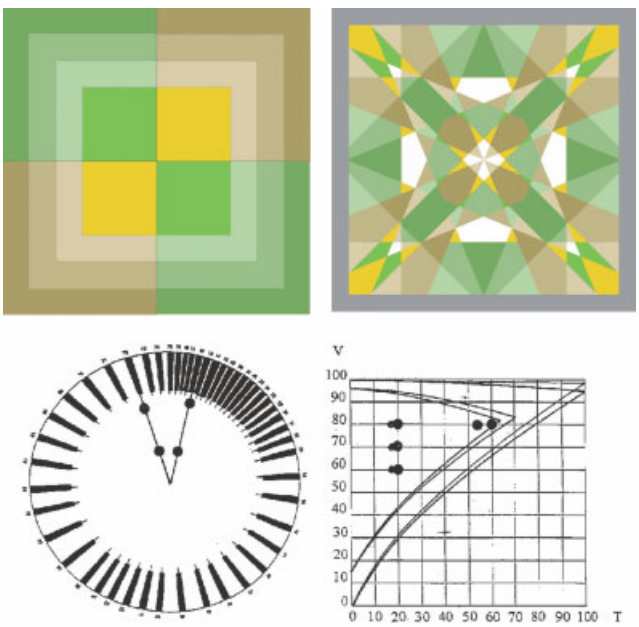

FIG. 6. Two compositions constructed of four colors each of hue pair *A*12-*A*72, painted on paper (left) and computer by computer (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

TABLE II. CIE color components and Coloroid coordinates of colors used in the compositions in Figures 3, 4, 5, and 6.

Compositions		CIE			Coloroid		
		X	*Y*	*Z*	*A*	*T*	*V*
Figure 3	Color 01	59.99	64.00	49.68	12.00	20.00	80.00
	Color 02	45.73	49.00	33.35	12.00	20.00	70.00
	Color 03	33.38	36.00	19.19	12.00	20.00	60.00
	Color 04	58.73	64.00	19.67	12.00	50.00	80.00
	Color 05	58.54	64.00	49.17	10.22	20.00	80.00
	Color 06	44.28	49.00	32.84	10.22	20.00	70.00
	Color 07	31.92	36.00	18.69	10.22	20.00	60.00
	Color 08	68.96	81.00	16.40	10.22	70.00	90.00
Figure 4	Color 01	59.99	64.00	49.68	12.00	20.00	80.00
	Color 02	45.73	49.00	33.35	12.00	20.00	70.00
	Color 03	33.38	36.00	19.19	12.00	20.00	60.00
	Color 04	58.31	64.00	9.67	12.00	60.00	80.00
	Color 05	69.02	64.00	83.44	43.14	21.71	80.00
	Color 06	54.76	49.00	67.11	43.14	21.71	70.00
	Color 07	42.40	36.00	52.95	43.14	21.71	60.00
	Color 08	58.78	36.00	80.47	43.14	65.12	60.00
Figure 5	Color 01	59.99	64.00	49.68	12.00	20.00	80.00
	Color 02	45.73	49.00	33.35	12.00	20.00	70.00
	Color 03	33.38	36.00	19.19	12.00	20.00	60.00
	Color 04	58.31	64.00	9.67	12.00	60.00	80.00
	Color 05	56.58	64.00	74.01	60.46	23.06	80.00
	Color 06	42.32	49.00	57.68	60.46	23.06	70.00
	Color 07	29.97	36.00	43.53	60.46	23.06	60.00
	Color 08	50.60	64.00	83.21	60.46	60.00	80.00
Figure 6	Color 01	59.99	64.00	49.68	12.00	20.00	80.00
	Color 02	45.73	49.00	33.35	12.00	20.00	70.00
	Color 03	33.38	36.00	19.19	12.00	20.00	60.00
	Color 04	58.31	64.00	9.67	12.00	60.00	80.00
	Color 05	53.16	64.00	49.98	72.01	18.19	80.00
	Color 06	38.90	49.00	33.65	72.01	18.19	70.00
	Color 07	26.54	36.00	19.49	72.01	18.19	60.00
	Color 08	37.81	64.00	10.57	72.01	54.56	80.00

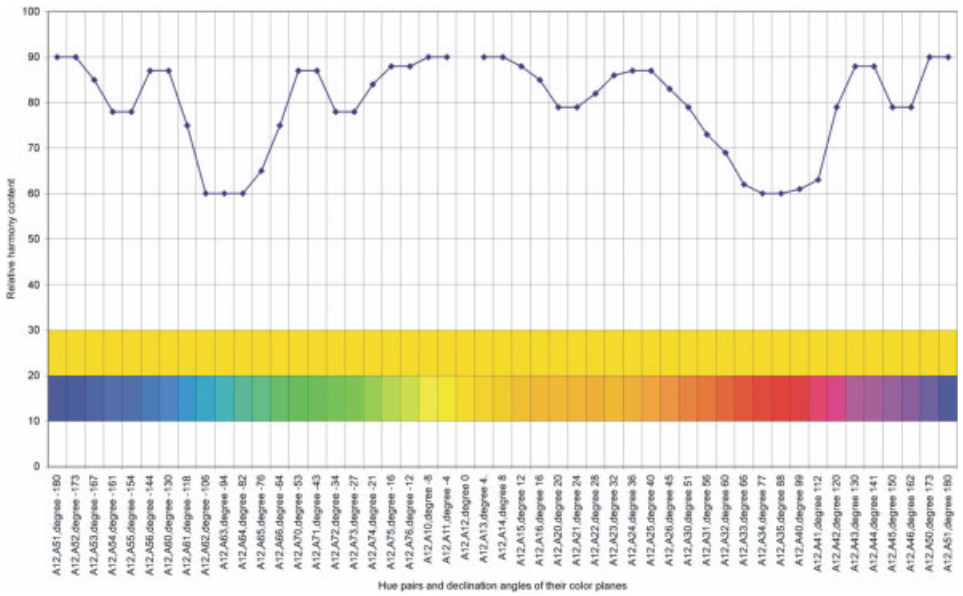

FIG. 7. Harmony content of hue pairs composed of Coloroid hue *A*12 and hues with different relative declinations.

started in 1982, there were approximately equal numbers of male and female participants. In the experiments, started in 2002, the majority of participants were men and a significant number were artists. Because the answers of men and women did not show appreciable differences, the results have been averaged. Because of the small differences in the answers from the former results and the results collected 20 years later, these results have also been averaged. The standard deviation of the answers fell between 4 and 13%. The answers have shown the highest standard deviation for the compositions made with hues declining from Coloroid hue *A*12 both in positive and negative directions by 80°–90°. The least standard deviation has been experienced at assessing the harmony

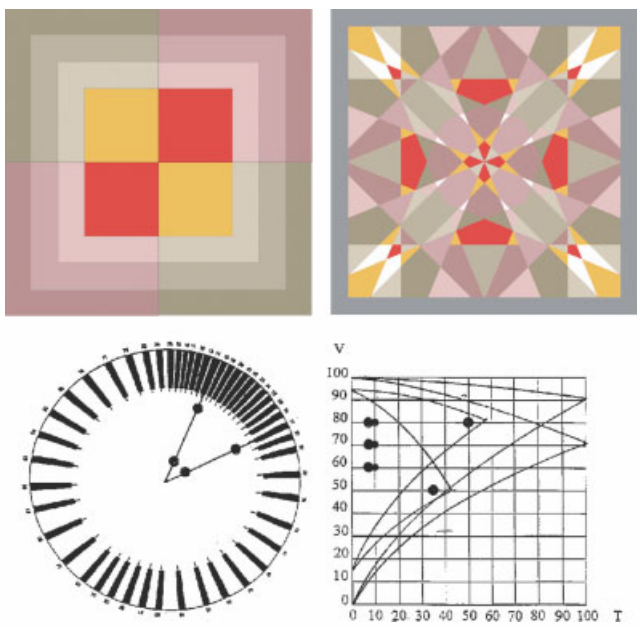

FIG. 8. Two compositions constructed of four colors each of hue pair *A*31-*A*14, painted on paper (left) and computer generated (right). The Coloroid diagram on the left under the compositions shows the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

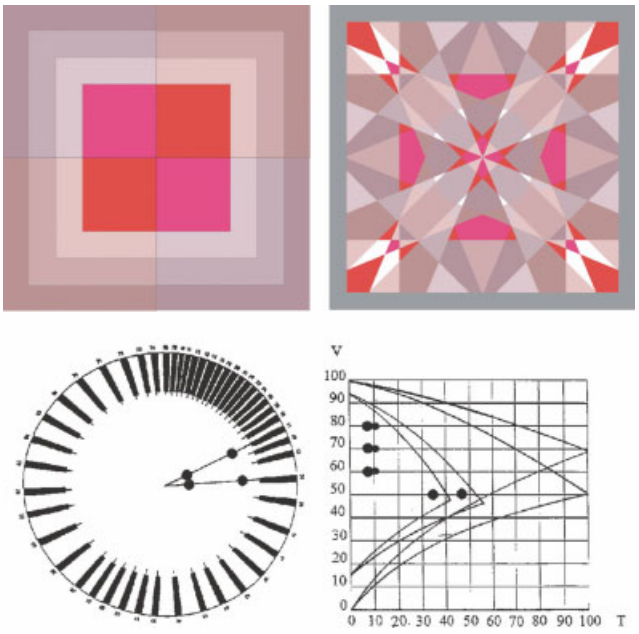

FIG. 9. Two compositions constructed of four colors each of hue pair *A*31-*A*34, painted on paper (left) and generated by computer (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

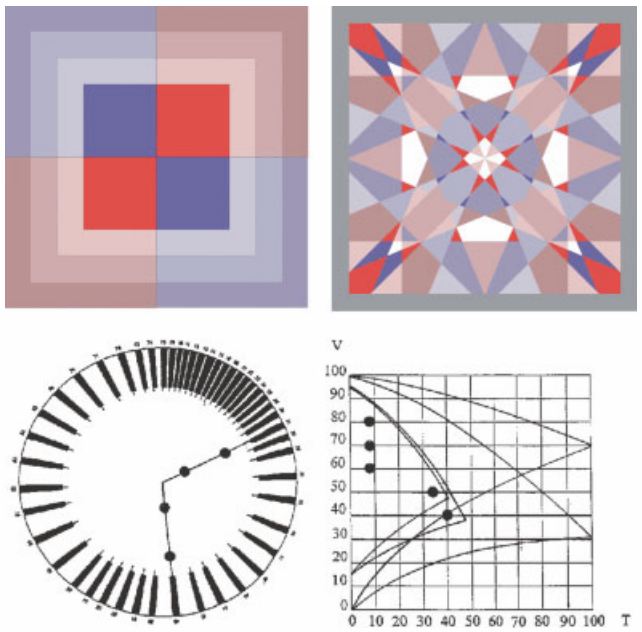

FIG. 10. Two compositions constructed of four colors each of hue pair *A*31-*A*46, painted on paper (left) and computer generated (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two coloroid color planes.

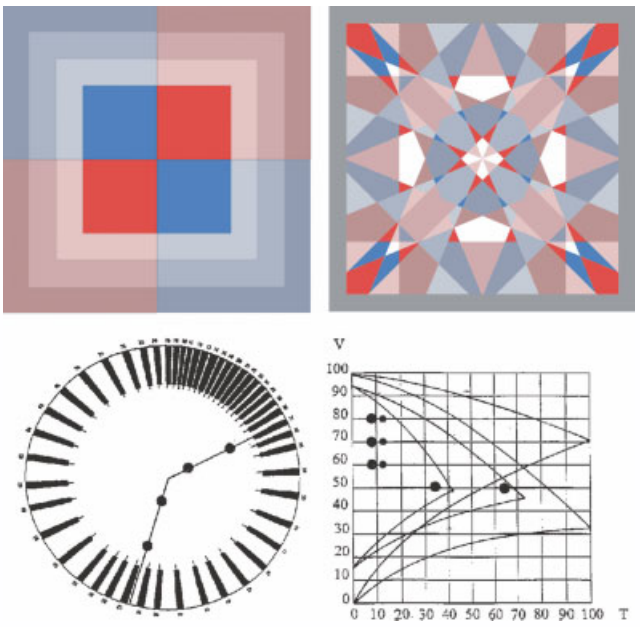

FIG. 11. Two compositions constructed of four colors each of hue pair *A*31-*A*51, painted on paper (left) and generated by computer (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

TABLE III. CIE color components and Coloroid coordinates of colors used in the compositions in Figures 8, 9, 10, and 11.

Compositions		CIE			Coloroid		
		X	*Y*	*Z*	*A*	*T*	*V*
Figure 8	Color 01	65.35	64.00	64.98	31.00	8.62	80.00
	Color 02	51.10	49.00	48.65	31.00	8.62	70.00
	Color 03	38.74	36.00	34.50	31.00	8.62	60.00
	Color 04	41.85	25.00	8.41	31.00	34.48	50.00
	Color 05	61.36	64.00	60.07	14.47	10.00	80.00
	Color 06	47.11	49.00	43.73	14.47	10.00	70.00
	Color 07	34.75	36.00	29.58	14.47	10.00	60.00
	Color 08	63.49	64.00	21.59	14.47	50.00	80.00
Figure 9	Color 01	65.35	64.00	64.98	31.00	8.62	80.00
	Color 02	51.10	49.00	48.65	31.00	8.62	70.00
	Color 03	38.74	36.00	34.50	31.00	8.62	60.00
	Color 04	41.85	25.00	8.41	31.00	34.48	50.00
	Color 05	64.88	64.00	70.60	34.88	9.77	80.00
	Color 06	50.63	49.00	54.27	34.88	9.77	70.00
	Color 07	38.27	36.00	40.12	34.88	9.77	60.00
	Color 08	44.03	25.00	31.81	34.88	48.84	50.00
Figure 10	Color 01	65.35	64.00	64.98	31.00	8.62	80.00
	Color 02	51.10	49.00	48.65	31.00	8.62	70.00
	Color 03	38.74	36.00	34.50	31.00	8.62	60.00
	Color 04	41.85	25.00	8.41	31.00	34.48	50.00
	Color 05	63.30	64.00	83.22	46.89	8.12	80.00
	Color 06	49.04	49.00	66.88	46.89	8.12	70.00
	Color 07	36.69	36.00	52.73	46.89	8.12	60.00
	Color 08	27.57	16.00	85.08	46.89	40.58	40.00
Figure 11	Color 01	65.35	64.00	64.98	31.00	8.62	80.00
	Color 02	51.10	49.00	48.65	31.00	8.62	70.00
	Color 03	38.74	36.00	34.50	31.00	8.62	60.00
	Color 04	41.85	25.00	8.41	31.00	34.48	50.00
	Color 05	61.32	64.00	80.23	51.80	11.10	80.00
	Color 06	47.06	49.00	63.90	51.80	11.10	70.00
	Color 07	34.70	36.00	49.75	51.80	11.10	60.00
	Color 08	26.67	25.00	90.52	51.80	66.57	50.00

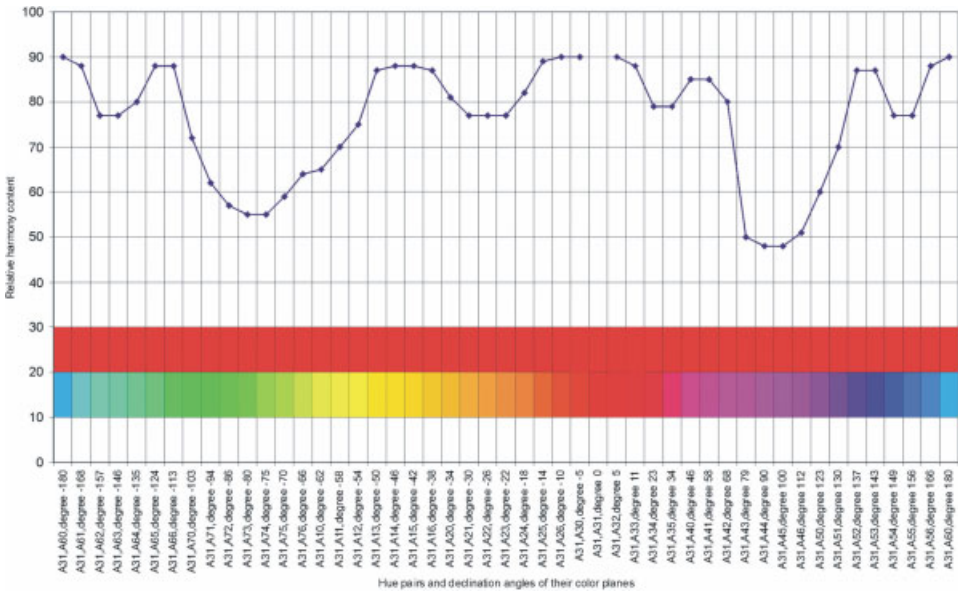

FIG. 12. Harmony content of hue pairs composed of Coloroid hue *A*31 and hues with different degree of declinations.

content of complementary hue pairs. The results also satisfied the significance criteria for every subsection of the experiment.

The graph of Fig. 7 illustrates the harmony content of pairs of Coloroid basic hue *A*12 with other basic hues. The graph is located above the colors of color circle projected onto a plane from the cut at the complement of the coloroid hue marked *A*12. It is possible to read from the diagram, that those colors forming compositions of high harmony content with the *A*12 warm yellow color are close within 10°. These are the near-yellow colors. Alternatively, there are those representing the colors within 30°–40°, left and right from *A*12, namely the yellowish-green and reddish colors. Adding to those are the ones

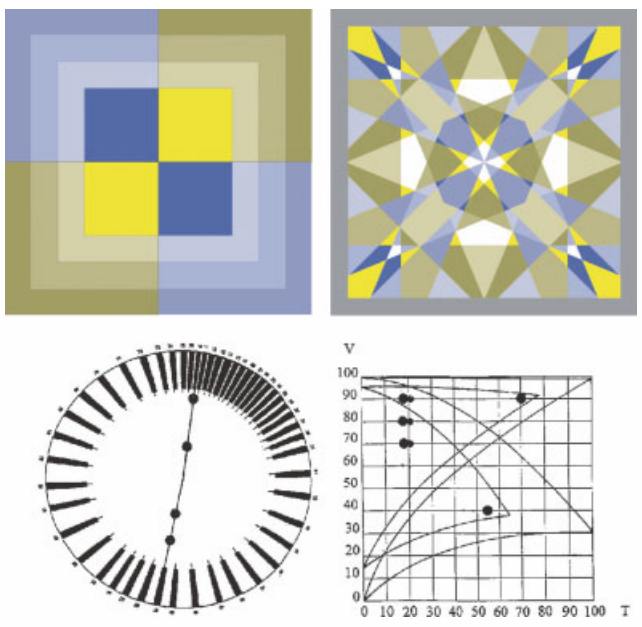

FIG. 13. Two compositions constructed of four colors each of hue pair *A*51-*A*10, painted on paper (left) and generated by computer (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

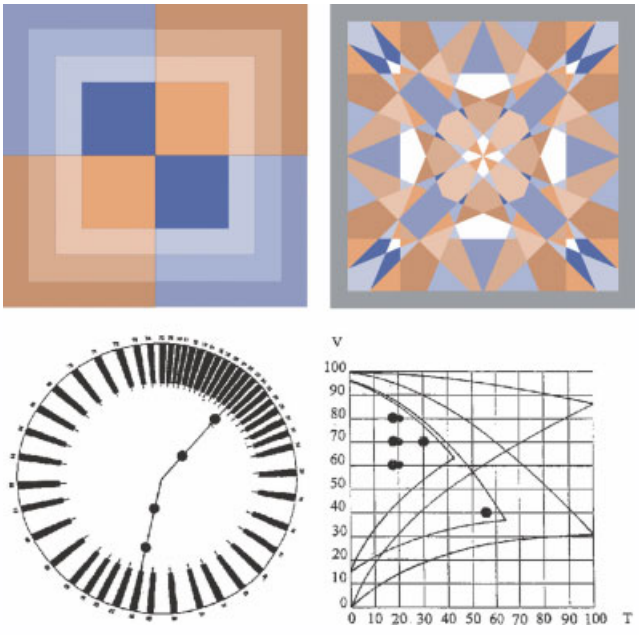

FIG. 14. Two compositions constructed of four colors each of hue pair *A*51-*A*21, painted on paper (left) and generated by computer (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

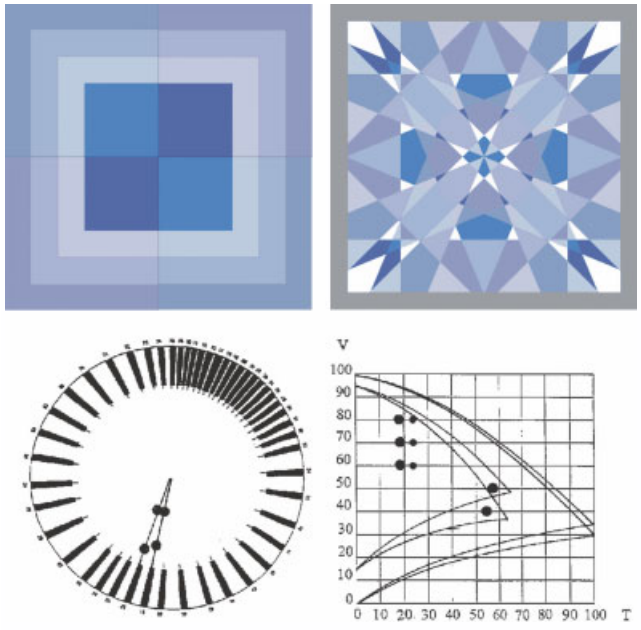

FIG. 15. Two compositions constructed of four colors each of hue pair *A*51-*A*52, painted on paper (left) and generated by computer (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

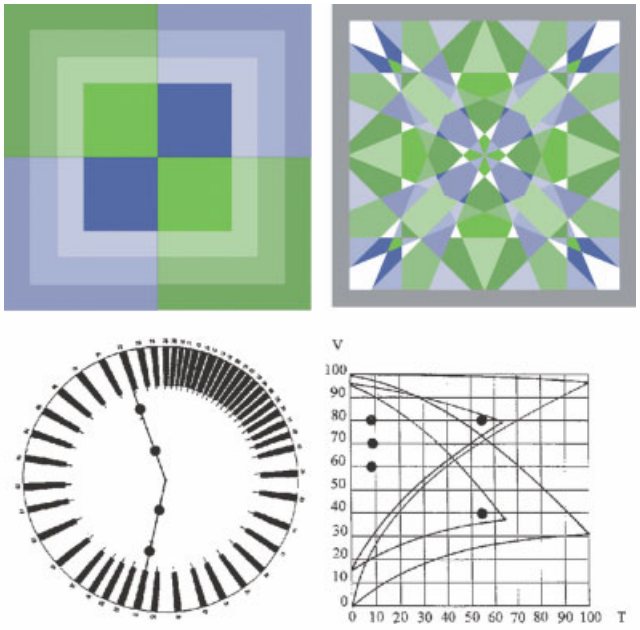

FIG. 16. Two compositions constructed of four colors each of hue pair *A*51-*A*72, painted on paper (left) and generated by computer (right). The Coloroid diagram on the left under the compositions demonstrates the degree of declination between color planes of the two hues in the color space. The figure on the right shows the superimposed picture of the two Coloroid color planes.

TABLE IV. CIE color components and Coloroid coordinates of colors used in the compositions in Figures 13, 14, 15, and 16.

Compositions		CIE			Coloroid		
		X	*Y*	*Z*	*A*	*T*	*V*
Figure 13	Color 01	63.14	64.00	92.37	51.00	18.02	80.00
	Color 02	48.88	49.00	76.04	51.00	18.02	70.00
	Color 03	36.52	36.00	61.88	51.00	18.02	60.00
	Color 04	22.13	16.00	85.48	51.00	54.05	40.00
	Color 05	58.75	64.00	49.24	10.48	20.00	80.00
	Color 06	44.50	49.00	32.91	10.48	20.00	70.00
	Color 07	32.14	36.00	18.76	10.48	20.00	60.00
	Color 08	69.72	81.00	16.65	10.48	70.00	90.00
Figure 14	Color 01	63.14	64.00	92.37	51.00	18.02	80.00
	Color 02	48.88	49.00	76.04	51.00	18.02	70.00
	Color 03	36.52	36.00	61.88	51.00	18.02	60.00
	Color 04	20.98	16.00	74.14	51.00	45.05	40.00
	Color 05	65.41	64.00	52.24	21.90	20.00	80.00
	Color 06	51.15	49.00	35.91	21.90	20.00	70.00
	Color 07	38.80	36.00	21.75	21.90	20.00	60.00
	Color 08	53.44	49.00	27.19	21.90	30.00	70.00
Figure 15	Color 01	63.14	64.00	92.37	51.00	18.02	80.00
	Color 02	48.88	49.00	76.04	51.00	18.02	70.00
	Color 03	36.52	36.00	61.88	51.00	18.02	60.00
	Color 04	22.13	16.00	85.48	51.00	54.05	40.00
	Color 05	61.50	64.00	90.74	52.00	23.53	80.00
	Color 06	47.24	49.00	74.41	52.00	23.53	70.00
	Color 07	34.88	36.00	60.26	52.00	23.53	60.00
	Color 10	25.43	25.00	79.86	52.00	58.82	50.00
Figure 16	Color 01	63.14	64.00	92.37	51.00	18.02	80.00
	Color 02	48.88	49.00	76.04	51.00	18.02	70.00
	Color 03	36.52	36.00	61.88	51.00	18.02	60.00
	Color 04	22.13	16.00	85.48	51.00	54.05	40.00
	Color 05	52.81	64.00	50.13	71.81	18.06	80.00
	Color 06	38.55	49.00	33.80	71.81	18.06	70.00
	Color 07	26.20	36.00	19.64	71.81	18.06	60.00
	Color 08	36.77	64.00	11.02	71.81	54.17	80.00

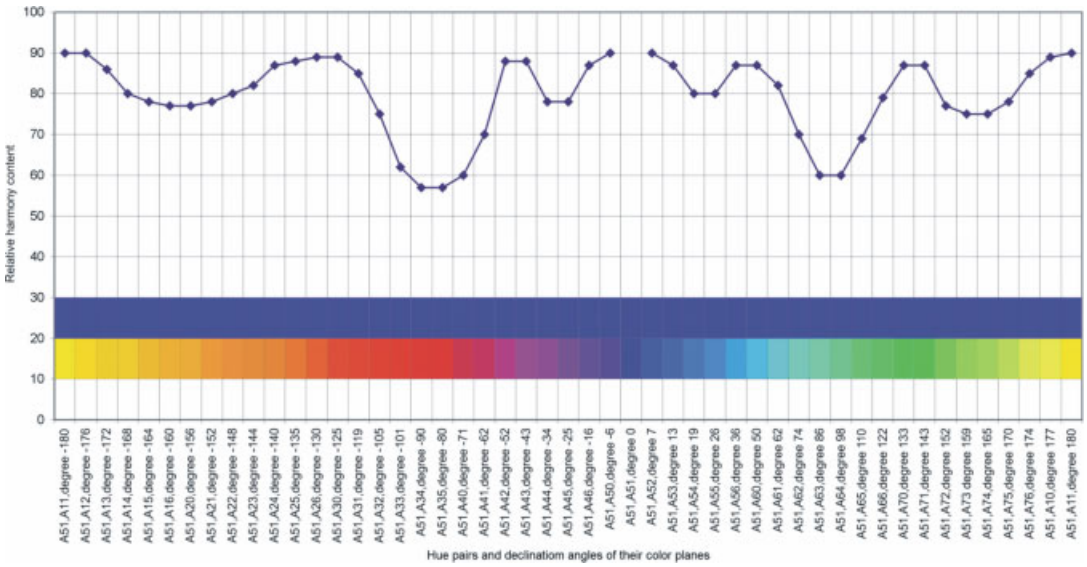

FIG. 17. Harmony content of the hue pairs composed of Coloroid hue *A*51 and hues with different angle of declinations.

with inclination of 130°–149°, namely the bluish-green and violet and finally, the complementing colors of the starting color and those bluish colors in its vicinity. The least harmonic compositions, formed with the *A*12 hue are those with hues declining between 70° and 90°, namely medium greens and magentas.

Figs. 8–11 show the compositions made of hue pairs *A*31-*A*14, *A*31-*A*35, *A*31-*A*46, and *A*31-*A*52, respectively, and demonstrate their locations in the color space of colors and the colors of the composition explained by the Coloroid diagram. The CIE color components (*XYZ*) and Coloroid coordinates (*ATV*) of the colors in the compositions are shown in Table III.

The graph in Fig. 12 illustrates the harmony content of pairs of the Coloroid basic hue *A*31 with other basic hues. The curve is located above the colors of the color circle projected onto a plane from the cut at the complement of the coloroid hue marked *A*31.

It can be read from the graph that compositions of high harmony content created with the red *A*31 color are firstly those in the vicinity of this color, within 10° to the right and to the left, namely the reddish colors. Secondly there are those representing hues within 30°–40° from *A*31, namely warm yellow and purple hues. Thirdly are those with 130°–140° inclination from the initial color, namely cold green and warm blue colors. Finally there are the complementing colors of the initial color. The least harmonic compositions are formed by those inclining by 70°–90° from the initial color, namely the yellowish-green, greenish-yellow, and the magenta-bluish colors.

Figs. 13–16 show the compositions made of hue pairs *A*51-*A*10, *A*51-*A*21, *A*51-*A*52, and *A*51-*A*72, respectively, and demonstrate the location in the color space of colors of the compositions, explained by the Coloroid diagram. CIE color components (*XYZ*) and Coloroid coordinates (*ATV*) of colors in the compositions made with Coloroid basic *A*51 hue are shown in Table IV.

The graph in Fig. 17 illustrates the harmony content of the pairs formed by the basic hue noted as A51 and other basic hues. The graph is located above the colors of color circle projected onto a plane from the cut at the complement of the coloroid hue marked *A*51. It can be read from the graph that the compositions formed by the blue color marked *A*51 with other hues, lie firstly within 10° right and left from the color, namely the near blue; secondly the ones representing the hues within 30°–40° inclination from *A*51 left and right, namely magentas and the cold blue; thirdly those within 130°–140° inclination from *A*51, namely the mid-green and the orange–red and finally comes the complementing color of the original color and near-yellows. The least harmonic compositions formed with *A*51 by the hues with declination between 70° and 90°, namely magentas and cold green.

In summary, it has been established that harmony content of the hue pairs can be represented in the Coloroid color space with the degrees of declination between the hue planes. It has been found also that the most harmony content exhibited by those hue pairs, which have the relative declination either less than 10° or falls between 30° and 40°, 130° and 140°, or lie in the vicinity of 180°. Least harmony content is exhibited by those hue pairs, which have the declination of hue planes in Coloroid color system between 70° and 90°. Our conclusions are related not only to the demonstrated samples but also to all investigated hue pairs.

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