CROATICA CHEMICA ACTA CCACAA **70** (4) 955–969 (1997)

ISSN-0011-1643
CCA-2467

Original Scientific Paper

Range Definition of Acceptable Differences of Chromatic Value by Color Measurement and Visual Estimation

Nina Knešaurek

Faculty of Graphic Arts,
HR 10000 Zagreb, Getaldićeva 2

Received May 20, 1996; revised June 12, 1997; accepted June 25, 1997

Under the defined conditions, 24 samples, considered to be similar to the chosen standards in their chromatic characteristics, were chosen by the visual method among 126 similar samples. The standard and all the tested (investigated) samples were measured on the spectral photometer. The measured reflenctancies were recalculated into numerical values of CIELAB. Based on the data obtained by the instrumental method, the developed differences of 24 visually similar samples were calculated and analyzed. The limits of the visual judgment expressed as ΔL^*, ΔH^*_{ab}, ΔC^*_{ab}, were numerically defined. The developed color differences are usually defined by one numerical data, *i.e.*, ΔE^*_{ab}. Based on the analysis of the calculated chromatic values of CIELAB and their chromatic influence in the visual estimation of the change of the expression of ΔE^*_{ab}, it is suggested to use three numerical values, ΔL^*, ΔH^*_{ab}, ΔC^*_{ab}, to define color differences. In this way, the values that caused the developed differences can be defined.

INTRODUCTION

Color sensation represents an individual experience. Whenever the observing conditions are defined, the color sensation itself is determined by the physiology of the eye and recognition of the observed in the conscience.[1] Man, as a participant in the world of colors which surround him, has often a chance to compare them. The aim of comparing can be to find the colors with the chromatic characteristics visually most similar to some defined color. Because of the great importance of quality reproduction of the desired color for marketing or graphic reproduction, color sensation and visual perception are not applicable in cases when it is not possible to express them numerically. Various measuring devices have been constructed to express the visual perception numerically. It is required from the measuring instruments that the sensitivity of instruments for measuring chromatic values should be more similar to the sensitivity of human eye. The measuring results have been recalculated into tristimulus values X,Y,Z which, when expressed as three numbers, define color in space.[2]

The color space has been transformed with time in order to show the same visual differences to be equal numerically and in space.[3] In 1976, CIE defined two such systems, called CIELAB and CIELUV color systems, according to the axes which determine them in space.[4]

The mentioned systems are widely used today in industry and scientific research.

Whenever it is necessary to compare the reproduced color with the existing defined one, visual evaluation or instrumental measuring is often used as the standard.

Up to now, no system has been absolutely accepted and completely finished. Individual perception represents the first changeable variable, which is influenced by various factors such as the experience, motivation and the age of observers who evaluate the characteristics of two colors. The observing conditions and measurements have been defined by CIE in order to standardize all the factors that have outer influence on color experience. This process involves the use of defined sample illumination, defined angle of observation and reflectance measuring (transmittance) of the colored sample, and defined values of the lightness of neutral background.[5] Based on numerous individual measurements, the standard observer has been determined, representing numerous processed statistical data of individual experiences of color stimulus. The color space defined as CIELAB[6] space has been determined by three axes of the plane (Figure 1).

These are axes a^* and b^*, *i.e.*, axes of undefined length in which the intersection is under the right angle and which can have positive and negative values. Vertically to their intersection, there is the third axis, the axis with the lightness L^* having a value range from 0 to 100.

Axis a^* represents the red-greenish axis, and axis b^* represents the yellow-bluish axis.

Tristimulus values X,Y,Z, which will be modified into the values of CIELAB system by using mathematical expressions, are given by the following equations:

$$X = k \sum_{\lambda} S(\lambda)\, R(\lambda)\, \bar{x}(\lambda)\, \Delta\lambda \qquad (1)$$

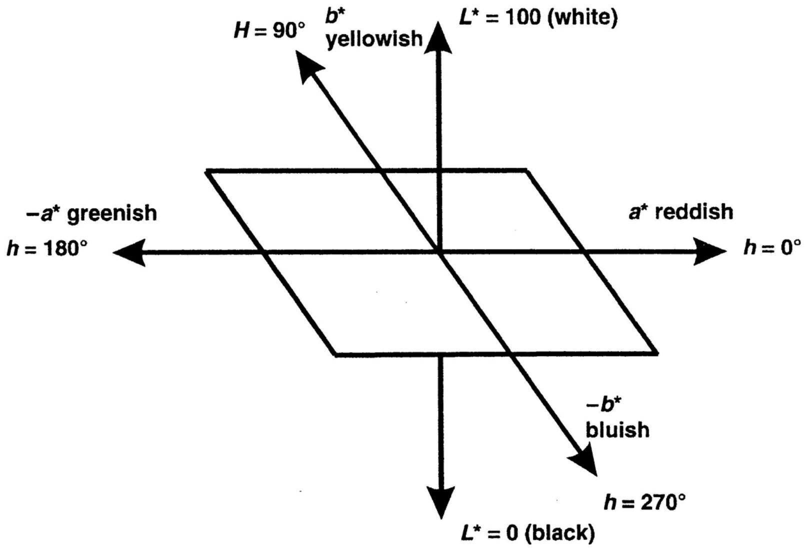

Figure 1. The CIELAB space in 3 dimensions.

$$Y = k \sum_{\lambda} S(\lambda)\, R(\lambda)\, \bar{y}(\lambda)\, \Delta\lambda \qquad (2)$$

$$Z = k \sum_{\lambda} S(\lambda)\, R(\lambda)\, \bar{z}(\lambda)\, \Delta\lambda \qquad (3)$$

$$k = 100 \,/\, \sum_{\lambda} S(\lambda)\, R(\lambda)\, \bar{y}(\lambda)\, \Delta\lambda \qquad (4)$$

where $S(\lambda)$ represents the relative quantity of light energy which is emitted from the standard light sources in particular parts of the spectrum. $R(\lambda)$ is the spectral reflectance (transmittance) of the sample. The values of the imaginary distribution coefficients, which refer to stimulus colors that depend on wavelength (λ), are expressed as $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$. k represents the normalization factor which differs in absolute and relative colorimetry. CIELAB values have been determined from the following expressions:

$$L^* = 116\,(Y/Y_o)^{1/3} - 16 \qquad (5)$$

$$a^* = 500\,[(X/X_o)^{1/3} - (Y/Y_o)^{1/3}] \qquad (6)$$

$$b^* = 200\,[(Y/Y_o)^{1/3} - (Z/Z_o)^{1/3}] \qquad (7)$$

X_o, Y_o, Z_o are the defined values for the white standard with the defined illumination and defined measuring angle. Inside this space there are all the colors that can be defined by stimulus. During the reproduction process, the characteristics of color can be changed. If these changes are small, the color is within the tolerance range.[7] The whole difference of two colors is often expressed by means of the following expression:

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \tag{8}$$

where ΔL^*, Δa^*, and Δb^* represent the difference of the chromatic values in the relation: value of standard – value of the sample. Is it possible to determine visually the space inside which the changes of three chromatic values can be accepted? What is the relation of the visual estimation and the measured numerical data which represent it? Does the accepted expression of the complete difference of two colors ΔE^*_{ab} really represent the visual difference, or is it only a mathematically correct expression for expressing the distance of two points (of color) in space? Is it possible to analyze the causes of tolerance? How can the tolerance limit be determined?

The purpose of this paper is to answer these questions.

EXPERIMENTAL

The yellow printed sample, taken as the standard, together with 126 printed yellow samples, visually similar but having different chromatic values, were used in the experiment. The space for visual estimation was defined. Samples were numbered at random. Visual estimation was done under the defined observation conditions. The space where the samples were compared was the inside of a medium gray illuminated booth. The light source was D65, the luminance of the room determined by Minolta CS-100 was $Y = 380$ c dm^{-1}, the visual angle of observation was 45° (geometry 0/45). Reflection of the gray surface with the compared samples on it was 14–15%, and it was determined by a portable spectral photometer Gretag SP M 60. 126 samples were compared with the standard. The procedure was repeated twice. The χ^2 test for equality of covariance of the matrix is determined by the fact that the difference between the first and second comparisons is statistically significant.[8] The samples which were visually found to satisfy were separated from the rest. Reflection of the standard and all tested samples was measured on a Hunter Lab Ultra Scan spectral colorimeter. The measured values are relative in relation to the measured absolute values of the ideal white diffuser under the same geometrical conditions.

The range of the wavelengths in which the measurements were performed was 375 to 750 nm in 5 nm intervals. Ultra Scan software enabled integration of tristimulus values of reflectance from 375 to 750 nm in X,Y,Z values. These values simulate the corresponding functions of spectral values of the observer, defined as the 10^0 CIE standard observer.

Immediately before the measurements, the instrument was calibrated with white, gray and black standards. Measuring geometry was d/o SPEX, a greater gap was used during measurements, UV filter was removed and the light source was made stronger by UV beams. Based on the measured reflectance and using mathematical expressions, L^*, a^* and b^* values of the standard and 126 samples were used. All the other values, such as chroma C^*_{ab}, differences expressed as Δ, hue difference ΔH^*_{ab}, in all used expressions, and the whole color difference ΔE^*_{ab} were calculated later. After visual estimation, 24 samples were separated. The observers thought their colorimetric characteristics to be equal to the standard.

From all the changes of color characteristics, the observer is most sensitive to the change of hue.[9] This is the reason for the appearance of numerous expressions aimed at determining the hue difference. Only three expressions are quoted in the article. They are:

$$\Delta H^*_{ab} = [(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2]^{1/2} \tag{9}$$

$$\Delta H^*_{ab1} = 2\ (C_1{}^*C_2)^{1/2} \sin\ (\Delta h/2) \tag{10}$$

$$\Delta H^*_{ab2} = C^*\Delta h\ (\pi/180) \tag{11}$$

Expression ΔH^*_{ab} is recommended by CIE and this is the commonly mentioned expression in literature. But, as errors in adjusting the printing ink hue can appear in practical usage of the mentioned example, the expression has been transformed.[10] In this way, the hue difference ΔH^*_{ab} is separated from the change of lightness ΔL^* and the whole change ΔE^*_{ab}. Expression ΔH^*_{ab} is always positive due to the use of square root, while the real hue difference in space can appear in two directions in relation to the standard. Therefore, the change of the color hue can have the mark ± and, in this way, it is not spatially undetermined. Expression ΔH^*_{ab} determines the change direction of the hue and at the same time, due to the decreased number of variables, it reduces the errors which appear by rounding the values into a smaller number. If angle Δh is small, and $C_1{}^*$ is very close to $C_2{}^*$, expression ΔH^*_{ab2} is used.[11] According to the new expressions, the hue difference depends on the chroma of the standard and on the tested sample. Chroma C^*_{ab} is determined from the following expression:

$$C^*_{ab} = [(a^*)^2 + (b^*)^2]^{1/2} \tag{12}$$

RESULTS AND DISCUSSION

Standard chromatic values have been measured in all samples. They are given in the tables as the values of the CIELAB system. 24 samples were separated by visual estimation, to be judged very similar to the standard on the basis of their colorimetric characteristics. Visual estimation was performed twice on two different days. As the differences between the estimations are small (of 24 chosen samples in the first estimation, two of them did not appear in the second visual estimation), the discussion concerning the results refers to one of the visual estimations. Numerical data which refer to twenty four chosen data are presented in the work.

Values of the measured standard and samples, as well as the calculated differences are given in Tables I and II.

Using the program which draws the standard and samples in dependence on axes L^*b^*, L^*a^*, a^*b^*, ellipses have been obtained. Their inner surface represents the tolerance area of the observer. 50% of the samples are inside the smaller ellipse, and 95% in the larger one.

Table I refers to the increasing chromatic values b^* of sample 77 which has the value b^* 79.33 CIELAB units to sample 65 with 85.42 CIELAB units. This is at the same time the widest range of values covered by the observer and the value is 6.09 CIELAB units. The difference in value L^* is 3.75 CIELAB units, and the value a^* 4.53 CIELAB units.

In addition, Table I gives the differences of particular values ΔL^*, Δa^*, Δb^*, ΔC^*_{ab}, ΔH^*_{ab1}, in relation to the standard. The difference in the change of chroma ΔC^*_{ab} in most samples follows the change of Δb^*. Considerable deviations from that order appear in the cases where Δa^* considerably differs from the previous values in the column (samples 81, 78, 51, 10 and 31). As the chroma difference depends only on values a^* and b^*, the considerable change of value a^* in Table I causes discontinuity of the value growth of ΔC^*_{ab}.

The change of lightness ΔL^*, chromatic values Δa^* and hue difference ΔH^*_{ab1}, are independent in their deviations in relation to value Δb^*. The hue difference in expression ΔH^*_{ab1} depends on the chroma of the sample and standard, as well as on the change of the hue angle, h.

In Table II, the total colour differences ΔE^*_{ab}, ΔE^*_{CMC},[12] ΔE^*_{94}[13] and the hue difference ΔH^*_{ab}, ΔH^*_{ab1}, ΔH^*_{ab2} are arranged from the smallest to the greatest value ΔE^*_{ab}.

It is seen from the table that ΔH^*_{ab} is always expressed with positive values. The positive value goes out from the form of the expression which ΔH^*_{ab} presents as the square root of the difference of the squares of the total difference, the differences in lightness and the differences in chroma. Expressions ΔH^*_{ab1} and ΔH^*_{ab2} have positive and negative values. The value is negative in the cases when the samples have the hue angle smaller than the hue angle of the standard. Samples 32 and 65 have the smallest hue difference. Their relation according to the total difference of the color does not show this. The greatest total difference appears because that sample has the biggest value Δb^* relative to the other Δb^* values. Sample 50 has the biggest hue difference of 2.9088 CIELAB units, but as to the size ΔE^*_{ab} it has the 21st place. Sample 10 has the smallest total difference of ΔE^*_{ab} = 0.4766 CIELAB units with the change of color hue = 0.4582 CIELAB units, which is the 8th place among 24 samples. The result is that the numerical value of the total difference does not give an insight into the change of the colorimetric characteristics of the samples in relation to standard. Previous investigation leads to the conclusion that expression ΔE^*_{ab} is data without

TABLE I

The chromatic value of the standard and visually chosen sample from the smallest to the greatest b^* value and the value difference ΔL^*, Δa^*, Δb^*, ΔC^*_{ab1}, ΔH^*_{ab1}, relative to the standard

Standard	L^* 63.39		a^* 17.39		b^* 82.10		C^*_{ab} 83.92		h 78.04	
Sample No.	L^*	ΔL^*	a^*	Δa^*	b^*	Δb^*	C^*_{ab}	ΔC^*	h	ΔH^*_{ab1}
77	62.20	−1.19	18.75	1.3633	79.33	−2.77	81.5157	−2.4051	76.7019	−1.9315
76	63.01	−0.38	16.72	−0.6666	80.01	−2.09	81.7383	−2.1824	78.1965	0.2262
81	62.13	−1.26	17.90	0.5133	80.24	−1.86	82.2123	−1.7085	77.4243	−0.8925
52	63.81	0.42	15.80	−1.5866	80.42	−1.68	81.9574	−1.9634	78.8847	1.2226
57	63.25	−0.14	16.03	−1.3566	80.48	−1.62	82.0608	−1.8599	78.7352	1.0069
32	63.67	0.28	17.10	−0.2866	80.83	−1.27	82.6189	−1.3018	78.0549	0.0216
73	63.21	−0.18	17.49	0.1033	80.89	−1.21	82.7592	−1.1615	77.7993	−0.3501
78	63.13	−0.26	20.11	2.7233	81.21	−0.89	83.6628	−0.2579	76.0916	−2.8492
72	63.58	0.19	15.85	−1.5366	81.42	−0.68	82.9484	−0.9724	78.9840	1.3746
27	63.96	0.57	16.61	−0.7766	81.43	−0.67	83.1067	−0.8140	78.4710	0.6282
56	64.60	1.21	17.20	−0.1866	81.57	−0.53	83.3636	−0.5571	78.0929	0.0772
11	62.39	−1.00	19.07	1.6833	81.74	−0.36	83.9350	0.0142	76.8677	−1.7171
26	63.52	0.13	18.44	1.0533	81.80	−0.30	83.8526	−0.0681	77.2962	−1.0888
51	64.79	1.40	17.33	−0.0566	81.87	−0.23	83.6840	−0.2367	78.0482	0.0117
50	64.54	1.15	20.33	2.9433	81.92	−0.18	84.4049	0.4841	76.0625	−2.9046
71	64.57	1.18	18.67	1.2833	82.17	0.07	84.2643	0.3435	77.1990	−1.2343
10	63.25	−0.14	16.95	−0.4366	82.23	0.13	83.9587	0.0379	78.3528	0.4582
30	64.51	1.12	19.27	1.8833	82.39	0.29	84.6135	0.6926	76.8358	−1.7708
31	64.30	0.91	17.24	−0.1466	82.61	0.51	84.3897	0.4689	78.2120	0.2526
45	65.88	2.49	18.52	1.1333	83.04	0.94	85.0801	1.1593	77.4273	−0.9034
68	64.07	0.68	17.14	−0.2466	83.39	1.29	85.1332	1.2124	78.3851	0.5092
21	64.74	1.35	16.88	−0.5066	84.82	2.72	86.4833	2.5624	78.7446	0.9905
22	65.40	2.01	18.51	1.1233	84.86	2.76	86.8552	2.9344	77.6951	−0.5139
65	65.17	1.78	18.05	0.6633	85.42	3.32	87.3062	3.3854	78.0684	0.0424

TABLE II

The total color differences and the hue difference from the lowest value to the higest ΔE^*_{ab}

Sample No.	ΔE^*_{ab}	ΔE^*_{cmc}	ΔE^*_{94}	ΔH^*_{ab}	ΔH^*_{ab1}	ΔH^*_{ab2}
10	0.4766	0.2986	0.1402	0.4540	0.4582	0.4583
31	1.0534	0.7717	0.9153	0.2484	0.2526	0.2533
26	1.1029	0.6725	0.1308	1.0931	−1.0888	−1.0884
27	1.1734	0.6519	0.5949	0.6240	0.6282	−0.6251
73	1.2276	0.4478	0.3026	0.3542	−0.3501	−0.3476
32	1.3317	0.4680	0.3907	0.0174	0.0216	0.0214
56	1.3341	1.0034	1.2156	0.0730	0.0772	0.0769
51	1.4198	1.1445	1.4009	0.0077	0.0117	0.0116
68	1.4789	0.7591	0.7258	0.5049	0.5092	0.5129
72	1.6911	0.8997	0.2785	1.3704	1.3746	1.3666
71	1.7447	1.2262	1.1822	1.2384	−1.2343	−1.2368
11	1.9907	1.3258	1.0000	1.7213	−1.7171	−1.7173
57	2.1176	0.8509	0.4138	1.0027	1.0069	0.9956
30	2.2103	1.4296	1.1293	1.7751	−1.7708	−1.7781
76	2.2264	0.7634	0.5943	0.2221	0.2262	0.2232
81	2.3044	1.2806	1.3098	0.8967	−0.8925	−0.8834
52	2.3486	1.0218	0.5877	1.2185	1.2226	1.2082
78	2.8768	1.7473	0.2655	2.8534	−2.8492	−2.8450
45	2.8927	2.1358	2.5018	0.9077	−0.9034	−0.9096
21	3.0785	1.5034	1.4527	1.0434	0.9905	1.0031
50	3.1651	2.0056	1.1545	2.9088	−2.9046	−2.9131
77	3.3087	1.7008	1.2921	1.9357	−1.9315	−1.9037
22	3.5943	1.9064	2.1018	0.5181	−0.5139	−0.5228
65	3.8250	1.7990	1.9159	0.0381	0.0424	0.0432

primary importance. To determine the cause of its high or low value in this expression, it is necessary to investigate all three components. In samples 78 and 45 or 30 and 76, which have relatively equal values of ΔE^*_{ab}, values ΔH^*_{ab1}, ΔL^*, ΔC^*_{ab}, differ.

Sample 78 (ΔE^*_{ab} = 2.8768 CIELAB units):

$$\Delta H^*_{ab1} = -2.8493 \text{ CIELAB units}$$

$$\Delta L^* = -0.2600 \text{ CIELAB units}$$

$$\Delta C^*_{ab} = -0.2580 \text{ CIELAB units}$$

Sample 45 (ΔE^*_{ab} = 2.8928 CIELAB units):

$$\Delta H^*_{ab1} = -0.9034 \text{ CIELAB units}$$

$$\Delta L^* = 2.4600 \text{ CIELAB units}$$

$$\Delta C^*_{ab} = 1.1593 \text{ CIELAB units}$$

Therefore, it is suggested that the total difference ΔE^*_{ab}, expressed up to now as one value, should be replaced by three expressions showing the change of colorimetric characteristics. The expressions should be arranged

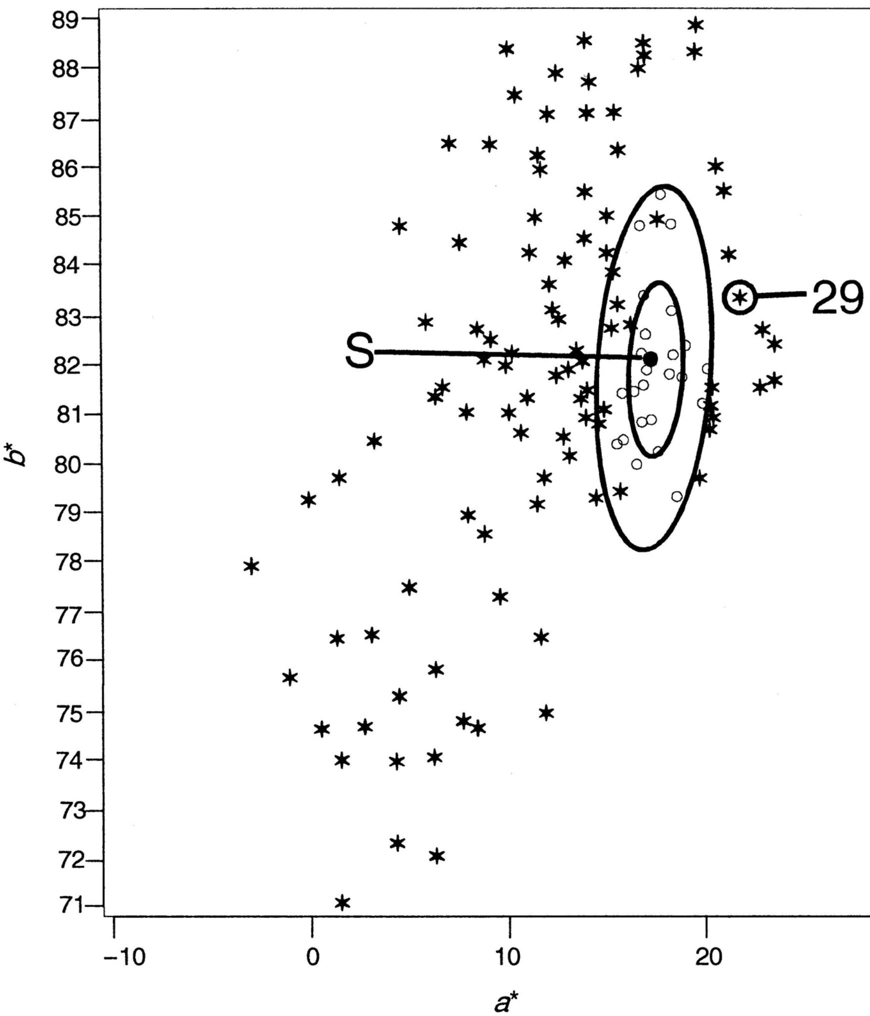

Figure 2. CIELAB confidence ellipses, a^* *vs.* b^* at 50% and 95% levels.

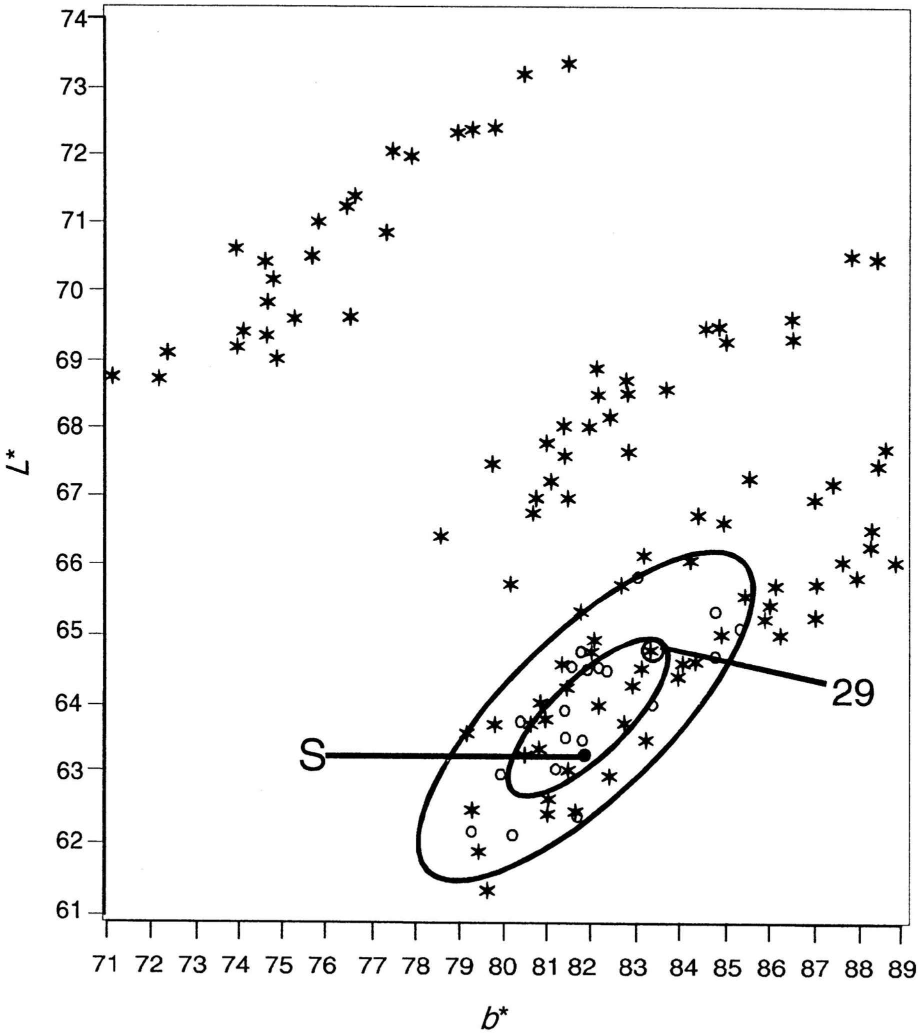

Figure 3. CIELAB confidence ellipses, b^* *vs.* L^* at 50% and 95% levels.

in Munsell's way of color presenting ΔH^*_{ab1}, ΔL^* (ΔV), ΔC^*_{ab}. In the case of sample 77, instead of ΔE^*_{ab} = 3.3087 units, the total difference should be:

$$\Delta H^*_{ab1}\ (-1.9316),\ \Delta L^*\ (-1.19),\ \Delta C^*_{ab}\ (-2.4051)$$

The places of all samples inside the CIELAB space are drawn in Figures 2, 3, 4.

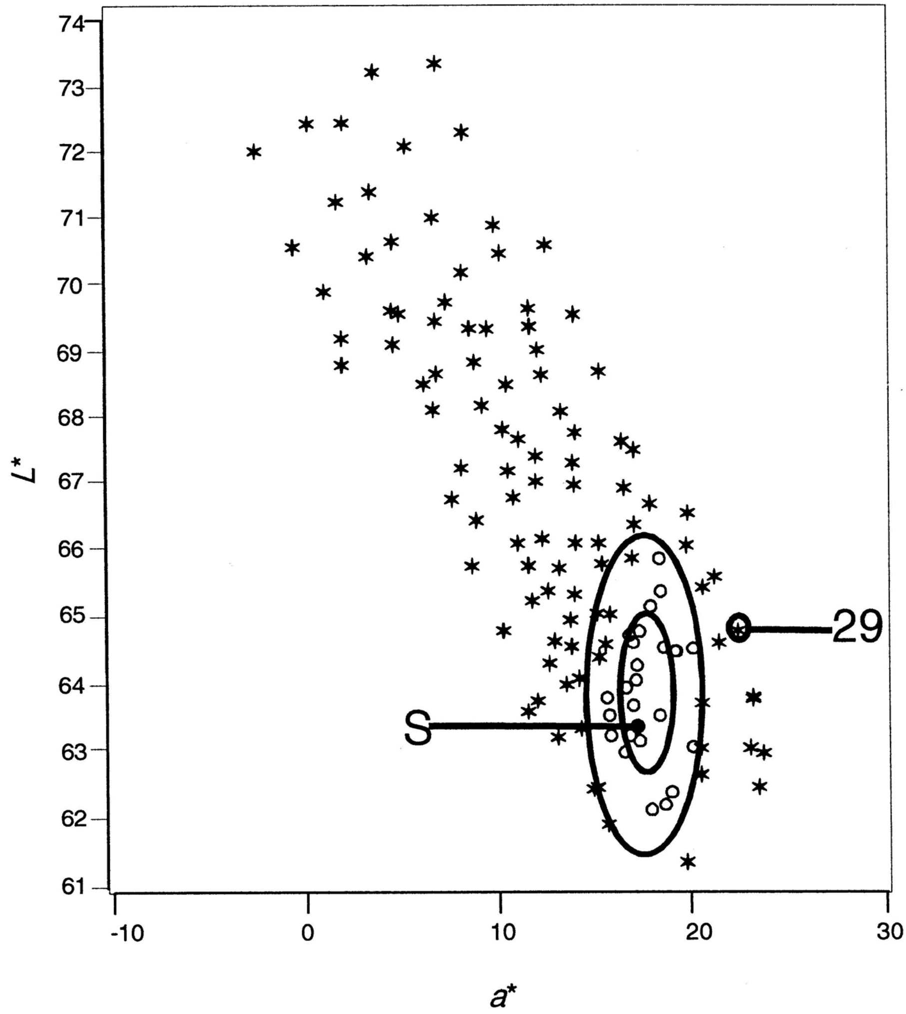

Figure 4. CIELAB confidence ellipses, a^* *vs.* L^* at 50% and 95% levels.

The samples which visually correspond to the standard are inside the ellipses in all three figures. The ellipses are computer drawn relative to axes a^*b^* a^*L^* b^*L^*. The values on the axes are not identical, which causes different positions and shapes of ellipses. The samples, which visually corresponded to the original are drawn as circles, and the samples which were not chosen are marked with asterisks. According to their a^*, b^*, L^* values, 24 chosen samples should be placed into the samples which slightly differ from the standard S. Table I shows that the greatest difference in a^*, b^*, L^* values is ΔL^*_{max} = 2.49, Δa^*_{max} = 2.94 and Δb^*_{max} = 3.32. The samples inside the ellipse, marked with an asterisk, satisfy by their differences the values lower than the determined maximum only in relation to the axes among which there is the ellipse. Sample 29 is placed only once inside the ellipses, and only with axis b^*L^*. The reason for this are its ΔL^* of 1.42 CIELAB units, Δa^* 4.75 CIELAB units and Δb^* 1.29 CIELAB units.

Figures 5, 6, 7 show randomly chosen samples 42, 60 and 82. All three samples are outside the ellipses. It means that by visual estimation they are not chosen as the samples similar to the standard. By analyzing the differ-

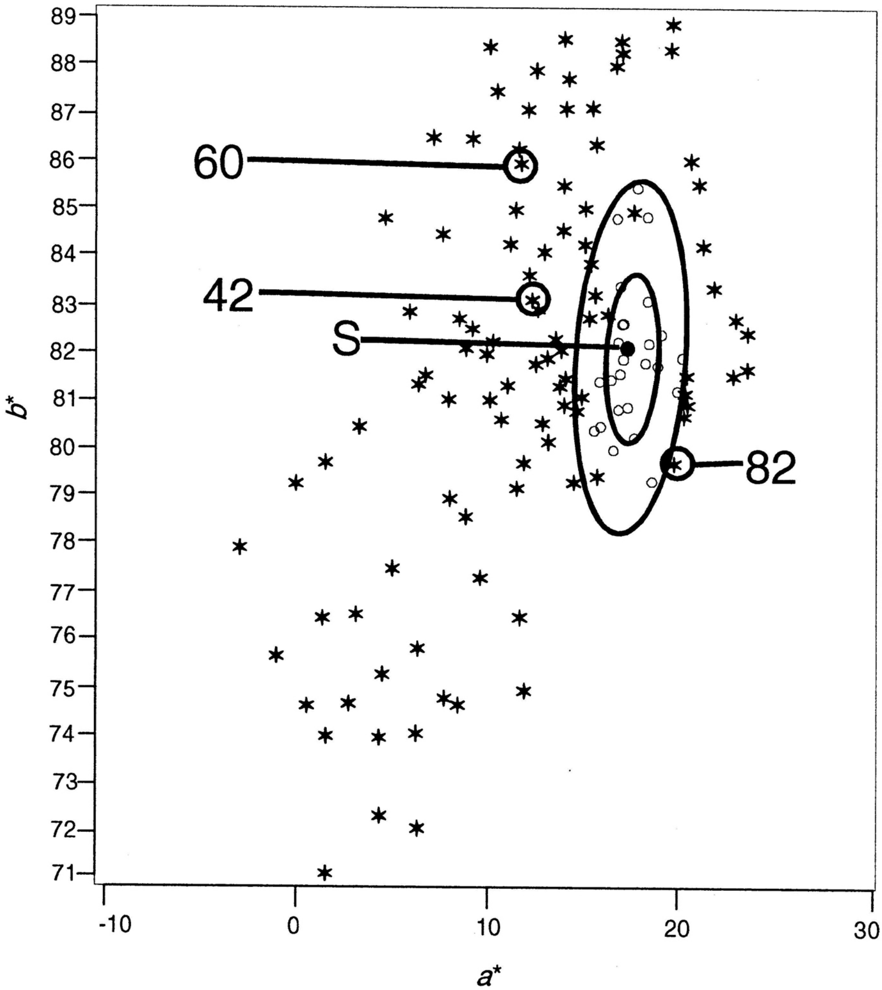

Figure 5. CIELAB confidence ellipses, a^* *vs.* b^* at 50% and 95% levels. (Figures 5, 6, 7; position of samples outside the tolerated space (samples No. 60, 42 and 82) in relation to the standard.)

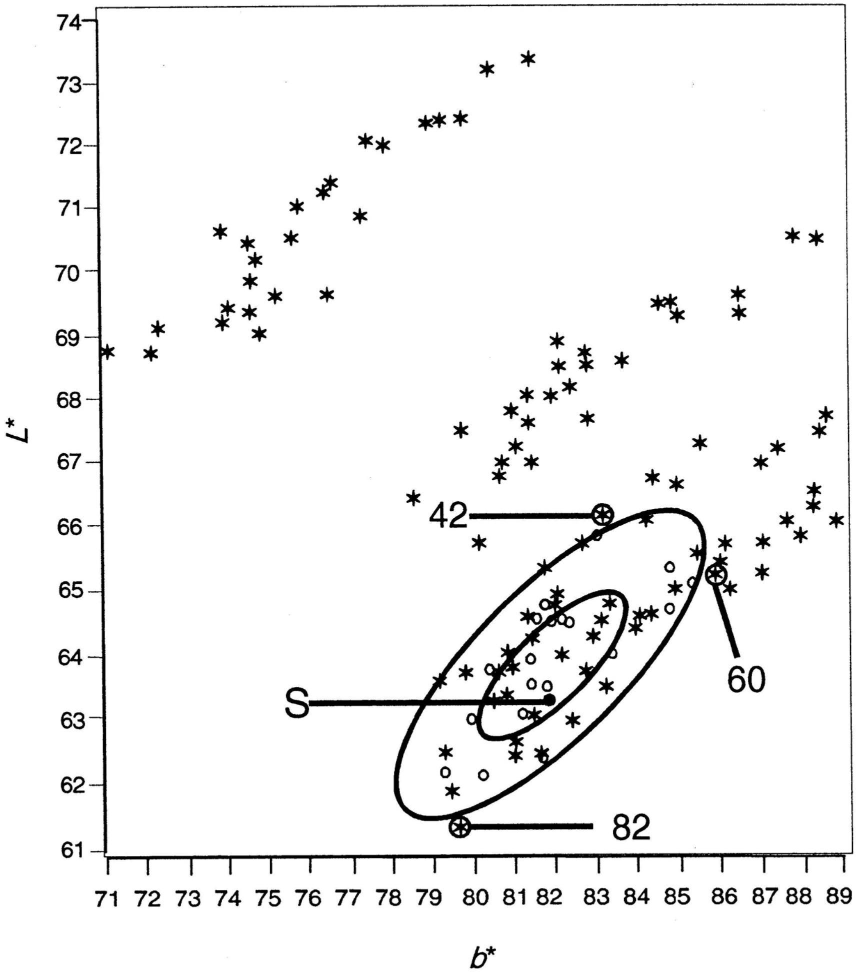

Figure 6. CIELAB confidence ellipses, b^* *vs.* L^* at 50% and 95% levels.

ences of all these samples, limits of ΔL^*, Δa^*, Δb^* have been determined within which lie the values of visually chosen samples. The samples with all three values within the limits have been visually estimated as acceptable, *i.e.* they are similar to the standard. The limits for all three values:

ΔL^* from –1.26 to 2.49

Δa^* from –1.59 to 2.94

Δb^* from –2.77 to 3.32

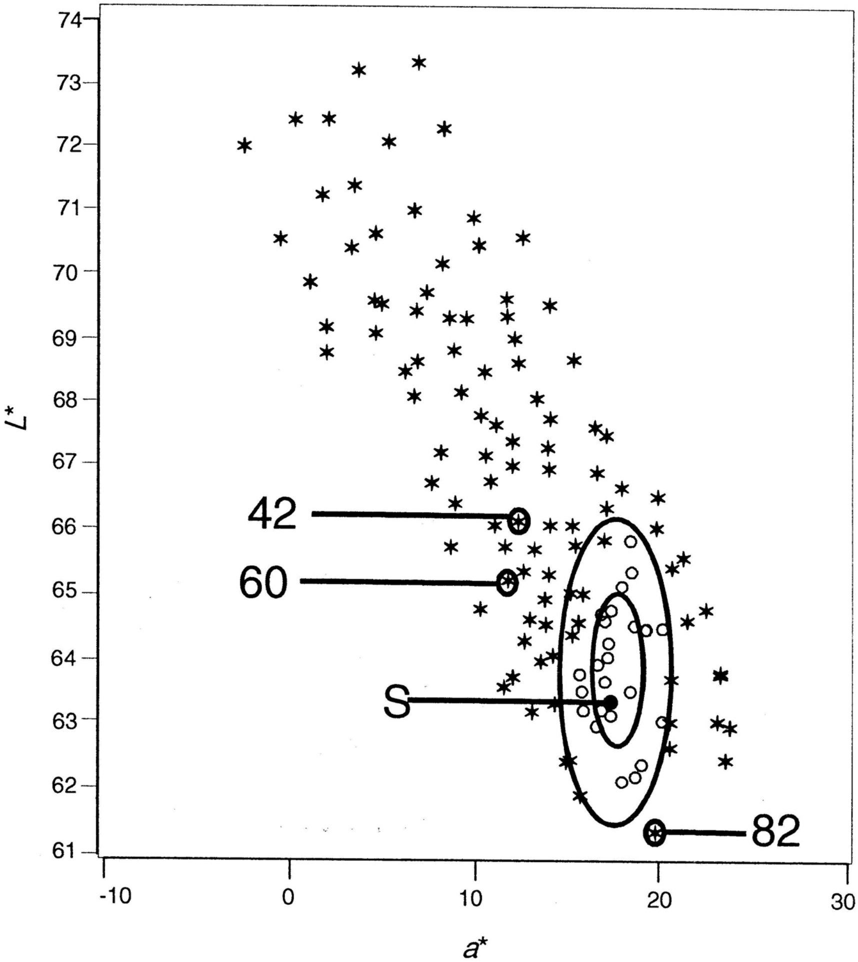

Figure 7. CIELAB confidence ellipses, a^* *vs.* L^* at 50% and 95% levels.

It can be concluded from the above that the visual estimation has the range of acceptance which is satisfactory in comparison with instrumental measurements, *i.e.* it has the role of acceptable quantity. The instrumental method of measuring chromatic values of the sample and its graphic presentation define the most similar sample. In this way, the method determines the quality of the chosen sample or the quality of color reproduction. Investigations of the optimal differences in chromatic values have been performed on yellow samples. The same method of investigation and presentation of results would be applied to each new color. Visual tolerances would differ in various colors and the instrumental method would enable numerical definition of tolerances.

REFERENCES

1. D. Jameson and L. M. Hurvich, *J. Opt. Soc. Am.* **58** (1968) 429.
2. R. W. G. Hunt, *Measuring Colour*, John Wiley and Sons, New York , 1989, pp. 77–83.
3. A. R. Robertson, *Color Res. Appl.* **3** (1990) 167.
4. D. B. Judd and G.Wyszecki, *Color in Business Science and Industry*, John Wiley and Sons, New York, 1975, pp. 313–329.
5. *CIE International Lighting Vocabulary*, 3rd Ed., Publ. No. **17** (E–1.1), Bureau central CIE, Paris, 1970.
6. R. G. Kuehni, *Color Res. Appl.* **5** (1990) 261.
7. F. Grum and C. J. Bartleson, *Color Measurement*, Academic Press, New York, 1980, pp. 125–130.
8. D. F. Morrison, *Multivariante Statistical Methods*, McGraw Hills, New York, 1976, p. 252.
9. R. S. Hunter, *The Measurement of Appearance*, John Wiley and Sons, New York, 1975, pp. 135–137.
10. J. R. Huntsman, *Proc. Technical Assoc. Graphic Arts* (TAGA), 1987, p. 83.
11. J. R. Huntsman, *Color Res. Appl.* **1** (1989) 41.
12. AATCC Committee RA 36, AATCC Technical Manual, 1990, pp. 327–330.
13. R. S. Berns, *Color Res. Appl.* **6** (1996) pp. 459–472.

SAŽETAK

Definiranje prihvatljivih razlika kromatskih vrijednosti pri mjerenju boja i vizualne procjene

Nina Knešaurek

Pod definiranim uvjetima promatranja, iz niza 126 sličnih uzoraka odabrana su vizualnom metodom 24 otisnuta uzorka boja za koje se smatralo da su po svojim kromatskim karakteristikama slični izabranom standardu. Standard i svi uzorci izmjereni su na spektralnom kolorimetru. Izmjerene reflektancije preračunane su u brojčane vrijednosti sustava CIELAB. Na temelju podataka dobivenih instrumentalnom metodom izračunane su i analizirane nastale razlike 24 vizualno slična uzorka. Brojčano su definirane granice vizualne procjene izražene kao ΔL^*, ΔH^*_{ab}, ΔC^*_{ab}. Na temelju analize izračunanih kromatskih vrijednosti sustava CIELAB i njihova utjecaja na vizualnu procjenu predlaže se zamjena izraza ΔE_{ab^*} izrazima ΔL^*, ΔH^*_{ab}, ΔC^*_{ab}, koji boju definiraju s tri brojčane vrijednosti. Na taj način definiraju se veličine koje su uzrok nastale razlike.