ACTA · GRAPHICA
ISSN: 0353-4707
e-ISSN: 1848-3828
ZNANSTVENI ČASOPIS ZA TISKARSTVO I GRAFIČKE KOMUNIKACIJE
JOURNAL FOR PRINTING SCIENCE AND GRAPHIC COMMUNICATIONS

Scientific article

Color differences vision test

Zoran Gazibarić[1], Predrag Živković[2], Vladimir Cviljušac[3], Nikola Mrvac[3]

[1] Banja Luka College 1; Miloša Obilića 30, 78000 Banja Luka, Bosnia and Herzegovina

[2] University of Belgrade, Faculty of Technology and Metallurgy 2; Karnegijeva 4, 11000 Beograd, Serbia

[3] University of Zagreb, Faculty of Graphics Arts 3, Getaldićeva 2, 10000 Zagreb, Croatia

[*] Correspondence: zoran.gazibaric@tf.unibl.org

***Abstract**: When different observers match the same color, using the same matching stimuli, it is found that there are slight differences in the amounts that they require to make up a match. The interpretation of color differences plays an important role in some cases, for example in color evaluation during print approval, when the designer has high requirements regarding the accuracy of color reproduction, for medical purposes, in the automotive or other industries. There are several tests for determining who is the best candidate for evaluating colors. One of the most convenient tests is the Farnsworth-Munsell 100 Hue Test. The main disadvantage of this and similar tests is that one can't straightforwardly connect perceptual interpretation of color differences with objective results done with instrumental measurement of color differences. The paper proposed a way to express in ΔE* units the results of testing the subject's sensitivity to color differences, and in that way to determine as precisely as possible the difference in color that an individual subject can perceive in some part of the colored space. By calculating the average value of ΔE* of the respondents for certain parts of the color space, a conclusion can be drawn about the general sensitivity of the respondents to differences in colors.*

***Keywords**: color differences; color assessment; perceptual interpretation*

1. Introduction

In his book The Reproduction of Color, Hunt claims that when different observers match the same color, using the same matching stimuli, however, it is found that there are slight differences in the amounts that they require to effect a match.

Some of these differences are random and disappear if the results of several matches by each observer are averaged.

But there remain real differences, which must be attributed to differences in the color vision of the individual observers. Some observers are very different from the average, and these are classed as color defective (or 'color blind'), but the results of most observers are scattered over only a limited range. [1]

With knowledge that color space is not uniform, perceptual interpretation of color differences deteriorates. A color difference formula is designed to give a quantitative measure of the perceived color difference between a pair of color samples under a given set of conditions [2].

ΔE^*_{ab}, ΔE^*_{CMC}, ΔE^*_{94} i ΔE^*_{00} equations are defined using the *CIE L*c*h** system and are calculated using the *L**, *a** i *b** variables [3].

A table for evaluating color differences ΔE*ab is made by Schapfler, 1993 [4].

Classification of the color difference rating shown in the Table 1 refers to the average observer for any color.

Table 1 *A table for evaluating color differences ΔE^*_{ab}*

$\Delta E < 0.2$	*The difference is not visible.*
$0.2 < \Delta E < 1$	*The difference is noticeable.*
$1 < \Delta E < 3$	*The difference is visible.*
$3 < \Delta E < 6$	*The difference is clearly visible.*
$6 < \Delta E$	*An obvious deviation.*

Hardeberg published in his book, rule of thumb for the practical interpretation of ΔE*ab measuring the color difference between two color patches viewed side by side [5]. (Table 2)

Table 2 *A table for evaluating color differences ΔE^*_{ab} "Rule of thumb"*

ΔE^*_{ab}	*Effect*
< 3	*Hardly perceptible*
3 < 6	*Perceptible, but acceptable*
> 6	*Not acceptable*

Perceptual interpretation of color differences plays a big role in some cases: when evaluating colors to approve prints, or designer is setting the color with strict color assessment, for medical purposes or in the automotive industry where criteria are very strict.

To find out who is the best candidate for evaluating colors there are several tests. One of the most convenient tests is the Farnsworth-Munsell 100 Hue Test [6]. It has been used for the past 60 years in various industries as a method for evaluating the respondent's ability in relation to perceptual abilities.

A satisfactory result from this test is ≤ 40 points, and for a strict color assessment, result of ≤ 16 points. Respondent can find out in which part of the color space has weaker or stronger perceptual abilities.

The main disadvantage of this and similar tests is that one can't straightforwardly connect perceptual interpretation of color differences with objective results done with instrumental measurement of color differences.

The paper proposed a way to express in ΔE* units the results of testing the subject's sensitivity to color differences, and in that way to determine as precisely as possible the difference in color that an individual subject can perceive in some part of the color space. One can conclude if respondents see color differences under or above a specific ΔE* value.

Equations ΔE*ab, ΔE*CMC, ΔE*94 or ΔE*00 can be used in the test to express abilities of respondent regarding distinguish color differences.

2. Materials and methods

The software, equipment, and procedure for the digital test of the observer's sensitivity to color differences is described in detail in a work published earlier [7].

The test is based on setting two matching stimuli that have identical spectral distribution Fig. 1.

The test is not set to match any metameric pairs [1], it is set to establish sensitivity of respondents to color differences.

The results obtained in this work are results of one respondent in details.

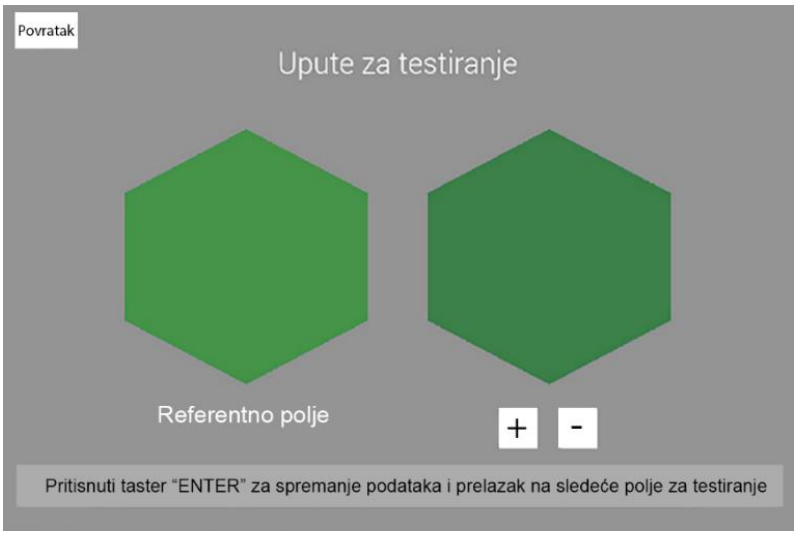

Figure 1 *Colored fields on a monitor shown to respondent (translation of original signs: "Upute za testiranje" - Testing instructions; „Referentno polje“ - Referent field; „Pritisnuti taster „ENTER“ za spremanje podataka i prelazak na sljedeće polje za testiranje“ - Press the ENTER key to save the data and move to the next test field; „Povratak“- Return) [7]*

3. Results and discussion

Generally, the meanings of the terms:

1. **ST** stands for the value of **Sensitivity Threshold** of the respondent's to differences in colors.
2. **BND** stands for the value of **Barely Noticeable Difference** that the respondent can perceive.
3. **UND** stands for the value of **Unacceptable Difference** that respondents perceive.

An explanation of abbreviations is given in table 3.

***Table 3** Interpretation of abbreviations*

No.	**There are 24 colors for the testing procedure.**
Color	The name of the color is taken from the X-Rite ColorChecker Classic card.
L(ref.)	L* value of referent color that respondent needs to match.
a(ref.)	a* value of referent color that respondent needs to match.
b(ref.)	b* value of referent color that respondent needs to match.
L+(ST)	L* value of color that the respondent reached during the testing.
a(ST)	a* value same as the referent
b(ST)	b* value same as the referent
ΔE^*_{00}	Calculated after L value increased.
Time (ST)[sec]	The time at which the respondent ended the first stage of testing.
L+(BND)	L* value of color that the respondent reached during the testing.
a(BND)	a* value same as the referent
b(BND)	b* value same as the referent
ΔE^*_{00}	Calculated after L value increased.
Time (BND) [sec]	The time at which the respondent ended the second stage of testing.
L+(UND)	L* value of color that the respondent reached during the testing.
a(UND)	a* value same as the referent
b(UND)	b* value same as the referent
ΔE^*_{00}	Calculated after L value increased.
Time (UND)[sec]	The time at which the respondent ended the third stage of testing.
Time shift [sec]	Delay time for starting the color change.
No. of circular color anim.	The number of circles of color changes.

In the next six tables (Table 4 to 9), complete data for one respondent is obtained. During the testing procedure, L*a*b* values increase (+) or decrease (-). Specific reaction to color differences of respondents when L*a*b* values decrease or increase is recorded during the test, and they are displayed in these six tables.

Table 4 *Change per L+*

No.	Color	L(ref.)	a(ref.)	b(ref.)	L+(ST)	a(ST)	b(ST)	**ΔE*00**	Time (ST)[sec]	L+(BND)	a(BND)	b(BND)	**ΔE*00**	Time (BND) [sec]	L+(UND)	a(UND)	b(UND)	**ΔE*00**	Time (UND)[sec]	Time shift [sec]	No. of circular color anim.
1.	black 2 (1.5 D)	20,81	0,03	-0,39	21,61	0,03	-0,39	0,56	12,20	25,83	0,03	-0,39	3,60	2,65	28,28	0,03	-0,39	5,43	3,95	2,00	0,00
2.	bluish green	70,69	-33,03	-0,11	71,04	-33,03	-0,11	0,27	15,16	73,96	-33,03	-0,11	2,46	1,55	76,52	-33,03	-0,11	4,33	2,71	2,00	0,00
3.	light skin	65,95	17,91	17,87	66,60	17,91	17,87	0,53	16,18	70,15	17,91	17,87	3,33	2,23	72,48	17,91	17,87	5,10	3,31	1,00	0,00
4.	yellow green	72,46	-23,30	57,00	72,81	-23,30	57,00	0,26	18,00	76,19	-23,30	57,00	2,75	1,87	77,94	-23,30	57,00	4,00	2,81	2,00	0,00
5.	dark skin	38,44	13,61	14,53	39,24	13,61	14,53	0,69	13,55	45,56	13,61	14,53	6,44	3,76	47,54	13,61	14,53	8,36	4,70	1,00	0,00
6.	blue sky	50,06	-4,52	-22,25	51,01	-4,52	-22,25	0,95	14,85	53,91	-4,52	-22,25	3,80	1,78	56,24	-4,52	-22,25	6,02	2,81	3,00	0,00
7.	orange	62,65	35,35	57,86	63,90	35,35	57,86	1,05	11,98	65,57	35,35	57,86	2,43	1,58	68,13	35,35	57,86	4,49	2,95	2,00	0,00
8.	green	55,15	-37,80	31,64	55,05	-37,80	31,64	0,09	16,48	60,05	-37,80	31,64	4,46	2,24	62,38	-37,80	31,64	6,47	3,26	1,00	0,00
9.	neutral 8 (.23 D)	81,21	-0,64	0,27	82,16	-0,64	0,27	0,65	12,31	85,99	-0,64	0,27	3,19	2,26	89,03	-0,64	0,27	5,13	3,62	1,00	0,00
10.	neutral 5 (.70 D)	50,83	-0,64	-0,14	52,38	-0,64	-0,14	1,54	12,40	52,46	-0,64	-0,14	1,62	0,77	55,26	-0,64	-0,14	4,32	2,01	3,00	0,00
11.	neutral 3.5 (1.05 D)	35,85	-0,54	-0,49	37,70	-0,54	-0,49	1,56	13,69	40,28	-0,54	-0,49	3,80	2,23	43,43	-0,54	-0,49	6,64	3,64	3,00	0,00
12.	foliage	43,28	-13,21	21,94	44,98	-13,21	21,94	1,59	11,74	48,41	-13,21	21,94	4,92	2,43	51,45	-13,21	21,94	8,01	4,03	2,00	0,00
13.	magenta	51,91	49,80	-13,82	52,86	49,80	-13,82	0,93	14,49	54,59	49,80	-13,82	2,61	1,49	57,39	49,80	-13,82	5,22	2,95	2,00	0,00
14.	cyan	50,72	-28,11	-27,95	51,52	-28,11	-27,95	0,80	14,08	54,22	-28,11	-27,95	3,44	1,90	56,55	-28,11	-27,95	5,64	3,10	3,00	0,00
15.	purple	30,50	21,07	-20,02	31,60	21,07	-20,02	0,86	14,94	34,70	21,07	-20,02	3,35	2,30	38,43	21,07	-20,02	6,48	3,97	2,00	0,00
16.	purplish blue	40,24	9,74	-44,35	40,29	9,74	-44,35	0,04	12,31	42,69	9,74	-44,35	2,20	1,16	46,77	9,74	-44,35	6,05	3,11	3,00	0,00
17.	moderate red	51,60	47,80	16,90	51,50	47,80	16,90	0,10	13,53	56,15	47,80	16,90	4,38	2,43	57,78	47,80	16,90	5,88	3,33	1,00	0,00
18.	yellow	82,27	4,02	79,99	83,37	4,02	79,99	0,74	12,81	86,94	4,02	79,99	3,08	2,51	88,80	4,02	79,99	4,27	3,47	2,00	0,00
19.	blue	28,87	14,81	-50,15	30,57	14,81	-50,15	1,31	13,00	33,89	14,81	-50,15	3,95	2,70	36,34	14,81	-50,15	5,96	4,00	1,00	0,00
20.	white 9.5 (.05 D)	96,53	-0,47	2,42	97,00	-0,47	2,42	0,28	9,86	99,10	-0,47	2,42	1,50	16,93	96,65	-0,47	2,42	0,07	20,89	1,00	12,00
21.	red	42,28	54,12	28,67	42,78	54,12	28,67	0,46	14,44	47,53	54,12	28,67	4,96	2,67	50,80	54,12	28,67	8,25	4,43	2,00	0,00
22.	blue flower	55,31	8,82	-24,60	55,06	8,82	-24,60	0,24	15,29	57,18	8,82	-24,60	1,73	1,04	59,16	8,82	-24,60	3,52	2,02	2,00	0,00
23.	orange yellow	71,95	19,46	68,12	71,85	19,46	68,12	0,08	13,63	77,20	19,46	68,12	3,85	2,82	79,77	19,46	68,12	5,66	4,19	1,00	0,00
24.	neutral 6.5 (.44 D)	66,48	-0,53	0,00	67,28	-0,53	0,00	0,64	18,97	67,41	-0,53	0,00	0,75	0,42	70,56	-0,53	0,00	3,22	2,10	3,00	0,00

Table 5 *Change per L-*

No.	Color	L(ref.)	a(ref.)	b(ref.)	L-(ST)	a(ST)	b(ST)	**ΔE*00**	Time (ST)[sec]	L-(BND)	a(BND)	b(BND)	**ΔE*00**	Time (BND) [sec]	L-(UND)	a(UND)	b(UND)	**ΔE*00**	Time (UND) [sec]	Time shift [sec]	No. of circular color anim.
1.	**black 2 (1.5 D)**	20,81	0,03	-0,39	21,31	0,03	-0,39	0,35	12,11	17,78	0,03	-0,39	2,08	1,69	14,63	0,03	-0,39	4,18	3,12	3,00	0,00
2.	**bluish green**	70,69	-33,03	-0,11	69,69	-33,03	-0,11	0,77	14,93	66,14	-33,03	-0,11	3,59	2,45	64,16	-33,03	-0,11	5,21	3,54	1,00	0,00
3.	**light skin**	65,95	17,91	17,87	66,75	17,91	17,87	0,65	15,48	63,03	17,91	17,87	2,42	1,35	61,40	17,91	17,87	3,81	2,05	3,00	0,00
4.	**yellow green**	72,46	-23,30	57,00	72,96	-23,30	57,00	0,37	17,34	70,01	-23,30	57,00	1,87	1,11	67,79	-23,30	57,00	3,60	2,13	2,00	0,00
5.	**dark skin**	38,44	13,61	14,53	38,64	13,61	14,53	0,17	12,73	34,94	13,61	14,53	2,94	1,90	32,37	13,61	14,53	5,02	3,23	1,00	0,00
6.	**blue sky**	50,06	-4,52	-22,25	51,01	-4,52	-22,25	0,95	12,37	46,79	-4,52	-22,25	3,24	1,75	44,93	-4,52	-22,25	5,04	2,76	1,00	0,00
7.	**orange**	62,65	35,35	57,86	64,35	35,35	57,86	1,43	11,37	59,38	35,35	57,86	2,83	1,79	57,05	35,35	57,86	4,94	2,84	3,00	0,00
8.	**green**	55,15	-37,80	31,64	54,60	-37,80	31,64	0,52	15,40	52,70	-37,80	31,64	2,36	1,38	51,07	-37,80	31,64	3,98	2,29	3,00	0,00
9.	**neutral 8 (.23 D)**	81,21	-0,64	0,27	81,11	-0,64	0,27	0,07	14,99	76,66	-0,64	0,27	3,18	2,05	74,21	-0,64	0,27	4,96	3,15	2,00	0,00
10.	**neutral 5 (.70 D)**	50,83	-0,64	-0,14	50,43	-0,64	-0,14	0,40	13,02	49,78	-0,64	-0,14	1,05	0,55	46,51	-0,64	-0,14	4,29	1,99	2,00	0,00
11.	**neutral 3.5 (1.05 D)**	35,85	-0,54	-0,49	36,35	-0,54	-0,49	0,42	25,79	32,82	-0,54	-0,49	2,47	1,43	29,55	-0,54	-0,49	5,04	2,93	2,00	0,00
12.	**foliage**	43,28	-13,21	21,94	43,93	-13,21	21,94	0,60	11,61	39,90	-13,21	21,94	3,04	1,87	37,56	-13,21	21,94	5,06	3,15	1,00	0,00
13.	**magenta**	51,91	49,80	-13,82	52,56	49,80	-13,82	0,64	12,78	49,81	49,80	-13,82	2,09	1,17	47,36	49,80	-13,82	4,55	2,22	2,00	0,00
14.	**cyan**	50,72	-28,11	-27,95	51,67	-28,11	-27,95	0,95	15,05	50,72	-28,11	-27,95	0,00	0,03	46,40	-28,11	-27,95	4,29	1,98	3,00	0,00
15.	**purple**	30,50	21,07	-20,02	30,40	21,07	-20,02	0,08	12,65	28,63	21,07	-20,02	1,44	0,97	25,72	21,07	-20,02	3,62	2,46	2,00	0,00
16.	**purplish blue**	40,24	9,74	-44,35	41,79	9,74	-44,35	1,38	15,02	38,26	9,74	-44,35	1,73	1,11	36,04	9,74	-44,35	3,60	2,31	2,00	0,00
17.	**moderate red**	51,60	47,80	16,90	54,05	47,80	16,90	2,40	11,10	48,33	47,80	16,90	3,27	1,58	45,88	47,80	16,90	5,69	2,70	1,00	0,00
18.	**yellow**	82,27	4,02	79,99	84,27	4,02	79,99	1,34	11,43	75,97	4,02	79,99	4,40	3,42	74,10	4,02	79,99	5,76	4,42	2,00	0,00
19.	**blue**	28,87	14,81	-50,15	30,27	14,81	-50,15	1,08	13,42	26,77	14,81	-50,15	1,58	1,13	24,20	14,81	-50,15	3,47	2,39	2,00	0,00
20.	**white 9.5 (.05 D)**	96,53	-0,47	2,42	98,65	-0,47	2,42	1,24	3,67	91,28	-0,47	2,42	3,17	2,57	88,13	-0,47	2,42	5,15	4,03	1,00	0,00
21.	**red**	42,28	54,12	28,67	43,23	54,12	28,67	0,87	12,79	39,25	54,12	28,67	2,70	1,41	36,68	54,12	28,67	4,89	2,61	2,00	0,00
22.	**blue flower**	55,31	8,82	-24,60	55,81	8,82	-24,60	0,47	15,99	52,63	8,82	-24,60	2,58	1,39	50,64	8,82	-24,60	4,55	2,43	1,00	0,00
23.	**orange yellow**	71,95	19,46	68,12	72,90	19,46	68,12	0,71	16,23	67,63	19,46	68,12	3,35	2,40	65,77	19,46	68,12	4,85	3,40	1,00	0,00
24.	**neutral 6.5 (.44 D)**	66,48	-0,53	0,00	66,83	-0,53	0,00	0,28	12,18	63,91	-0,53	0,00	2,11	1,14	62,05	-0,53	0,00	3,68	2,02	1,00	0,00

Table 6 *Change per a+*

No.	Color	L(ref.)	a(ref.)	b(ref.)	L(ST)	a+(ST)	b(ST)	**ΔE*00**	Time (ST)[sec]	L(BND)	a+(BND)	b(BND)	**ΔE*00**	Time (BND) [sec]	L(UND)	a+(UND)	b(UND)	**ΔE*00**	Time (UND) [sec]	Time shift [sec]	No. of circular color anim.
1.	black 2 (1.5 D)	20,81	0,03	-0,39	20,81	-0,22	-0,39	0,37	20,31	20,81	3,65	-0,39	4,84	1,76	20,81	6,56	-0,39	8,05	3,06	1,00	0,00
2.	bluish green	70,69	-33,03	-0,11	70,69	-32,38	-0,11	0,27	12,48	70,69	-27,78	-0,11	2,27	2,85	70,69	-23,35	-0,11	4,42	4,83	3,00	0,00
3.	light skin	65,95	17,91	17,87	65,95	20,81	17,87	1,93	10,22	65,95	21,64	17,87	2,45	2,02	65,95	25,03	17,87	4,44	3,82	3,00	0,00
4.	yellow green	72,46	-23,30	57,00	72,46	-22,95	57,00	0,18	12,39	72,46	-23,07	57,00	0,12	0,13	72,46	-17,35	57,00	3,16	3,17	3,00	0,00
5.	dark skin	38,44	13,61	14,53	38,44	14,11	14,53	0,41	15,72	38,44	18,04	14,53	3,34	2,46	38,44	20,61	14,53	5,01	3,80	1,00	0,00
6.	blue sky	50,06	-4,52	-22,25	50,06	-4,17	-22,25	0,31	17,86	50,06	-0,20	-22,25	4,08	1,95	50,06	2,25	-22,25	6,51	3,04	1,00	0,00
7.	orange	62,65	35,35	57,86	62,65	35,55	57,86	0,11	11,86	62,65	43,98	57,86	4,44	4,28	62,65	46,08	57,86	5,46	5,21	2,00	0,00
8.	green	55,15	-37,80	31,64	55,15	-37,00	31,64	0,32	15,27	55,15	-31,27	31,64	2,74	3,50	55,15	-28,35	31,64	4,07	5,02	3,00	0,00
9.	neutral 8 (.23 D)	81,21	-0,64	0,27	81,21	0,16	0,27	1,18	18,50	81,21	2,39	0,27	4,35	1,74	81,21	4,61	0,27	7,10	2,88	1,00	0,00
10.	neutral 5 (.70 D)	50,83	-0,64	-0,14	50,83	-0,14	-0,14	0,73	20,37	50,83	2,74	-0,14	4,81	1,87	50,83	5,19	-0,14	7,75	3,12	3,00	0,00
11.	neutral 3.5 (1.05 D)	35,85	-0,54	-0,49	35,85	-0,34	-0,49	0,29	14,61	35,85	1,56	-0,49	3,08	0,96	35,85	4,36	-0,49	6,67	2,40	3,00	0,00
12.	foliage	43,28	-13,21	21,94	43,28	-13,46	21,94	0,17	12,90	43,28	-10,18	21,94	2,24	1,62	43,28	-7,73	21,94	4,23	2,94	3,00	0,00
13.	magenta	51,91	49,80	-13,82	51,91	51,35	-13,82	0,48	12,64	51,91	52,48	-13,82	0,83	1,27	51,91	56,92	-13,82	2,14	3,26	2,00	0,00
14.	cyan	50,72	-28,11	-27,95	50,72	-23,71	-27,95	2,08	13,71	50,72	-22,74	-27,95	2,56	2,90	50,72	-19,01	-27,95	4,48	4,86	1,00	0,00
15.	purple	30,50	21,07	-20,02	30,50	20,37	-20,02	0,42	13,03	30,50	24,34	-20,02	1,83	1,79	30,50	29,00	-20,02	4,17	4,27	3,00	0,00
16.	purplish blue	40,24	9,74	-44,35	40,24	11,29	-44,35	1,09	15,16	40,24	11,72	-44,35	1,40	1,07	40,24	14,87	-44,35	3,59	2,49	3,00	0,00
17.	moderate red	51,60	47,80	16,90	51,60	49,20	16,90	0,48	12,18	51,60	56,32	16,90	2,75	4,52	51,60	59,58	16,90	3,72	6,27	2,00	0,00
18.	yellow	82,27	4,02	79,99	82,27	6,02	79,99	1,16	14,95	82,27	9,97	79,99	3,46	2,95	82,27	13,12	79,99	5,29	4,64	3,00	0,00
19.	blue	28,87	14,81	-50,15	28,87	13,36	-50,15	0,99	25,82	28,87	18,54	-50,15	2,52	1,74	28,87	21,11	-50,15	4,21	3,04	2,00	0,00
20.	white 9.5 (.05 D)	96,53	-0,47	2,42	96,53	-0,12	2,42	0,51	11,65	96,53	7,81	2,42	10,38	4,10	96,53	-0,47	2,42	0,00	6,70	1,00	1,00
21.	red	42,28	54,12	28,67	42,28	53,87	28,67	0,09	13,25	42,28	56,80	28,67	0,93	1,47	42,28	60,54	28,67	2,16	3,40	3,00	0,00
22.	blue flower	55,31	8,82	-24,60	55,31	9,62	-24,60	0,66	13,99	55,31	11,85	-24,60	2,44	1,62	55,31	15,24	-24,60	4,93	3,42	2,00	0,00
23.	orange yellow	71,95	19,46	68,12	71,95	22,06	68,12	1,54	15,15	71,95	26,34	68,12	4,04	3,21	71,95	30,31	68,12	6,28	5,20	1,00	0,00
24.	neutral 6.5 (.44 D)	66,48	-0,53	0,00	66,48	-0,63	0,00	0,14	15,88	66,48	1,45	0,00	2,90	0,96	66,48	3,90	0,00	6,06	2,06	3,00	0,00

Table 7 *Change per a-*

No.	Color	L(ref.)	a(ref.)	b(ref.)	L(ST)	a-(ST)	b(ST)	**ΔE*00**	Time (ST)[sec]	L(BND)	a-(BND)	b(BND)	**ΔE*00**	Time (BND) [sec]	L(UND)	a-(UND)	b(UND)	**ΔE*00**	Time (UND) [sec]	Time shift [sec]	No. of circular color anim.
1.	**black 2 (1.5 D)**	20,81	0,03	-0,39	20,81	1,13	-0,39	1,59	11,21	20,81	-4,05	-0,39	5,39	2,21	20,81	-6,39	-0,39	7,93	3,46	1,00	0,00
2.	**bluish green**	70,69	-33,03	-0,11	70,69	-31,03	-0,11	0,83	10,68	70,69	-35,95	-0,11	1,15	1,34	70,69	-39,91	-0,11	2,62	3,39	3,00	0,00
3.	**light skin**	65,95	17,91	17,87	65,95	21,11	17,87	2,12	10,21	65,95	14,06	17,87	2,89	2,13	65,95	11,84	17,87	4,74	3,26	2,00	0,00
4.	**yellow green**	72,46	-23,30	57,00	72,46	-22,80	57,00	0,25	11,99	72,46	-28,90	57,00	2,72	2,57	72,46	-30,88	57,00	3,63	3,62	2,00	0,00
5.	**dark skin**	38,44	13,61	14,53	38,44	15,31	14,53	1,35	12,06	38,44	9,53	14,53	3,68	2,21	38,44	7,08	14,53	6,20	3,55	1,00	0,00
6.	**blue sky**	50,06	-4,52	-22,25	50,06	-3,72	-22,25	0,72	12,42	50,06	-5,57	-22,25	0,92	0,56	50,06	-9,19	-22,25	3,84	2,52	3,00	0,00
7.	**orange**	62,65	35,35	57,86	62,65	37,20	57,86	0,99	11,16	62,65	30,45	57,86	2,71	2,21	62,65	26,83	57,86	4,80	4,20	3,00	0,00
8.	**green**	55,15	-37,80	31,64	55,15	-38,95	31,64	0,45	12,78	55,15	-43,52	31,64	2,18	2,84	55,15	-46,90	31,64	3,38	4,33	3,00	0,00
9.	**neutral 8 (.23 D)**	81,21	-0,64	0,27	81,21	-0,29	0,27	0,51	12,90	81,21	-3,67	0,27	3,97	1,37	81,21	-5,54	0,27	6,08	2,32	1,00	0,00
10.	**neutral 5 (.70 D)**	50,83	-0,64	-0,14	50,83	0,31	-0,14	1,41	11,98	50,83	-2,74	-0,14	2,83	1,01	50,83	-5,54	-0,14	6,08	2,33	3,00	0,00
11.	**neutral 3.5 (1.05 D)**	35,85	-0,54	-0,49	35,85	-0,64	-0,49	0,14	17,94	35,85	-3,92	-0,49	4,42	1,81	35,85	-6,14	-0,49	6,86	2,97	3,00	0,00
12.	**foliage**	43,28	-13,21	21,94	43,28	-12,56	21,94	0,46	12,51	43,28	-16,24	21,94	2,02	1,66	43,28	-19,51	21,94	3,98	3,18	1,00	0,00
13.	**magenta**	51,91	49,80	-13,82	51,91	51,20	-13,82	0,44	11,07	51,91	45,95	-13,82	1,25	2,07	51,91	43,03	-13,82	2,25	3,44	3,00	0,00
14.	**cyan**	50,72	-28,11	-27,95	50,72	-21,61	-27,95	3,13	8,83	50,72	-34,53	-27,95	2,80	2,92	50,72	-38,73	-27,95	4,50	5,06	1,00	0,00
15.	**purple**	30,50	21,07	-20,02	30,50	20,97	-20,02	0,06	14,03	30,50	16,29	-20,02	3,05	2,26	30,50	13,72	-20,02	4,90	3,62	3,00	0,00
16.	**purplish blue**	40,24	9,74	-44,35	40,24	10,39	-44,35	0,46	12,35	40,24	5,19	-44,35	3,21	2,16	40,24	2,62	-44,35	5,01	3,34	2,00	0,00
17.	**moderate red**	51,60	47,80	16,90	51,60	49,95	16,90	0,73	10,55	51,60	40,80	16,90	2,57	3,23	51,60	37,30	16,90	3,98	4,89	2,00	0,00
18.	**yellow**	82,27	4,02	79,99	82,27	2,27	79,99	1,01	14,30	82,27	0,40	79,99	2,09	1,98	82,27	-2,98	79,99	4,03	3,74	2,00	0,00
19.	**blue**	28,87	14,81	-50,15	28,87	12,46	-50,15	1,61	20,24	28,87	10,49	-50,15	2,96	2,30	28,87	8,39	-50,15	4,40	3,37	2,00	0,00
20.	**white 9.5 (.05 D)**	96,53	-0,47	2,42	96,53	0,48	2,42	1,39	13,68	96,53	-3,39	2,42	3,88	1,41	96,53	-6,19	2,42	7,04	2,85	1,00	0,00
21.	**red**	42,28	54,12	28,67	42,28	54,62	28,67	0,18	14,94	42,28	47,82	28,67	2,35	3,40	42,28	45,95	28,67	3,10	4,34	2,00	0,00
22.	**blue flower**	55,31	8,82	-24,60	55,31	8,87	-24,60	0,04	13,14	55,31	5,32	-24,60	3,03	1,93	55,31	2,29	-24,60	5,79	3,48	2,00	0,00
23.	**orange yellow**	71,95	19,46	68,12	71,95	19,36	68,12	0,06	12,18	71,95	15,96	68,12	2,11	1,86	71,95	12,23	68,12	4,40	3,79	3,00	0,00
24.	**neutral 6.5 (.44 D)**	66,48	-0,53	0,00	66,48	-1,08	0,00	0,78	12,98	66,48	-2,28	0,00	2,40	0,99	66,48	-4,61	0,00	5,22	2,20	2,00	0,00

Table 8 *Change per b+*

No.	Color	L(ref.)	a(ref.)	b(ref.)	L(ST)	a(ST)	b+(ST)	**ΔE*00**	Time (ST)[sec]	L(BND)	a(BND)	b+(BND)	**ΔE*00**	Time (BND) [sec]	L(UND)	a(UND)	b+(UND)	**ΔE*00**	Time (UND) [sec]	Time shift [sec]	No. of circular color anim.
1.	black 2 (1.5 D)	20,81	0,03	-0,39	20,81	0,03	-1,54	1,10	23,00	20,81	0,03	3,11	3,30	1,70	20,81	0,03	5,09	4,97	2,59	1,00	0,00
2.	bluish green	70,69	-33,03	-0,11	70,69	-33,03	0,54	0,43	13,92	70,69	-33,03	4,09	2,76	2,31	70,69	-33,03	6,66	4,39	3,62	3,00	0,00
3.	light skin	65,95	17,91	17,87	65,95	17,91	19,42	1,00	12,04	65,95	17,91	23,00	3,21	2,32	65,95	17,91	25,80	4,83	3,69	1,00	0,00
4.	yellow green	72,46	-23,30	57,00	72,46	-23,30	57,95	0,30	14,98	72,46	-23,30	61,55	1,41	2,31	72,46	-23,30	64,58	2,31	3,64	2,00	0,00
5.	dark skin	38,44	13,61	14,53	38,44	13,61	13,83	0,49	13,58	38,44	13,61	17,68	2,12	1,72	38,44	13,61	20,36	3,82	2,95	2,00	0,00
6.	blue sky	50,06	-4,52	-22,25	50,06	-4,52	-22,50	0,11	14,74	50,06	-4,52	-20,38	0,87	0,96	50,06	-4,52	-15,72	3,33	3,48	3,00	0,00
7.	orange	62,65	35,35	57,86	62,65	35,35	58,96	0,42	12,18	62,65	35,35	65,09	2,65	3,48	62,65	35,35	67,78	3,57	4,71	1,00	0,00
8.	green	55,15	-37,80	31,64	55,15	-37,80	33,34	0,72	16,45	55,15	-37,80	34,32	1,13	1,44	55,15	-37,80	38,64	2,88	3,51	3,00	0,00
9.	neutral 8 (.23 D)	81,21	-0,64	0,27	81,21	-0,64	-0,88	1,13	13,63	81,21	-0,64	3,77	3,21	1,88	81,21	-0,64	5,99	5,03	2,87	2,00	0,00
10.	neutral 5 (.70 D)	50,83	-0,64	-0,14	50,83	-0,64	-0,84	0,68	13,79	50,83	-0,64	1,84	1,90	1,07	50,83	-0,64	4,53	4,25	2,48	2,00	0,00
11.	neutral 3.5 (1.05 D)	35,85	-0,54	-0,49	35,85	-0,54	0,46	0,94	11,76	35,85	-0,54	3,36	3,61	2,12	35,85	-0,54	5,58	5,45	3,25	1,00	0,00
12.	foliage	43,28	-13,21	21,94	43,28	-13,21	22,29	0,19	13,55	43,28	-13,21	27,89	3,02	3,21	43,28	-13,21	30,81	4,38	4,78	2,00	0,00
13.	magenta	51,91	49,80	-13,82	51,91	49,80	-12,87	0,44	11,91	51,91	49,80	-8,57	2,45	2,84	51,91	49,80	-6,12	3,62	4,11	1,00	0,00
14.	cyan	50,72	-28,11	-27,95	50,72	-28,11	-27,60	0,16	12,79	50,72	-28,11	-23,52	2,08	2,01	50,72	-28,11	-20,48	3,63	3,48	2,00	0,00
15.	purple	30,50	21,07	-20,02	30,50	21,07	-19,67	0,21	13,00	30,50	21,07	-15,00	3,04	2,30	30,50	21,07	-12,79	4,39	3,45	1,00	0,00
16.	purplish blue	40,24	9,74	-44,35	40,24	9,74	-43,25	0,52	12,88	40,24	9,74	-41,08	1,57	1,51	40,24	9,74	-37,93	3,17	2,96	3,00	0,00
17.	moderate red	51,60	47,80	16,90	51,60	47,80	18,15	0,69	17,28	51,60	47,80	21,33	2,45	2,42	51,60	47,80	23,67	3,73	3,67	3,00	0,00
18.	yellow	82,27	4,02	79,99	82,27	4,02	86,04	1,29	20,01	82,27	4,02	85,01	1,07	2,55	82,27	4,02	85,01	1,07	9,81	3,00	1,00
19.	blue	28,87	14,81	-50,15	28,87	14,81	-51,30	0,54	12,75	28,87	14,81	-48,52	0,78	0,90	28,87	14,81	-46,88	1,58	1,81	3,00	0,00
20.	white 9.5 (.05 D)	96,53	-0,47	2,42	96,53	-0,47	4,12	1,49	10,57	96,53	-0,47	8,14	4,63	2,81	96,53	-0,47	14,44	8,73	6,18	1,00	0,00
21.	red	42,28	54,12	28,67	42,28	54,12	30,07	0,72	11,40	42,28	54,12	33,80	2,62	2,78	42,28	54,12	36,95	4,19	4,17	3,00	0,00
22.	blue flower	55,31	8,82	-24,60	55,31	8,82	-24,40	0,13	12,86	55,31	8,82	-21,68	1,91	1,33	55,31	8,82	-19,12	3,63	2,56	1,00	0,00
23.	orange yellow	71,95	19,46	68,12	71,95	19,46	68,02	0,03	12,71	71,95	19,46	73,49	1,48	2,90	71,95	19,46	76,64	2,31	4,58	1,00	0,00
24.	neutral 6.5 (.44 D)	66,48	-0,53	0,00	66,48	-0,53	0,05	0,05	16,39	66,48	-0,53	1,98	1,90	0,91	66,48	-0,53	4,20	3,84	1,88	3,00	0,00

Table 9 *Change per b-*

No.	Color	L(ref.)	a(ref.)	b(ref.)	L(ST)	a(ST)	b-(ST)	**ΔE*00**	Time (ST)[sec]	L(BND)	a(BND)	b-(BND)	**ΔE*00**	Time (BND) [sec]	L(UND)	a(UND)	b-(UND)	**ΔE*00**	Time (UND) [sec]	Time shift [sec]	No. of circular color anim.
1.	black 2 (1.5 D)	20,81	0,03	-0,39	20,81	0,03	-1,24	0,82	12,51	20,81	0,03	-3,54	2,89	1,73	20,81	0,03	-5,52	4,53	2,75	1,00	0,00
2.	bluish green	70,69	-33,03	-0,11	70,69	-33,03	1,44	1,03	20,09	70,69	-33,03	-2,79	1,80	1,19	70,69	-33,03	-5,24	3,45	2,32	3,00	0,00
3.	light skin	65,95	17,91	17,87	65,95	17,91	20,62	1,76	11,32	65,95	17,91	13,55	2,93	2,06	65,95	17,91	10,64	5,00	3,62	1,00	0,00
4.	yellow green	72,46	-23,30	57,00	72,46	-23,30	58,70	0,54	12,90	72,46	-23,30	50,93	2,01	2,90	72,46	-23,30	47,90	3,08	4,26	3,00	0,00
5.	dark skin	38,44	13,61	14,53	38,44	13,61	16,08	1,06	11,21	38,44	13,61	11,15	2,42	1,57	38,44	13,61	8,11	4,67	2,97	2,00	0,00
6.	blue sky	50,06	-4,52	-22,25	50,06	-4,52	-21,15	0,51	16,26	50,06	-4,52	-27,03	1,99	2,38	50,06	-4,52	-29,72	2,98	3,75	2,00	0,00
7.	orange	62,65	35,35	57,86	62,65	35,35	57,91	0,02	12,19	62,65	35,35	53,54	1,70	2,35	62,65	35,35	51,91	2,37	3,24	3,00	0,00
8.	green	55,15	-37,80	31,64	55,15	-37,80	32,44	0,34	11,76	55,15	-37,80	27,67	1,74	1,76	55,15	-37,80	24,87	3,02	3,04	2,00	0,00
9.	neutral 8 (.23 D)	81,21	-0,64	0,27	81,21	-0,64	0,47	0,20	12,59	81,21	-0,64	-3,58	3,59	2,07	81,21	-0,64	-6,61	6,05	3,58	2,00	0,00
10.	neutral 5 (.70 D)	50,83	-0,64	-0,14	50,83	-0,64	0,51	0,64	16,26	50,83	-0,64	-2,36	2,10	1,04	50,83	-0,64	-4,69	4,10	2,15	3,00	0,00
11.	neutral 3.5 (1.05 D)	35,85	-0,54	-0,49	35,85	-0,54	-1,34	0,81	13,33	35,85	-0,54	-3,99	3,18	1,86	35,85	-0,54	-6,56	5,24	3,01	3,00	0,00
12.	foliage	43,28	-13,21	21,94	43,28	-13,21	22,29	0,19	12,12	43,28	-13,21	18,91	1,68	1,62	43,28	-13,21	16,57	3,03	2,65	2,00	0,00
13.	magenta	51,91	49,80	-13,82	51,91	49,80	-14,22	0,18	13,05	51,91	49,80	-19,07	2,39	2,40	51,91	49,80	-22,10	3,74	3,76	1,00	0,00
14.	cyan	50,72	-28,11	-27,95	50,72	-28,11	-26,85	0,50	12,95	50,72	-28,11	-33,67	2,42	3,01	50,72	-28,11	-38,45	4,25	5,22	2,00	0,00
15.	purple	30,50	21,07	-20,02	30,50	21,07	-20,42	0,24	13,47	30,50	21,07	-25,15	3,09	2,32	30,50	21,07	-27,84	4,68	3,59	1,00	0,00
16.	purplish blue	40,24	9,74	-44,35	40,24	9,74	-43,85	0,23	11,90	40,24	9,74	-48,67	1,94	2,04	40,24	9,74	-51,70	3,23	3,39	1,00	0,00
17.	moderate red	51,60	47,80	16,90	51,60	47,80	18,00	0,61	12,42	51,60	47,80	11,53	2,95	2,85	51,60	47,80	8,85	4,41	4,27	1,00	0,00
18.	yellow	82,27	4,02	79,99	82,27	4,02	87,24	1,53	10,11	82,27	4,02	75,79	0,94	2,13	82,27	4,02	71,71	1,89	4,08	3,00	0,00
19.	blue	28,87	14,81	-50,15	28,87	14,81	-51,90	0,82	13,13	28,87	14,81	-54,58	2,03	2,37	28,87	14,81	-56,68	2,95	3,50	3,00	0,00
20.	white 9.5 (.05 D)	96,53	-0,47	2,42	96,53	-0,47	8,92	5,19	7,99	96,53	-0,47	-3,18	5,37	2,66	96,53	-0,47	-8,08	9,42	5,25	1,00	0,00
21.	red	42,28	54,12	28,67	42,28	54,12	30,82	1,10	11,39	42,28	54,12	23,54	2,67	2,62	42,28	54,12	20,15	4,44	4,17	2,00	0,00
22.	blue flower	55,31	8,82	-24,60	55,31	8,82	-23,95	0,42	14,55	55,31	8,82	-25,30	0,45	0,41	55,31	8,82	-29,50	3,06	2,60	3,00	0,00
23.	orange yellow	71,95	19,46	68,12	71,95	19,46	69,07	0,27	17,59	71,95	19,46	63,45	1,37	2,46	71,95	19,46	58,67	2,87	4,88	2,00	0,00
24.	neutral 6.5 (.44 D)	66,48	-0,53	0,00	66,48	-0,53	-0,25	0,25	12,50	66,48	-0,53	-2,45	2,32	1,32	66,48	-0,53	-4,78	4,32	2,56	3,00	0,00

By calculating the average value of ΔE* of the respondent for certain parts of the color space, a conclusion can be drawn about the general sensitivity of the respondents to differences in colors.

The mean value ΔE*00 was calculated for one respondent on behalf of the results obtained in the previous tables for each color covered by the test. (Table 10)

Table 10 *Mean value ΔE^*_{00} for ST, BND and UND*

ST ΔE^*_{00}	***BND ΔE^*_{00}***	***UND ΔE^*_{00}***	***COLOR***
0.80	*3.69*	*5.85*	***black 2 (1.5 D)***
0.60	*2.34*	*4.07*	***bluish green***
1.33	*2.87*	*4.65*	***light skin***
0.32	*1.81*	*3.30*	***yellow green***
0.70	*3.49*	*5.51*	***dark skin***
0.59	*2.48*	*4.62*	***blue sky***
0.67	*2.79*	*4.27*	***orange***
0.41	*2.44*	*3.97*	***green***
0.62	*3.58*	*5.73*	***neutral 8 (.23 D)***
0.90	*2.38*	*5.13*	***neutral 5 (.70 D)***
0.69	*3.43*	*5.98*	***neutral 3.5 (1.05 D)***
0.53	*2.82*	*4.78*	***foliage***
0.52	*1.94*	*3.59*	***magenta***
1.27	*2.22*	*4.46*	***cyan***
0.31	*2.63*	*4.71*	***purple***
0.62	*2.01*	*4.11*	***purplish blue***
0.83	*3.06*	*4.57*	***moderate red***
1.18	*2.51*	*3.72*	***yellow***
1.06	*2.30*	*3.76*	***blue***
1.68	*4.82*	*5.07*	***white 9.5 (.05 D)***
0.57	*2.70*	*4.50*	***red***
0.33	*2.02*	*4.25*	***blue flower***
0.45	*2.70*	*4.39*	***orange yellow***
0.36	*2.06*	*4.39*	***neutral 6.5 (.44 D)***
0.72	***2.71***	***4.56***	***Average ΔE^*_{00} for all the colors covered by the test.***

A table of sensitivity to color differences for all colors covered by the test for one respondent can be established. (Table 11)

Table 11 *Sensitivity to color differences for all colors covered by the test*

$\Delta E_{00} \leq 0.72$	*The difference is not noticeable.*
$\Delta E_{00} \leq 2.71$	*The difference is acceptable.*
$2.71 < \Delta E_{00} < 4.56$	*The difference is clearly visible.*
$4.56 \leq \Delta E_{00}$	*The difference is visible and not acceptable.*

4. Conclusion

Real differences, which must be attributed to differences in the color vision of the individual observers, can be determined by a color difference vision test proposed in this paper.

The real color difference can be straightforwardly expressed in ΔE* units. One can conclude exactly the ΔE* of color difference the subject can perceive, and that unit is comparable with objective units taken by instrumental measuring.

One can express a table of sensitivity to color differences for any specific color covered by the test and that data can be used for perceptual interpretation for any color used for spot color printing, painting in the automotive industry, or evaluating colors for medical purposes.

One can say that the results obtained in this work meet the results published earlier by Schapler [4] and Hardeberg [5].

5. Rereferences

[1] R. Hunt, “Colour Standards and Calculations,” in The Reproduction of Colour, John Wiley & Sons, Ltd, 2004, pp. 92-125.

[2] D. Nyström, Colorimetric and Multispectral Image Acquisition, Norrköping: Dept. of Science and Technology, 2006.

[3] B. Fraser, C. Murphy and F. Bunting, Real World Color Management, 2nd ed., 2004.

[4] K. Schläpfer, Farbmetrik in der Reproduktionstechnik und im Mehrfarbendruck. 2. izd., St. Gallen.: UGRA, 1993.

[5] J. Y. Hardeberg, Acquisition and Reproduction of Color Images: Colorimetric and Multispectral Approaches., Universal-Publishers, 2001.

[6] “www.xrite.com,” [Online]. Available: https://www.xrite.com/categories/visual-assessment-tools/fm-100-hue-test. [Accessed 15 9 2022].

[7] Gazibarić, Z; Cviljušac, V; Živković, P; Mrvac, N, “A Method for Evaluating Human Observer's Perception of Color Differences,” Technical Gazette, vol. 28, no. 6, pp. 2094-2101, 2021. Karimifard, S., Moghaddam, M., Application of response surface methodology in physicochemical removal of dyes from wastewater: A critical review, Sci. Total Environ. 640-641 (2018) 772-797.