Experimental Determination of Laws of Color Harmony. Part 6: Numerical Index System of Color Harmony

Antal Nemcsics*

Department of Architecture, Budapest University of Technology and Economics, 3. Műegyetem rakpart, H 1111 Budapest, Hungary

Received 30 January 2010; revised 16 January 2011; accepted 21 January 2011

Abstract: The numerical index system of color harmony is intended to mark a great number of color pairs, optimally any number of existing color pairs, by a number between 0 and 100. This number expresses the extent to which a color pair is being felt harmonious by the average of people and the level of harmony content it possesses. The experiments described in this article have determined the basic data necessary to create this system. The series of the experiments have been done in two stages. The first stage, in which 24 test objects were presented to the experimental subjects, was carried out twice first in 1988–1990 and again in 2004–2006. Every test set was composed of eight compositions. The number of scores, given to each of the compositions, determined the harmony content of the color pair groups, whose members are formed from the saturated colors of different hues and from the members of the grey scale. In the second stage of the experiment, these data served as references for the experimental subjects. In the second stage, there were 192 tests. In these tests, there were different numbers of compositions each formed of different color pairs. One of the members of these color pairs was the member of the saturated color of the first experiment. The second member was always of different saturation and lightness for each of the compositions, purposefully chosen to match the saturated colors. Based on the experimental scores, we obtained a color harmony surface linked to the intersections with the coordinates in the Coloroid system. The color harmony surfaces and the distances between the related intersections indicate the harmony content of the color pair. The numerical values of these distances are called the color harmony index number of the color pair. These data make the creation of a color harmony indexing system possible, expressing the color harmony content of all possible color pairs, in the color space.

Col Res Appl, 37, 343 – 358, 2012; Published online 12 September 2011 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.20700

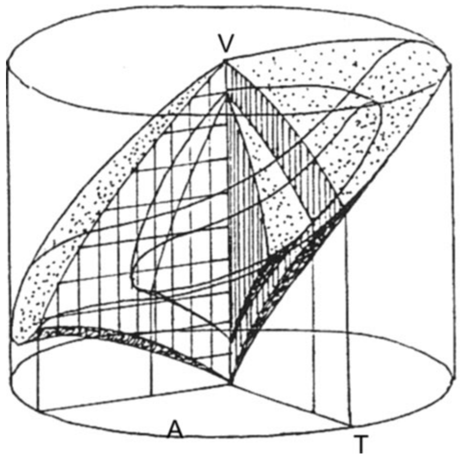
Key words: color harmony; color composition; color science; color theory; Coloroid color system; experimental color harmony; theory of color harmony

INTRODUCTION

People, working with colors in a creative fashion, often get into a difficult position when they have to choose between two or more color pairs. They have difficulty deciding which of the pair gives the more harmonious impression. There is no information in the literature on color pairs of low harmony content. So far, the literature has concentrated on the listing of those with significant harmony. The theoretical treatments are also related only to this latest category.[1–35] Our earlier publications are also related only to the harmony relations between the various regions of the color space rather than to particular color pairs.[36–48]

The totality of the laws, correlating our color sensation with harmony pairs, represents the essence of the harmony concept. Judged by the grade of generalization, the harmony content has three levels, built on the top of each other. The first level relates closely to the color perception. This covers the relations, identical to almost all humans, because they depend only on the process of color perception and can be interpreted by psychophysical relations. The second level represents the effect of the perceived color pairs on the subject's psyche. At this level, the formation of the judgement was influenced by the subject's psychic, somatic attributes as well as characteristic properties determined by age, culture, and social standing. The third level represents the complex interaction between the color, the human subject and his

*Correspondence to: Antal Nemcsics (e-mail: nemcsics.antal@t-online.hu).



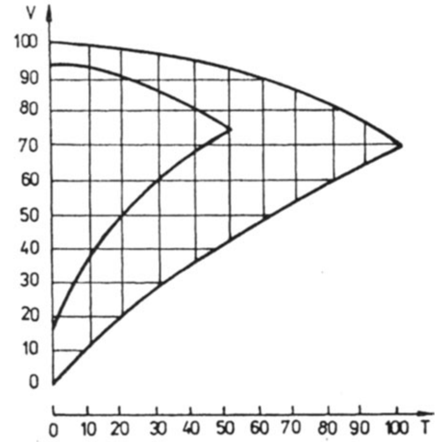


FIG. 1. Spatial model of Coloroid and one axis intersection. All colors of an axis intersection possess the same Coloroid hue (*A*). The vertical lines of an axis intersection bear color of the same Coloroid saturation (*T*). The horizontal lines of the intersections bear colors of the same Coloroid lightness (*V*). The border lines of the axis intersection are colors cut out of the Coloroid color space; the inner curved lines are simply bordering lines of surface colors. The colors of our experiments lie on surfaces embedded between the axis bearing the grey colors and the inner curved lines.

surrounding. The judgement representing the harmony perception depends on the surroundings, i.e., illumination, structure, material as well as the location in space, and the intended function or application.[49–51]

In this article, we intend to deal with the first level of the harmony content. Here, magnitude of the harmony content was determined by the hue of the color pair's color, its saturation level, and its lightness. The collection of the color perception attributes, which can be extended to the harmony content of all perceptible colors, forms as yet an imaginary system. This collection forms the color harmony index system. This article defines the founding data, required for the preparation of the creation of such indexing system for color harmony.

HARMONY INDEX

The color harmony index is intended to mark a great number of color pairs—optimal case: any number of existing color pairs—by a number between 0 and 100. This number expresses the extent to which the color pair is being felt harmonious by the average of people and the level of harmony content it possesses. The number of perceptible color pairs is very high, and it approaches infinity. Therefore, the numeric system of color harmony has been connected to the Coloroid color system being capable of denoting each perceptible color.

The Coloroid color system[52–58] is based on surface colors, illuminated by daylight and harmonious color differences as perceived by people with normal vision. The Coloroid locates the colors inside a straight symmetrical cylinder. Colors with identical Coloroid hues and identical dominant wavelength are positioned on the intersections with the axis (Fig. 1). The Coloroid hue is marked with A. The axis shows the grey colors, the vertical right lines of axis intersections show colors of identical Coloroid hues (T), and the horizontal right lines of axis intersections show colors of identical Coloroid lightnesses (*V*).

Let us allocate to every color of the axis intersection, another color of totally different hue. We have to assume that the harmony contents of the so created color pairs are also different. The visual representation of these differences can be made by introducing perpendicular lines, whose length is proportional to the harmony content, at points containing color pairs of the axis intersection selected at the start (Fig. 2). The higher harmony content is represented by a longer line whilst the shorter perpen-

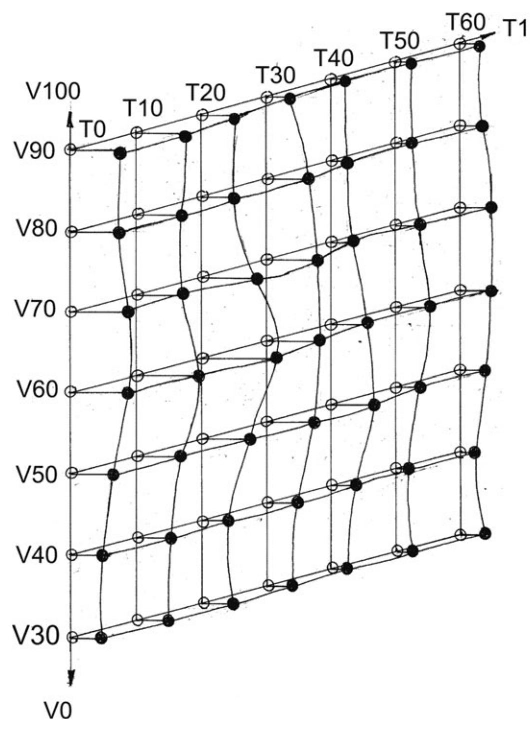


FIG. 2. Harmony surface over one of the Coloroid axial intersections.

dicular line corresponds to a lower harmony content. When the harmony content of the neighbouring color pairs do not differ much, then the warped surface formed by the end points of these lines is continuous. This surface is called the color harmony surface.

In the next step of the experiment, we next take the colors of the given Coloroid axis intersection and allocate to each one a color of other, further hues of the color space to create color pairs. Then even for them the color harmony surfaces are created. Repeating this operation for all the fundamental hues of the Coloroid, we arrive to 47 color harmony surfaces. Next we select another axis intersection and repeat the procedure with all the 48 axis intersections, which result in 1128 color harmony surfaces.

The next target of investigation was, with which distribution in the color space and how many harmony surfaces or surface parts need to be defined experimentally as basic data to enable creation of the color harmony index number system. To reduce the number of harmony surfaces in this experiment, only 24 Coloroid axis intersections were used to provide a saturated color as the first color of the pairs. The experimental results from an earlier experiment[47] were used to select the second color to form the color pairs. This earlier experiment found a correlation between the color preference of the experimental subjects to a particular color group and the degree of harmony experienced by the same color group. Therefore, for our experiment, only a small number of colors were selected from regions where color preference shows only minor changes in function of hue, whereas a large number of colors were selected from regions where color preference shows major changes.

We have found that, for the sake of this experiment, 192 experimentally determined color harmony surfaces, uniformly distributed in the color space, will satisfy this requirement. These harmony surfaces belong to eight axis intersections of the color space, for each of 24 Coloroid color spaces.

EXPERIMENTS

In our experiments, we applied the classifying system of psychology.[59] During the experiments, compositions were presented to the experimental subjects. These compositions had to be placed by them, on the psychometric scale with a defined starting and end value, according to their harmony content. The large scatter in a judgements, due to subjectivity, had to be reduced to possible minimum. To achieve this aim, we carried out a pre-experiment with volunteers from the group of the experimental candidates to select the possible experimental subjects. First, between two compositions one with very low harmony and the other with high harmony content as the two outside limits, we placed three compositions. The candidates had to select from the three, one that according to their view represents the half way between the harmony content of the two end compositions. The experiment was repeated three times on three consecutive days. We selected those from the candidates whose choice fell at least within the 95% limit.

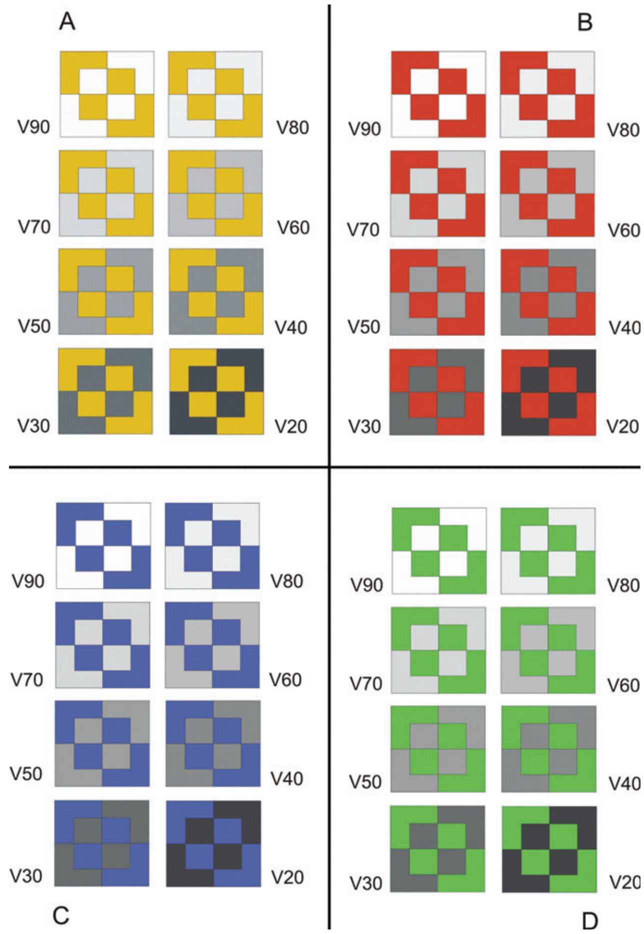


FIG. 3. The four tests of phase 1 of the experiments. (A) In the order of introduction: (A) Test 3, where the saturated color has the code 14-50-70; (B) test 8, where the saturated color has the code 30-30-50; (C) Test 15, where the saturated color has the code 51-30-40; (D) test 21, where the saturated color has the code 14-50-70.

The rest of the experiment was carried out in two phases. In the first stage, we selected 24 Coloroid axial intersections and investigated the harmony content of the color pairs, formed by various hues of one particular saturated color and the members of the grey scale with different lightness. This experiment was carried out between 1998 and 1990 for the first time and repeated again between 2004 and 2006. The experimental circumstances and the selection of the tests presented to the experimental subjects were the same. Each of the 24 tests was made of eight compositions. The compositions, measuring 18×18 cm^2, placed in two columns, in easily exchangeable form, on 52×96 cm^2 birch plates in vertical position, were presented to the experimental subjects (Fig. 3). Every composition was made of a grey and a saturated color. The lightness of the grey color was reduced step by step on every test chart in the order of the compositions (Table I). The second color of the compositions was the same on every test chart, but they differed from test chart

TABLE I. The chromatic details of the grey colors in the test compositions of the first stage of the experiment.

	COLOROID			CIE			MUNSELL			
	A	*T*	*V*	*X*	*Y*	*Z*	*H*	*V*	*C*	*d* (%)
1.	10.00	0.01	90.00	76.98	81.00	88.14	5.0G	9.00	2.00	8.61
2.	10.00	0.01	80.00	60.83	64.00	69.67	7.5G	8.00	2.00	8.61
3.	10.00	0.01	70.00	46.57	48.00	53.34	5.0G	7.00	2.00	8.86
4.	10.00	0.01	60.00	34.22	36.00	38.19	10.0G	6.00	2.00	9.30
5.	10.00	0.01	50.00	23.76	25.00	27.21	10.0G	6.00	2.00	9.17
6.	10.00	0.01	40.00	15.21	16.00	17.41	5.0G	5.00	2.00	8.91
7.	10.00	0.01	30.00	8.55	9.00	9.79	5.0G	3.00	2.00	8.85
8.	10.00	0.01	20.00	3.80	4.00	4.34	2.5G	2.00	2.00	6.79

The columns of the table contain Coloroid coordinates (*A*, *T*, *V*), CIE color components (*X*, *Y*, *Z*), and Munsell color codes (*H*, *V*, *C*), respectively. Munsell color codes are always codes of a color appearing in the Munsell Atlas, being nearest to the color of the composition. The last column (*d*) shows the relative difference between the Munsell color and the current Coloroid color expressed in percentage.

to test chart (Table II). The test compositions of the earlier experiment have been prepared by collage technique, whilst the later ones by a computer-controlled printer. The color details of these compositions were checked by spectrophotometers. Whenever it was necessary, the compositions were remade.

The columns of Tables I, II, IV–VII contain Coloroid coordinates (A, T, V), CIE color components (X, Y, Z), and Munsell color codes (H, V, C), respectively. Munsell color codes are always codes of a color appearing in the Munsell Atlas, being nearest to the color of the composition. The last column (d) shows the relative difference between the Munsell color and the current Coloroid color expressed in percentage.

The subjects of the experiment carried out between 1988 and 1990 were (50% male and 50% female) undergraduates between the age of 18 and 24, of the Department of Architecture, Budapest University of Technology and Economics, whilst the participants of the second experiment between 2004 and 2006 were painters, textile designers, and printers between the age of 30 and 50 (with the same distribution of male and female, 50% each). The experiments were carried out in a room lit by reflected light from the northern sky, near to the window where the illumination was between 1600 and 1800 lux. The birch plates carrying the compositions were placed in vertical position. The tests were surrounded by grey surfaces with $Y = 30$ CIE color component. The tests were

TABLE II. The chromatic details of the staurated colors in the test compositions of the first stage of the experiment.

	COLOROID			CIE			MUNSELL			
	A	*T*	*V*	*X*	*Y*	*Z*	*H*	*V*	*C*	*d* (%)
1.	10.00	50.00	80.00	54.64	64.00	18.26	2.5GY	8.00	10.00	7.79
2.	12.00	50.00	80.00	58.72	64.00	19.67	7.5Y	8.00	8.00	4.36
3.	14.00	40.00	70.00	48.00	49.00	14.57	5.0Y	7.00	8.00	5.01
4.	16.00	40.00	70.00	51.03	49.00	15.34	10.0YR	7.00	8.00	5.86
5.	21.00	40.00	70.00	54.20	49.00	17.59	7.5YR	7.00	8.00	6.94
6.	23.00	30.00	60.00	42.53	36.00	13.92	5.0YR	6.00	8.00	5.77
7.	25.00	30.00	60.00	45.61	36.00	16.11	10.0R	6.00	10.00	6.30
8.	30.00	30.00	50.00	38.45	25.00	7.77	7.5R	6.00	14.00	6.54
9.	32.00	30.00	50.00	37.15	25.00	16.74	5.0R	6.00	12.00	6.44
10.	34.00	30.00	50.00	36.50	25.00	26.02	7.5RP	6.00	10.00	6.55
11.	40.00	40.00	50.00	39.96	25.00	36.81	5.0RP	6.00	14.00	6.19
12.	42.00	40.00	50.00	39.28	25.00	46.49	2.5RP	6.00	14.00	5.98
13.	44.00	40.00	50.00	38.49	25.00	57.65	7.5P	6.00	14.00	5.61
14.	46.00	30.00	40.00	25.15	16.00	55.94	2.5P	5.00	16.00	6.59
15.	51.00	30.00	40.00	19.05	16.00	55.19	7.5PB	5.00	12.00	4.73
16.	53.00	50.00	50.00	22.42	25.00	62.03	10.0B	6.00	10.00	6.39
17.	55.00	50.00	60.00	29.52	36.00	62.30	5.0B	6.00	6.00	5.51
18.	60.00	60.00	60.00	23.99	36.00	52.72	7.5BG	7.00	10.0	6.39
19.	62.00	50.00	60.00	22.47	36.00	42.34	2.5BG	6.00	10.00	5.00
20.	64.00	40.00	70.00	32.74	49.00	46.93	7.5G	7.00	8.00	6.64
21.	66.00	20.00	60.00	21.92	36.00	25.11	2.5G	5.00	10.00	6.09
22.	71.00	30.00	70.00	30.49	49.00	21.30	10.0GY	7.00	12.00	6.68
23.	73.00	40.00	70.00	33.08	49.00	10.24	7.5GY	7.00	12.00	5.87
24.	75.00	50.00	80.00	50.14	64.00	16.99	5.0GY	8.00	10.00	3.31

The columns of the table contain Coloroid coordinates (*A*, *T*, *V*), CIE color components (*X*, *Y*, *Z*), and Munsell color codes (*H*, *V*, *C*), respectively. Munsell color codes are always codes of a color appearing in the Munsell Atlas, being nearest to the color of the composition. The last column (*d*) shows the relative difference between the Munsell color and the current Coloroid color expressed in percentage.

TABLE III. The hues of the colors used for the test compositions in the second stage of the experiment.

Serial number of tests	The first color of compositions, Comp. 1 to 8	Coloroid hue and characteristc wavelength of the second color in compositions							
		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
1–8	10–50–80	A14 577.50 nm	A23 588.59 nm	A32 625.00 nm	A42 (−520.4) nm	A51 492.72 nm	A55 509.12 nm	A64 502.69 nm	A73 560.74 nm
9–16	**12–50–80**	A16 580.95 nm	A25 594.00 nm	A34 (−495.3) nm	**A53** **498.45 nm**	A44 (−548.1) nm	A60 490.40 nm	A66 520.40 nm	A75 566.78 nm
17–24	14–40–70	A10 570.83 nm	A21 584.46 nm	A30 602.72 nm	A40 (−502.7) nm	A46 (−564.2) nm	A53 498.45 nm	A62 495.28 nm	A71 548.11 nm
25–32	16–40–70	A12 574.38 nm	A23 588.59 nm	A32 625.00 nm	A42 (−520.4) nm	A51 492.72 nm	A55 484.29 nm	A64 502.69 nm	A73 560.74 nm
33–40	**21–40–70**	A14 577.50 nm	A25 594.00 nm	A34 (−495.28)	A44 (−548.11)	A53 498.45	A61 492.72	A66 520.40	A75 566.78
41–48	23–30–60	A10 570.83 nm	A16 580.95 nm	A30 602.72 nm	A40 (−502.7) nm	A46 (−564.2) nm	A53 498.4 nm	A62 495.28 nm	A71 548.11 nm
49–56	25–30–60	A12 574.38	A21 584.46	A32 625.00	A42 (−520.4)	A51 492.72	A55 484.29	A64 502.69	A73 560.74
57–64	**30–30–50**	A35 (−498.4) nm	A14 577.50 nm	A66 520.4 nm	A53 479.29 nm	A44 (−548.1) nm	A60 490.4 nm	A23 588.59 nm	A75 566.78 nm
65–72	32–30–50	A40 (−502.7) nm	A46 (−564.2) nm	A71 548.11 nm	A53 498.45 nm	A16 580.95 nm	A62 495.28 nm	A25 594.0 nm	A10 570.83 nm
73–80	34–30–50	A42 (−520.4) nm	A55 484.29 nm	A51 492.72 nm	A64 502.69 nm	A73 560.74 nm	A12 574.38 nm	A21 584.46 nm	A30 602.72 nm
81–88	40–40–50	A44 (−548.1) nm	A53 498.45 nm	A66 520.4 nm	A60 490.4 nm	A23 588.59 nm	A75 566.78 nm	A32 625.00 nm	A14 577.50 nm
89–96	42–40–50	A46 (−564.2) nm	A53 498.45 nm	A71 548.11 nm	A62 495.28 nm	A16 580.95 nm	A10 570.83 nm	A25 594.0 nm	A34 (−495.3) nm
97–104	44–40–50	A51 492.72 nm	A55 484.29 nm	A64 502.69 nm	A73 560.74 nm	A21 584.46 nm	A12 574.38 nm	A30 602.72 nm	A40 (−502.7) nm
105–112	46–30–40	A66 520.4 nm	A53 498.45 nm	A23 588.59 nm	A60 490.4 nm	A32 625.00 nm	A75 566.78 nm	A42 (−520.4) nm	A14 577.50 nm
113–120	51–30–40	A71 548.11 nm	A53 479.29 nm	A16 580.95 nm	A62 495.28 nm	A23 588.59 nm	A10 570.83 nm	A34 (−495.3) nm	A44 (−548.1) nm
121–128	53–50–50	A64 502.69 nm	A55 520.4 nm	A73 560.74 nm	A12 574.38 nm	A21 584.46 nm	A30 602.72 nm	A40 (−502.7) nm	A46 (−564.2) nm
129–136	55–50–60	A66 520.40 nm	A60 490.4 nm	A23 588.59 nm	A75 566.78 nm	A32 625.00 nm	A14 577.50 nm	A42 (−520.4) nm	A51 468.71 nm
137–144	60–60–60	A71 548.11 nm	A62 495.28 nm	A16 580.95 nm	A10 570.83 nm	A25 594.00 nm	A34 (−495.3) nm	A44 (−548.1) nm	A53 498.45 nm
145–152	62–50–60	A66 520.4 nm	A75 566.78 nm	A23 588.59 nm	A14 577.50 nm	A32 625.00 nm	A42 (−520.4) nm	A51 468.71 nm	A55 484.29 nm
153–160	64–40–70	A71 548.11 nm	A10 570.83 nm	A16 580.95 nm	A25 594.00 nm	A34 (−495.3) nm	A53 498.45 nm	A44 (−548.1) nm	A60 490.4 nm
161–168	66–20–60	A73 560.74 nm	A12 574.38 nm	A21 584.46 nm	A30 602.72 nm	A40 (−502.7) nm	A46 (−564.2) nm	A53 498.45 nm	A62 495.28 nm
169–176	71–30–70	A23 588.59 nm	A75 566.78 nm	A32 625.00 nm	A14 577.50 nm	A42 (−520.4) nm	A55 484.29 nm	A51 468.71 nm	A64 502.69 nm
177–184	73–40–70	A16 580.95 nm	A10 570.83 nm	A25 594.00 nm	A34 (−495.3) nm	A44 (−548.1) nm	A53 498.45 nm	A66 520.40 nm	A60 490.40 nm
185–192	**75–55–80**	A21 584.46 nm	A12 574.38 nm	A30 602.72 nm	A40 (−502.7) nm	A46 (−564.2) nm	A35 (−498.5) nm	A71 548.11 nm	A62 495.28 nm

illuminated in 45° and observed in right angle from a distance of 200 cm.

At the beginning of the experiment, the supervisor introduced the test objects to the experimental subjects and explained their tasks. He explained the criteria for the concept of the color harmony perception and described further that the harmony perception of a composition, ignoring its shape and form, is created by the harmony, based on the proportional relations between the saturation and the illumination levels of the colors in the composition. This was followed by the illustrations of harmonious and disharmonious compositions, with shapes and forms different from those used in the experiment. The subjects had 10 min to decide over the harmony content of the compositions. There were 110 participants.

We set the numerical limits for the possible magnitude arbitrarily between 0 and 25. These figures were concluded from an earlier experiment. In the previous experiment, the experimental subjects were 10 painters, five men, and five women. They were given the task to judge the harmony content of 12 compositions selected randomly from compositions used in the second phase of the experiment and grade them between the limits of 0–100 by magnitude. Nobody judged the harmony content of the compositions, which were composed of grey

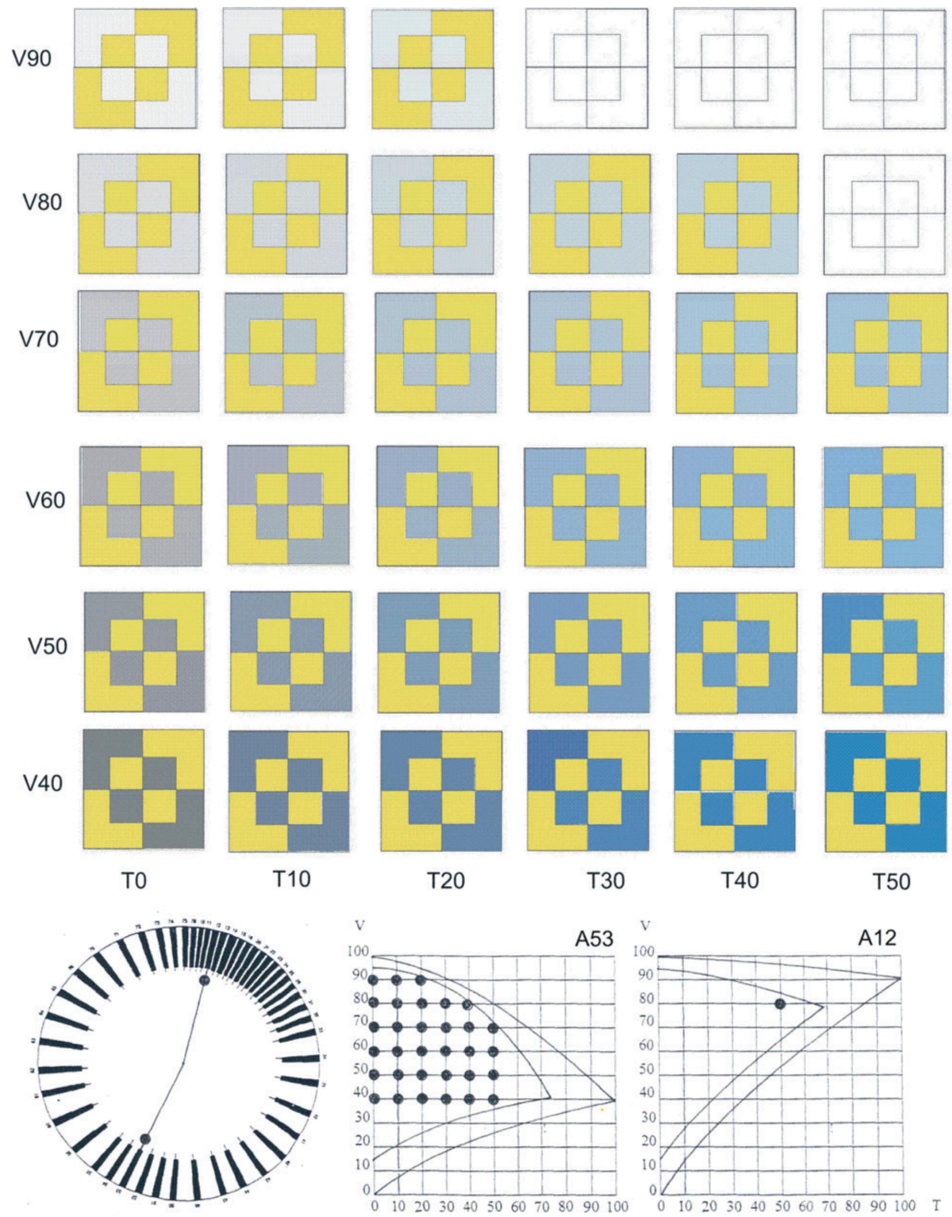


FIG. 4. The 12th test of the second stage of the experiments. The Coloroid coordinates of one of the colors in the composition used in the test are 12-50-80. The second color in the composition is a shade with various saturation and lightness of a hue with A53 Coloroid index.

as one of the colors, with higher grade than 25. Preference was given to the limits of 0–25 because it made the decisions of the experimental subjects easier. The score has to be recorded individually for every test on a form prepared for the purpose. The subjects were divided into groups of 10. Fifty subjects participated on both occasions.

To give an idea to the readers what the visual presentation of the tests were, we have depicted four out of the 24 tests (Fig. 3).

In the second phase of the experiment, we presented 192 tests objects to the experimental subjects. This was only carried out once during the 2006–2008 experiment. These test objects were sets of compositions made on 140 $\times$ 140 cm^2 birch plates. The plates were made out for six off 18 $\times$ 18 cm^2 size compositions. The test variation, for the experimental subjects, consisted of changes of the compositions on the plates. The compositions for each test were made by using color pairs, formed by colors of different lightness and saturation, belonging to an axis intersection and another saturated color of another axis intersection of the Coloroid.

In the two to six columns of the tests, we listed the values of the saturations for the first elements of the composition's color pairs in the following order T10, T20, T30, T40, T50 and also their lightness values in this order V90, V80, V70, V60, V50, V40. Each of the first columns of the tests were made out of the first six

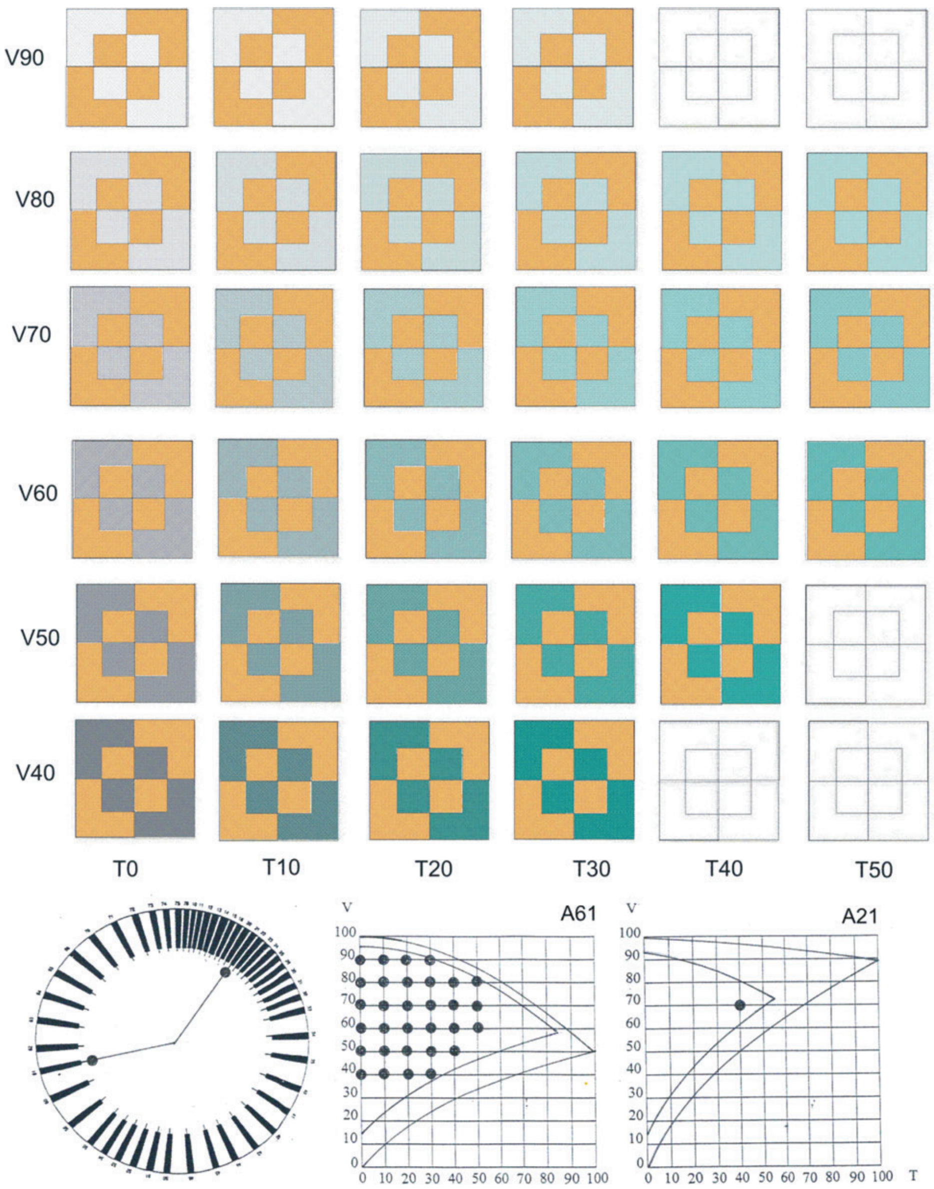


FIG. 5. The 38th test of the second stage of the experiments. The Coloroid coordinates of one of the colors in the composition used in the test are 21-40-70. The second color in the composition is a shade with various saturation and lightness of a hue with A61 Coloroid index.

compositions of appropriate colors forming part of the first stage of the experiment. Depending on the actual axis intersection in the Coloroid, the number of compositions varied. Their number was governed by the size of the color surface (the area enclosed by the border lines) related to that particular axis intersection. In Table III, the hues of the color pairs present in the color pairs used in the 192 test compositions are listed. The details of the color pairs of Figs. 4–7 are highlighted in the table.

The experimental conditions in producing the compositions for the tests in the second phase, the number of the experimental subjects, and the experimental procedure were same as the ones in the first stage of the first experiment, conducted between 2004 and 3006. The forms for the participants and their layout, related to the tests shown in Figs. 4–7, contained 36 places for the data. The first column contained the data of the first stage of the experiment. The subjects had to relate the harmony content of the other color pairs to these data. The score limits were set to 0–100.

Figures 4–7 depict the visual presentation of the tests in the second phase. The chromatic details of colors used in the tests are given in Tables IV–VII.

RESULTS

Preceding the processing of the results from these experiments, we verified the validity and reliability of the collected data. With the help of the root mean square

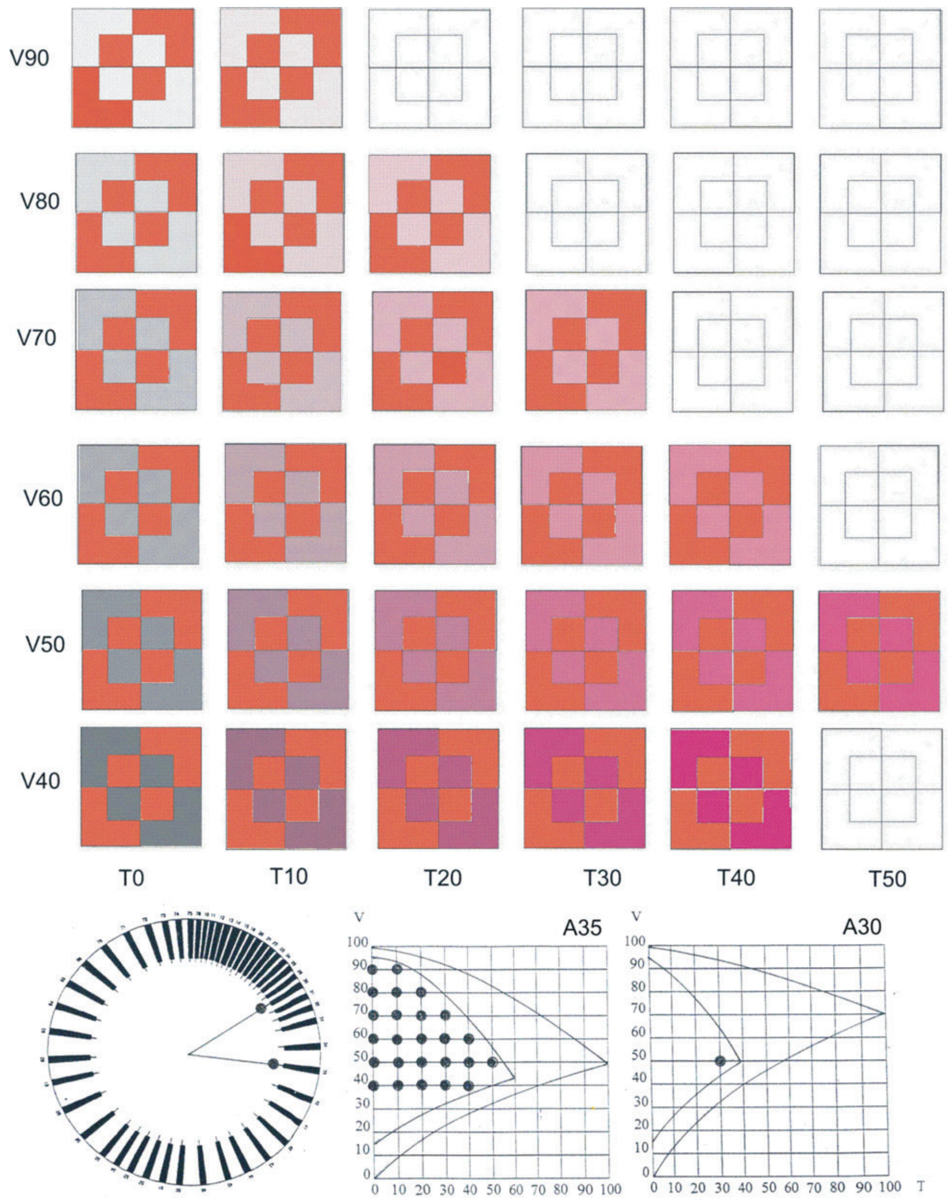


FIG. 6. The 57th test of the second stage of the experiments. The Coloroid coordinates of one of the colors in the composition used in the test are 30-30-50. The second color in the composition is a shade with various saturation and lightness of a hue with A35 Coloroid index.

method,[60] we checked the coincidence of the views of the experimental subjects regarding the harmony content of each and every composition (standard deviation). We have found that the dispersion of the results, with a few exceptions, did not exceed 7%.

The maximum dispersion of the assessed harmony content of different color pairs within the first stage of experiments has been 3.2. More specifically, the dispersion related to 95% of the votes did not exceed the value of 1.5. The characteristics of dispersions are demonstrated with four examples appearing in Fig. 8. The notations of the dispersion diagrams of the figure are as follows: the empty circles indicate single votes and the full black circles denote a bigger (3–15) number of votes. The extent of dispersion of votes judging color pairs containing different greys and colors of different hues was approximately similar. Nevertheless, the density function of the dispersion of votes has been different. Figure 9 shows an example diagram demonstrating the density function of the dispersion of votes given for a grey-green and a grey-red color pair.

The results of the experiments conducted between 2004 and 2006 are demonstrated in Figs. 10–13. The results are mirroring the opinion of 95% of the votes assessing the color pairs. The establishment of data readable from the figure has been made by the method of calculating arithmetic mean values. The sum of deviations from the arithmetic mean value is zero.

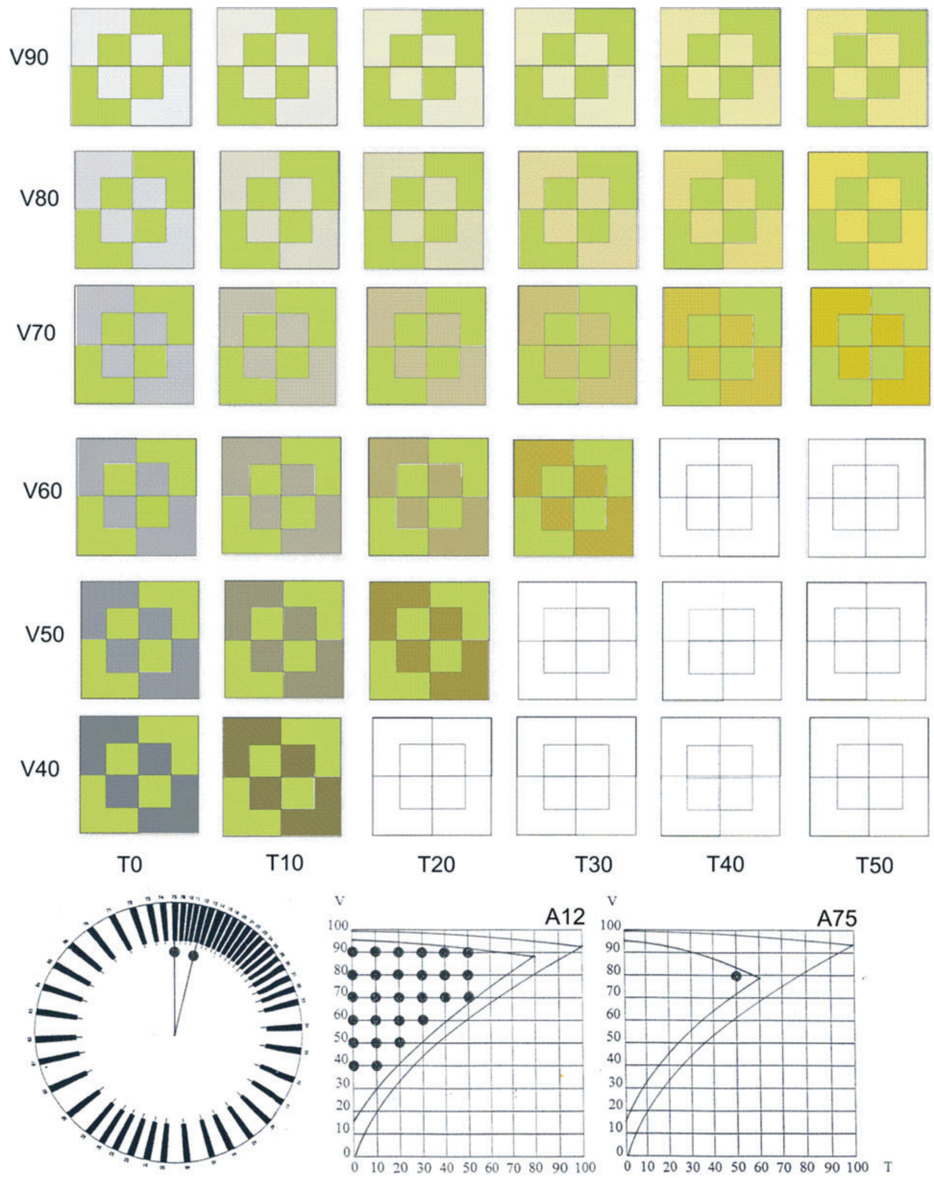


FIG. 7. The 186th test of the second stage of the experiments. The Coloroid coordinates of one of the colors in the composition used in the test are 75-55-80. The second color in the composition is a shade with various saturation and lightness of a hue with A12 Coloroid index.

The results of the experiment conducted between 1988 and 1990 are not included, because the average of the scores given to each of the compositions are only marginally different from the results of the 2004–2006 experiment. The difference between them did not exceed 0.8%. At the same time, however, the dispersion of the scores was larger than that in the later case. Our decision was slightly influenced by the view that the subjects of the first and the second experiment should be selected from the same age and professional group.

From the first experiment, we drew the following conclusions:

- The harmony content of a color pair formed by a color and a grey component depends substantially on the lightness of the grey.
- The harmony content of the color pairs formed with a darker shade of grey is less than the ones formed with lighter grey.
- The harmony content depends also on the hue of the actual colors present. The harmony content of the color pairs formed with yellow color is always greater than the ones formed with blue or green.
- Depending on the hue, the lightness of grey in the color pairs with the highest harmony content falls between V80 and V60.

The second phase of the experiment resulted in 192 color harmony surfaces. Out of these, there are four shown in Figs. 14–17. The color harmony surfaces are plotted in polar coordinates. The horizontal plane contains the network of the Coloroid axis intersections of identical

TABLE IV. The chromatic details of the colors used in the compositions shown in Fig. 4.

	COLOROID			CIE			MUNSELL			
	A	*T*	*V*	*X*	*Y*	*Z*	*H*	*V*	*C*	*d* (%)
C	12	50	80	58.72	64.00	19.67	7.5Y	8.00	8.00	4.36
1	53	0	90	76.99	81.00	88.20	5.0G	9.00	2.00	8.00
2.	53	10	90	76.72	81.00	95.16	2.5B	9.00	2.00	5.66
3.	53	20	90	76.45	81.00	102.12	5.0B	9.00	2.00	1.54
4.	53	0	80	60.83	64.00	69.69	7.5G	8.00	2.00	8.62
5.	53	10	80	60.56	64.00	76.65	5.0B	8.00	2.00	5.08
6.	53	20	80	60.29	64.00	83.61	5.0B	8.00	2.00	2.83
7.	53	30	80	60.03	64.00	90.57	10.0B	8.00	4.00	4.21
8.	53	40	80	59.76	64.00	97.53	10.0B	8.00	4.00	3.00
9.	53	0	70	46.57	49.00	53.35	5.0G	7.00	2.00	8.86
10.	53	10	70	46.31	49.00	60.31	5.0B	7.00	2.00	5.22
11.	53	20	70	46.04	49.00	67.28	7.5B	7.00	2.00	4.61
12.	53	30	70	45.77	49.00	74.24	10.0B	7.00	4.00	3.88
13.	53	40	70	45.50	49.00	81.20	10.0B	7.00	6.00	5.26
14.	53	50	70	45.23	49.00	88.16	10.0B	7.00	6.00	5.01
15.	53	0	60	34.22	36.00	39.20	10.0G	6.00	2.00	9.30
16.	53	10	60	33.95	36.00	46.16	7.5B	6.00	2.00	5.28
17.	53	20	60	33.68	36.00	53.12	10.0B	6.00	4.00	5.70
18.	53	30	60	33.48	36.00	60.08	10.0B	6.00	4.00	6.08
19.	53	40	60	33.15	36.00	57.05	10.0B	6.00	6.00	5.32
20.	53	50	60	32.88	36.00	74.01	10.0B	6.00	8.00	5.73
21.	53	0	50	23.76	25.00	27.22	10.0G	6.00	2.00	9.17
22.	53	10	50	23.44	25.00	34.18	7.5B	6.00	2.00	4.61
23.	53	20	50	23.23	25.00	41.15	10.0B	6.00	4.00	4.64
24.	53	30	50	22.91	25.00	48.11	10.0B	6.00	6.00	4.94
25.	53	40	50	22.69	25.00	55.07	10.0B	6.00	8.00	5.52
26.	53	50	50	22.42	25.00	62.03	10.0B	6.00	10.00	6.39
27.	53	0	40	15.21	16.00	17.42	5.0G	5.00	2.00	8.91
28.	53	10	40	14.94	16.00	24.38	10.0B	5.00	2.00	5.32
29.	53	20	40	14.67	16.00	31.35	10.0B	5.00	6.00	5.90
30.	53	30	40	14.40	16.00	38.31	10.0B	5.00	8.00	5.59
31.	53	40	40	14.14	16.00	46.22	10.0B	5.00	10.00	5.64
32.	53	50	40	13.87	16.00	52.23	10.0B	5.00	12.00	6.16

The columns of the table contain Coloroid coordinates (*A*, *T*, *V*), CIE color components (*X*, *Y*, *Z*), and Munsell color codes (*H*, *V*, *C*), respectively. Munsell color codes are always codes of a color appearing in the Munsell Atlas, being nearest to the color of the composition. The last column (*d*) shows the relative difference between the Munsell color and the current Coloroid color expressed in percentage.

lightness and identical saturation. In the intersections of the network, the various shades of one of the color pair colors are sited. In every one of these points, there is another color, with parameters fixed in the experiment. The lengths of the perpendicular lines, in these points, are proportional to the harmony content of the color pair represented by the point itself. The surface is the result of the entirety of these points. The shape and the curvature of the surface illustrate the harmony content of the color pair, formed by the shades of the one particular color and another color.

The harmony surface, depicted in Fig. 14, expresses the harmony contents of the color pairs formed by the cadmium yellow, 12-50-80 Coloroid index and the A53 manganese blue, Coloroid color of various saturations and different lightnesses. One can see from this surface that the lightness and saturation values of the color pair of the lowest harmony content, marked A53 are V60 and T20, respectively. The one with the highest harmony content has a lightness of V60 and a saturation of T40. The difference between the harmony content of the two color pairs makes 40 numerical units. The surface also shows that harmony content of the color pairs of hues of the cadmium yellow and manganese blue is high, when the difference in saturation is around 10 dT and the difference in lightness is approximately 20 dV. When these differences are much smaller or bigger, then the harmony content will drop. Harmony surfaces of similar dynamic properties will be created when the inclinations between the two Coloroid interceptions containing one of each elements of the color pair fall between 30–60 and 140–160°. The following color pairs fall into these inclination ranges: lemon yellow (A11)-Lincoln green (A72), Mars yellow (A13)-Parma lilac (A43), Vermillion (A30)-Triton green, ultramarine blue (A51) violet (A44).

The harmony surface, shown in Fig. 15, represents the harmony content of color pairs formed by Persian orange (21-40-70 Coloroid index) color and the cromium-oxi-hydrate (A61 Coloroid hue) green shade with various saturation and lightness. Here, the lightness and the saturation of color pair with the lowest harmony content (Coloroid hue A61) are V90 and T30, respectively. The one with highest harmony content has the lightness of V90 and the saturation of T30. The difference in harmony content between the two is 39 units. Out of the color pairs forming the surface in the illustration, the ones with the high harmony content show the saturation difference of 10 dT and the difference in lightness of 10 dV. Similar

TABLE V. The chromatic details of the colors used in the compositions shown in Fig. 5.

	COLOROID			CIE			MUNSELL			
	A	*T*	*V*	*X*	*Y*	*Z*	*H*	*V*	*C*	*d* (%)
C	21	40	70	54.20	49.00	17.59	7.5YR	7.00	8.00	6.94
1.	61	0	90	76.99	81.00	88.20	5.0G	9.00	2.00	8.61
2.	61	10	90	74.98	81.00	89.65	2.5G	9.00	2.00	4.54
3.	61	20	90	72.97	81.00	91.10	10.0G	9.00	2.00	1.22
4.	61	30	90	70.96	81.00	92.55	10.0G	9.00	2.00	4.39
5.	61	0	80	60.83	64.00	69.69	7.5G	8.00	2.00	8.62
6.	61	10	80	58.82	64.00	71.14	7.5G	8.00	2.00	4.24
7.	61	20	80	56.81	64.00	72.54	10.0G	8.00	2.00	3.20
8.	61	30	80	54.80	64.00	74.04	2.5BG	8.00	4.00	4.26
9.	61	40	80	52.79	64.00	75.49	2.5BG	8.00	4.00	3.57
10.	61	50	80	50.79	64.00	76.94	5.0BG	8.00	6.00	3.36
11.	61	0	70	46.57	49.00	52.35	5.0G	7.00	2.00	8.86
12.	61	10	70	44.56	49.00	54.80	10.0G	7.00	2.00	4.43
13.	61	20	70	42.56	49.00	56.25	10.0G	7.00	2.00	5.53
14.	61	30	70	40.55	49.00	57.70	2.5BG	7.00	4.00	4.01
15.	61	40	70	38.44	49.00	59.15	5.0BG	7.00	6.00	4.56
16.	61	50	70	36.52	49.00	60.60	5.0BG	7.00	6.00	6.42
17.	61	0	60	34.22	36.00	39.20	10.0G	6.00	2.00	9.30
18.	61	10	60	32.21	36.00	40.65	10.0G	6.00	2.00	4.88
19.	61	20	60	30.20	36.00	42.10	2.5BG	7.00	4.00	5.92
20.	61	30	60	28.19	36.00	43.55	2.5BG	6.00	4.00	6.47
21.	61	40	60	26.80	36.00	45.00	5.0BG	6.00	6.00	6.32
22.	61	50	60	24.17	36.00	48.45	5.0BG	6.00	8.00	5.81
23.	61	0	50	23.26	25.00	27.22	10.0G	6.00	2.00	8.17
24.	61	10	50	21.75	25.00	28.67	10.0G	6.00	2.00	4.84
25.	61	20	50	19.74	25.00	30.12	2.5BG	6.00	4.00	4.78
26.	61	30	50	17.73	25.00	31.57	5.0BG	6.00	6.00	5.81
27.	61	40	50	15.73	25.00	33.02	5.0BG	6.00	8.00	6.55
28.	61	50	50	13.72	25.00	34.48	5.0BG	6.00	12.00	6.06
29.	61	0	40	15.21	16.00	17.42	5.0G	5.00	2.00	8.91
30.	61	10	40	13.20	16.00	18.87	2.5BG	5.00	4.00	6.78
31.	61	20	40	11.19	16.00	20.32	2.5BG	5.00	6.00	5.19
32.	61	30	40	9.18	16.00	21.77	2.5BG	4.00	8.00	7.37
33.	61	40	40	7.17	16.00	23.22	5.0BG	5.00	12.00	6.60

The columns of the table contain Coloroid coordinates (*A*, *T*, *V*), CIE color components (*X*, *Y*, *Z*), and Munsell color codes (*H*, *V*, *C*), respectively. Munsell color codes are always codes of a color appearing in the Munsell Atlas, being nearest to the color of the composition. The last column (*d*) shows the relative difference between the Munsell color and the current Coloroid color expressed in percentage.

harmony surfaces could be created when the inclination between the axis intersections, where the two Coloroid colors of the pair lie, is either between 90° and 100° or between 120° and 130°. Color pairs in these axis intersections are for instance the Indian orange (A16)-turquoise blue (A56) and the ultramarine-old green (A71) combinations.

The harmony surface, shown in Fig. 16, represents the harmony content of color pairs formed by cinnabar red (30-30-50 Coloroid index) color and the magenta (A35 Coloroid hue index) shade with various saturation and lightness. Here, the lightness and the saturation of color pair with the lowest harmony content (hue number A35) are V40 and T30, respectively. The one with highest harmony content has the lightness of V80 and the saturation of T20. The difference in harmony content between the two gives 20 units. The inclination of the two Coloroid axis intersections, where the two colors, forming the pair, is 35°. We noted that none of the shades of the magenta forms high harmony content pairs with the cinnabar red color. Out of these, the least harmonious are the shades formed with the dark magenta. The color harmony surfaces are similar, when the inclination is similar between the axis intersections, where the colors of the color pairs lie. Color pairs falling into this category for instance are: Medici blue (A54)-chromium-oxi-hydrate, Turquoise blue (A60)-peacock green (A64), and scarlet (A42)-Spanish violet (A46) combinations.

The harmony surface, shown in Fig. 17, represents the harmony content of color pairs formed by chalcedon green (75-50-80 Coloroid index) color and the cadmium yellow (A12 Coloroid index) shade with various saturation and lightness. Here, the lightness and the saturation of color pair with the lowest harmony content (hue index A12) are V70 and T10, respectively. The one with highest harmony content has the lightness of V60 and the saturation of T30. The difference in harmony content between the two gives eight units. The color harmony content of the color pairs forming the color harmony surface depicted in the illustration differ only a very small amount. The inclination of the two Coloroid axis intersections, where the two colors, forming the pair, is only 16°. The color harmony content of the surfaces with similar inclinations, where the colors of the color pairs lie, represents similar harmony surfaces. Such color pairs are magenta (A42)-fiery violet, Triton green

TABLE VI. The chromatic details of the colors used in the compositions shown in Fig. 6.

	COLOROID			CIE			MUNSELL			
	A	*T*	*V*	*X*	*Y*	*Z*	*H*	*V*	*C*	*d* (%)
C	30	30	50	38.45	25.00	7.77	7.5R	6.00	14.00	6.54
1.	35	0	90	76.99	81.00	88.20	5.0G	9.00	2.00	8.61
2.	35	10	90	81.13	81.00	89.30	7.5R	9.00	2.00	2.49
3.	35	0	80	60.83	64.00	69.69	7.5G	8.00	2.00	8.62
4.	35	10	80	64.47	64.00	70.79	5.0R	8.00	2.00	2.75
5.	35	20	80	69.11	64.00	71.90	7.5RP	8.00	4.00	2.89
6.	35	0	70	46.57	49.00	53.35	5.0G	7.00	2.00	8.86
7.	35	10	70	50.71	49.00	54.46	2.5R	7.00	2.00	3.88
8.	35	20	70	54.85	49.00	55.57	7.5RP	7.00	4.00	5.02
9.	35	30	70	58.99	49.00	56.68	7.5RP	7.00	6.00	5.88
10.	35	0	60	34.22	36.00	39.20	10.0G	6.00	2.00	9.30
11.	35	10	60	38.36	36.00	40.31	2.5R	6.00	2.00	5.57
12.	35	20	60	42.50	36.00	41.42	7.5RP	7.00	6.00	5.33
13.	35	30	60	46.64	36.00	42.52	5.0RP	7.00	8.00	5.91
14.	35	40	60	50.72	36.00	43.63	5.0RP	6.00	12.00	6.39
15.	35	0	50	23.76	25.00	27.22	10.0G	6.00	2.00	8.17
16.	35	10	50	27.90	25.00	28.33	7.5RP	6.00	4.00	5.09
17.	35	20	50	32.04	25.00	27.44	7.5RP	6.00	8.00	6.03
18.	35	30	50	36.18	25.00	30.55	5.0RP	6.00	10.00	6.17
19.	35	40	50	40.32	25.00	31.66	5.0RP	6.00	14.00	5.65
20.	35	50	50	44.46	25.00	32.77	5.0RP	6.00	16.00	6.41
21.	35	0	40	15.21	16.00	17.42	5.0G	5.00	2.00	8.91
22.	35	10	40	19.35	16.00	18.53	7.5RP	5.00	4.00	5.23
23.	35	20	40	23.49	16.00	19.64	5.0RP	5.00	8.00	6.73
24.	35	30	40	27.63	16.00	20.75	5.0RP	5.00	14.00	6.80
25.	35	40	40	31.72	16.00	21.86	5.0RP	5.00	16.00	7.38

The columns of the table contain Coloroid coordinates (*A*, *T*, *V*), CIE color components (*X*, *Y*, *Z*), and Munsell color codes (*H*, *V*, *C*), respectively. Munsell color codes are always codes of a color appearing in the Munsell Atlas, being nearest to the color of the composition. The last column (*d*) shows the relative difference between the Munsell color and the current Coloroid color expressed in percentage.

TABLE VII. The chromatic details of the colors used in the compositions shown in Fig. 7.

	COLOROID			CIE			MUNSELL			
	A	*T*	*V*	*X*	*Y*	*Z*	*H*	*V*	*C*	*d* (%)
C	75	50	80	50.14	64.00	16.99	5.0GY	8.00	10.00	3.31
1	12	0	90	76.99	81.00	88.20	5.0G	9.00	2.00	8.67
2.	12	10	90	76.57	81.00	78.19	5.0GY	9.00	2.00	4.89
3.	12	20	90	76.15	81.00	68.19	10.0Y	9.00	2.00	3.10
4.	12	30	90	75.73	81.00	58.19	7.5Y	9.00	4.00	3.45
5.	12	40	90	75.31	81.00	48.18	10.0Y	9.00	4.00	6.78
6.	12	50	90	74.89	81.00	38.18	7.5Y	9.00	6.00	3.48
7.	12	0	80	60.83	64.00	69.69	7.5G	8.00	2.00	8.62
8.	12	10	80	60.41	64.00	59.68	5.0GY	8.00	2.00	4.06
9.	12	20	80	59.99	64.00	49.68	10.0Y	8.00	2.00	6.92
10.	12	30	80	59.57	64.00	39.66	7.5Y	8.00	4.00	4.24
11.	12	40	80	59.15	64.00	29.67	7.5Y	8.00	6.00	3.14
12.	12	50	80	58.73	64.00	19.67	7.5Y	8.00	8.00	4.36
13.	12	0	70	46.57	49.00	53.35	10.0Y	7.00	2.00	8.36
14.	12	10	70	51.82	49.00	48.10	7.5Y	7.00	2.00	3.99
15.	12	20	70	45.73	49.00	33.35	7.5Y	7.00	4.00	5.38
16.	12	30	70	46.31	49.00	23.34	7.5Y	7.00	6.00	4.93
17.	12	40	70	44.89	49.00	13.34	7.5Y	7.00	8.00	4.54
18.	12	50	70	44.48	49.00	3.34	7.5Y	7.00	14.00	5.97
19.	12	0	60	34.22	36.00	39.20	10.0G	6.00	2.00	9.30
20.	12	10	60	33.80	36.00	29.19	10.0Y	6.00	2.00	5.12
21.	12	20	60	33.38	36.00	19.19	7.5Y	6.00	4.00	6.17
22.	12	30	60	32.96	36.00	9.19	7.5Y	7.00	8.00	5.22
23.	12	0	50	23.78	25.00	27.22	10.0G	6.00	2.00	9.17
24.	12	10	50	23.34	25.00	17.22	10.0Y	6.00	2.00	7.74
25.	12	20	50	22.92	25.00	7.21	7.5Y	6.00	6.00	5.45
26.	12	0	40	13.21	16.00	17.42	5.0G	5.00	2.00	8.91
27.	12	10	40	14.75	16.00	7.42	7.5Y	5.00	4.00	4.69

The columns of the table contain Coloroid coordinates (*A*, *T*, *V*), CIE color components (*X*, *Y*, *Z*), and Munsell color codes (*H*, *V*, *C*), respectively. Munsell color codes are always codes of a color appearing in the Munsell Atlas, being nearest to the color of the composition. The last column (*d*) shows the relative difference between the Munsell color and the current Coloroid color expressed in percentage.

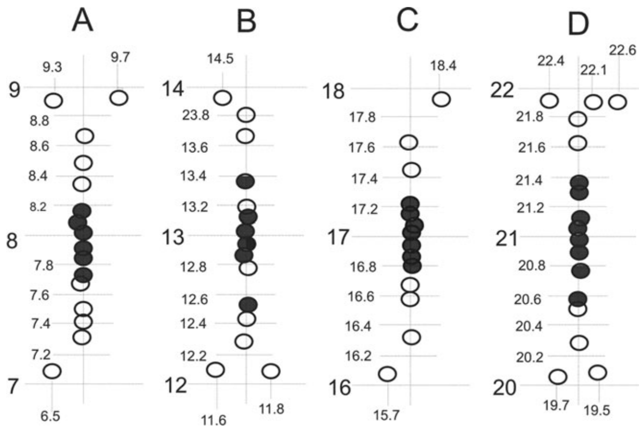


FIG. 8. Examples of dispersion of experimental results. (A) Harmony content of the composition consisting of a color with 23-30-60 Coloroid code and of grey with V50 Coloroid lightness. (B) Harmony content of the composition consisting of a color with 40-40-50 Coloroid code and of grey with V60 Coloroid lightness. (C) Harmony content of the composition consisting of a color with 16-40-70 Coloroid code and of grey with V80 Coloroid lightness. (D) Harmony content of the composition consisting of a color with 66-20-60 Coloroid code and of grey with V60 Coloroid lightness.

(A62)-peacock green (A64), and crimson red (A32)-ruby red (A34) pairs.

CONCLUSIONS

The results of the experiment provide 24 Coloroid color spaces, and eight axial intersections for every color space. So there are 192 axial intersections connected to 192 harmony surfaces. Every harmony surface, verified by the experiment, include 22–30 (in average 26) points representing color pairs of definite harmony content. In every one of the 24 Coloroid color spaces, with approximately uniform distribution, there are 208 points representing color pairs, whose harmony contents are defined by the experiment. These points, in every one of the color spaces, represent eight Coloroid hues, six Coloroid saturation levels, and six Coloroid lightness values, located equidistant from each other. As a result of the experiment, we can lay surfaces in three directions over the points, representing those harmony contents, defined by the Coloroid coordinates. One of the surface directions is the axial intersection formed by identical hues, the second is a set of concentric cylinder surfaces for identical saturation levels, whilst the third one is in right angle to the axis and located above the surface representing identical lightness. All surfaces, in these three directions, are called harmony surfaces. When we draw a perpendicular line to any point of the surface lying above the harmony surface, then the distance between the foot end and the stabbing point of the perpendicular line on the harmony surface represents the numerical value of the harmony content of the color pair, defined by the coordinates of the foot end of the perpendicular. The extension and generalization of this mental process could form the base for the determination of the harmony content of any color in the Coloroid color space and also for the establishment of the numerical indexing system of color harmony.

In this article, we have included the basic data, related to the judgements on color harmony perception, dependent on the hue, saturation level and lightness of the color

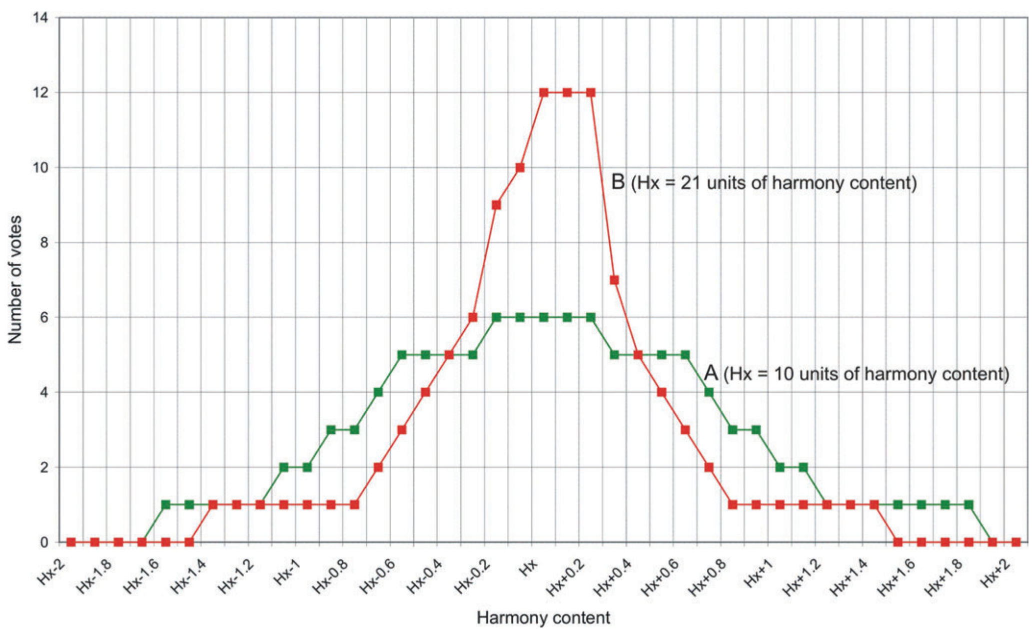


FIG. 9. Two different density functions of votes dispersion. (A) Harmony content of the composition consisting of a color with 73-40-50 Coloroid code and of grey with V50 Coloroid lightness. (B) Harmony content of the composition consisting of a color with 32-30-50 Coloroid code and of grey with V70 Coloroid lightness.

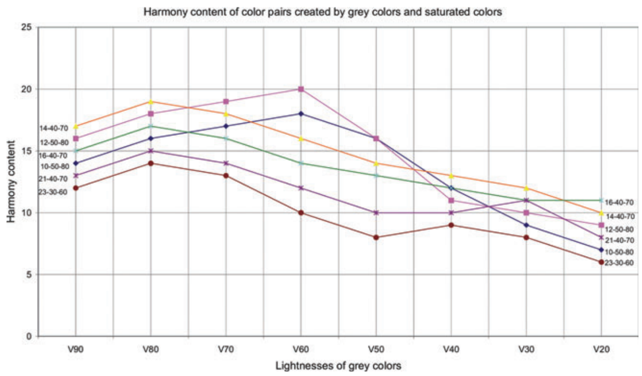


FIG. 10. The harmony content of the compositions used in the 1–6 tests of the first stage of the experiments.

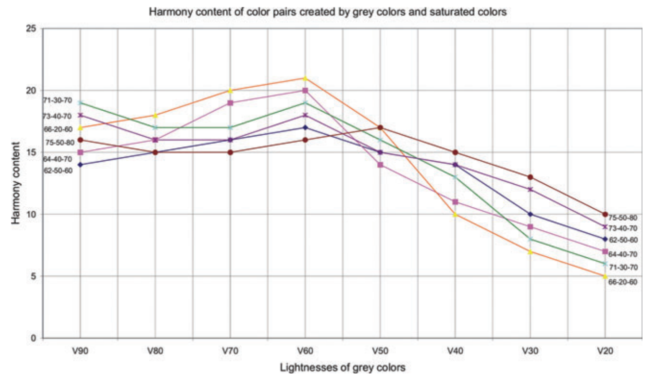


FIG. 13. The harmony content of the compositions used in the 19–24 tests of the first stage of the experiments.

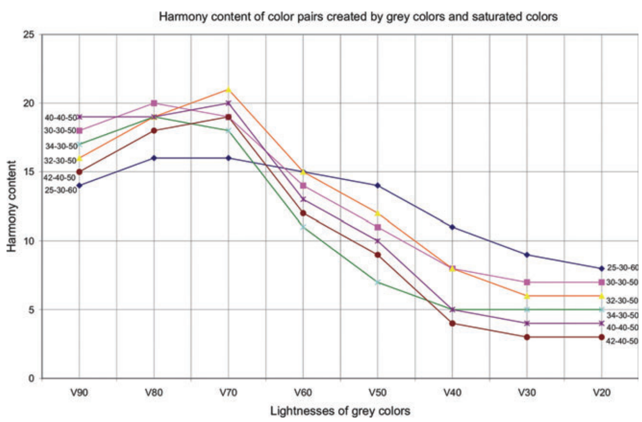


FIG. 11. The harmony content of the compositions used in the 7–12 tests of the first stage of the experiments.

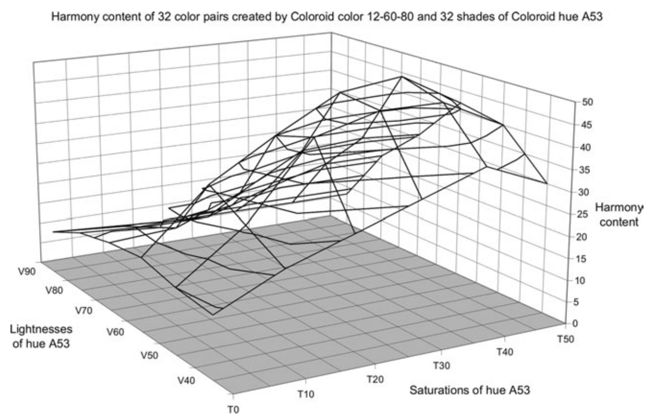


FIG. 14. The harmony surface defined by the color contents of the color with 12-50-80 Coloroid index and that of the hues with various saturation and lightness of the A53 Coloroid hue (see 12th test in the second stage of the experiment).

group, which can form the foundation for the proposed index system of color harmony. For most people these data are identical. Discussion of the system will be the scope of another article.

These decisions over the color harmony perception are influenced by the psychic, somatic, age, cultural and social state of the observing subjects. The collated data on the numerical indexing of color preference might be influenced or changed by the new data coming from results of existing[47] or planned future experiments and observations. These data will be valid for smaller but specific group of people.

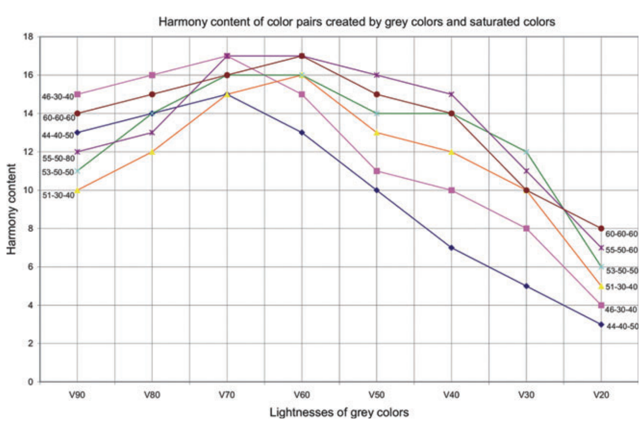


FIG. 12. The harmony content of the compositions used in the 13–18 tests of the first stage of the experiments.

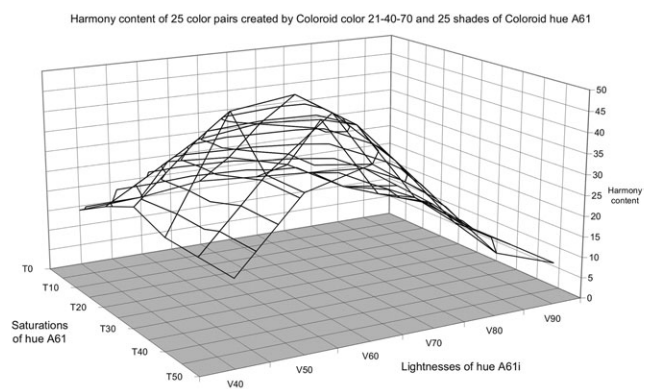


FIG. 15. The harmony surface defined by the color contents of the color with 21-40-70 Coloroid index and that of the hues with various saturation and lightness of the A61 Coloroid hue (see 38th test in the second stage of the experiment).

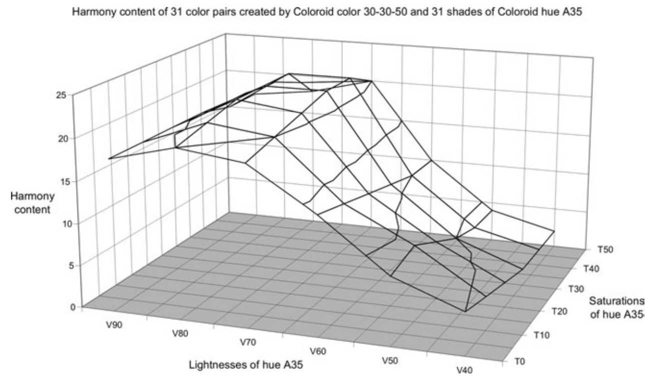


FIG. 16. The harmony surface defined by the color contents of the color with 30-30-50 Coloroid index and that of the hues with various saturation and lightness of the A35 Coloroid hue (see 57th test in the second stage of the experiment).

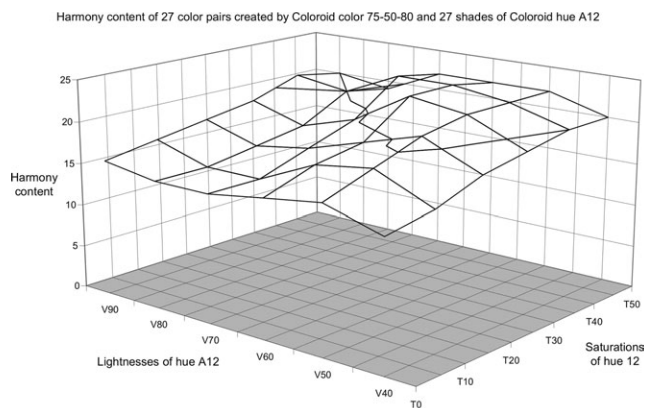


FIG. 17. The harmony surface defined by the color contents of the color with 75-50-80 Coloroid index and that of the hues with various saturation and lightness of the A12 Coloroid hue (see 186th test in the second stage of the experiment).

The formation of the harmony perception depends on factors such as the specific circumstance, the location in space of the colors of the color group, its expressed functionality, illumination, and a number of other factors. The experimental investigation of these factors is a task for the future. Data coming from these experiments will also modify the data of the numerical index system of color harmony.

ACKNOWLEDGMENTS

The author is indebted to Dr. J. Takacs of Oxford University for his valuable comments on the manuscript.

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