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EVALUATION OF THE CHROMATIC ASSIMILATION EFFECT INTENSITY IN MUNKER-WHITE SAMPLES PRODUCED USING STANDARD METHODS OF RENDERING

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Original scientific paper

In everyday communication it is common that a particular wavelength of visible light spectrum or physical object is identified with its color. Determination of color as a physical phenomenon belongs to the area of spectrophotometry or spectrum-diometry. It can be said that, under certain conditions of viewing, a particular wavelength is perceived as their color. Occurrence of color of viewed pictures depends on the change of the viewing conditions. Such a phenomenon is a challenge to communication technologies which use information about the color for the transmission of information. Systems of parallel lines of various colors that with their shape are similar to the classic Munker-White samples are used daily in a variety of design solutions. The use of such line systems may potentially, due to the manifestation of certain psychophysical visual effects, cause deviation in color perception of individual elements. Therefore, the researches in this paper are focused on determining the impact of certain standard methods of rendering on the magnitude of the most intensive effect that is manifested in different types of Munker-White pattern, or the chromatic assimilation effect.

Keywords: *chromatic assimilation, Munker-White, psychophysical effect, rendering*

Evaluacija intenziteta efekta kromatske asimilacije na Munker-White uzorcima koji su producirani standardnim metodama renderiranja

Izvorni znanstveni članak

U svakodnevnoj komunikaciji uobičajeno je da se određena valna duljina svjetlosti vidljivog spektra ili fizičkog objekta poistovjeti s njegovom bojom. Određivanje boje spada, kao fizikalni fenomen, u područje spektrofotometrije ili spektroradiometrije. Možemo reći da se određena valna duljina pod određenim uvjetima gledanja percipira kao njihova boja. Pojavnost boje neke slike koju promatramo uvjetovana je promjenom uvjeta gledanja. Takav fenomen predstavlja izazov komunikacijskim tehnologijama koje se za prijenos informacija služe informacijom o boji. Sustavi paralelnih linija različitog obojenja koji su svojim oblikom slični klasičnim Munker-White uzorcima upotrebljavaju se svakodnevno u različitim dizajnerskim rješenjima. Upotreba takovih sustava linija može uslijed manifestacije određenih psihofizikalnih vizualnih efekata uzrokovati potencijalno odstupanje u percepciji boje pojedinih elemenata. Zbog toga istraživanja u ovom radu usmjerena su na određivanje utjecaja pojedinih standardnih metoda renderiranja na magnitudu najintenzivnijeg efekta koji se manifestira kod različitih tipova Munker-White uzorka, odnosno efekta kromatske asimilacije.

Ključne riječi: *kromatična asimilacija, Munker-White, psihofizikalni efekt, renderiranje*

1 Introduction
Uvod

Although the CIE L*a*b color model is the model that provides connectivity between the brightness, chromaticity and hue, and allows the exact calculation of colorimetric difference (ΔE) it is not able to determine the impacts associated with a number of psychophysical effects, such as background effects (simultaneous and complementary contrast, the extension and folding), ambient-adaptation effects (chromatic and light assimilation), and structural geometrical effects that occur at specific imagery [1].

For these reasons and because of the ICC standard methods of rendering [2] the need is felt for introducing additional methods of rendering [3] that will not rely directly on the base colorimetry.

On Munker-White patterns the change in color perception occurs primarily as a result of geometric structure in combination with psychophysical visual effects of chromatic assimilation. The chromatic assimilation effect itself depends both on the light and on the surface [4]. It is important to emphasize that different forms of brightness affect the visual effect [5, 6], and that the assimilation plays an important role in the visual effect [7].

Mutual relations and selection of line colors determine the intensity of effects, but they are not essential to the existence of the same.

Samples are basically chromatic performances from which stems primarily the geometric structure, and not staining, the main factor that determines the stability of the effect, while the combination of color pairs determines the experience of a certain intensity, causing the effects of chromatic assimilation.

For the purposes of chromatic assimilation effects intensity evaluation Munker-White samples (a combination of two secondary and one primary color of additive synthesis for evaluation of the assimilation) were created [8, 9]. The samples, together with a segment of instrumental analysis, were produced by the standard method of rendering on the machine for digital printing on the principle of liquid toner.

The aim of the research was to determine the influence of some standard rendering methods on the intensity of the chromatic assimilation effect, and potential differences in the intensity manifestation of these effects of different investigated color combinations of Munker-White samples within each of the standard rendering methods as well.

2 Design of the printing form for reproduction
Dizajn tiskovne forme za reprodukciju

With regard to the aims of the research the test form was created from two parts. The first part is a part for instrumental analysis, and the second part is for visual assessment.

Instrumental analysis part consists of 210 fields of different color combinations of subtractive synthesis (PrintOpen Heidelberg 4-color Standard Test chart), made with vector graphics with a difference of 5 % of HTV between the fields and is intended for spectrophotometric analysis with the aim of calculating the volume and gamut characteristics of associated reproductions.

***Table 1** Color pairs combinations of Munker-White samples*
***Tablica 1.** Kombinacije parova boja Munker-White uzoraka*

arrangement of samples in the group	colors of the external grid lines	colors of the inner grid lines
1	yellow, magenta	red
2	cyan, magenta	blue
3	cyan, yellow	green
4	blue, green	cyan
5	red, blue	magenta
6	red, green	yellow

The part of the visual assessment was made so that it consists of six different combinations of color pairs (a total of 6 samples, size 5×10 cm). Six Munker-White patterns were designed in a way that the external grid was made from two colors that build (using additive or subtractive synthesis) colors of the interior lines that are assimilated (such patterns do not have unprinted or white background). By the described principle the Munker-White-samples with color combinations shown in the table were obtained.

Since the psychophysical visual effect of chromatic assimilation, among other results, is generated as a consequence of global chromatic induction based on a localized chromatic adaptation, it is evident that the selection of color combinations in the design of Munker-White samples is precisely focused towards determining the intensity of the above psychophysical effect for combinations of primary colors of additive and subtractive synthesis, considering the use of certain standard rendering methods.

3 Experimental part
Eksperimentalni dio

3.1 Reproduction of test samples
Reprodukcija testnih uzoraka

The test form is saved as the PDF file in CMYK color space, and printed on the calibrated machine for digital printing on the principle of liquid toner (tint) with the resolution of 1200 dpi by using standard ICC rendering methods (perceptual, saturation, relative colorimetric and absolute colorimetric) in 10 copies for each of the mentioned rendering methods.

As a printing substrate the multiple coated glossy paper for art printing, high whiteness (CIE $L^*a^*b^*$ values: L^*= 94,4, a^*= 0,2, b^*= 0,2), grammage 175 g/m^2, conditioned before printing in a period of 48 hours of the prescribed standard ambient conditions (temperature of 23 °C and relative humidity of 55 %) was used.

3.2 Instrumental Analysis
Instrumentalna analiza

For instrumental analysis (PrintOpen test form) the measurement of samples using X-Rite DTP 41 reflexive spectrophotometer, ranging in wavelength from 390 nm to 710 nm of D50 light source, the step of 10 mm and illumination geometry 45°/0° was carried out. In order to increase the statistical accuracy of instrumental analysis, the values of the control fields were measured on 10 printed copies of samples for each of the rendering methods. Each sample was measured twice, after which the average values were calculated.

The average deviation in terms of reflectance amounts to 0,5 % per step of the wavelengths. Etalon for the calibration was moderated by Munsell's laboratory (RIT) with an accuracy ΔE^*= 0,25 for the D50 light source and angle of 2°.

3.3 Visual assessment
Vizualno ocjenjivanje

Only visual assessment aims to determine changes in the perception of stimulus experience (lines that are assimilated) within a particular method of rendering for different color combinations that create the Munker-White's samples.

The fact of such evaluation is that the determination of the size of the change (i.e. deviation) in the perception between the physically identical patterns in basis is determining the value of the size of the magnitude of actual manifested psychophysical effect - chromatic assimilation.

Testing was conducted at the Department for Printing, University of Zagreb on the sample of 18 participants, mixed population, with an average age of 21 years. All participants previously successfully met the criteria of the Ishihara test (24 samples) for detection of potential vision defection.

Ambient conditions of the room for visual evaluation were consistent with the guidelines of ISO 3664 from the year 2000 (for the process of evaluation with Atlas), and of ISO 12646 from the year 2004 (for visual Colorimetric experiment). Time for evaluation by both processes was not limited.

The procedure of intensity evaluation of the chromatic assimilation effect for each of the 6 White-Munker's samples was carried out through two separate series of visual assessment for each of the standard rendering methods using the simultaneous binocular reconciliation technique. With this technique of visual evaluation the examined stimuli are simultaneously in the whole visual field, where the evaluation is done with simultaneous comparison between the surveyed samples [10].

The above difference in the two conducted series of visual evaluation refers to the exactly applied psychophysical method used during the evaluation of deviation between physically identical stimuli that have interior lines (those that assimilate) of the Munker-White's colored grid.

The first series of the implemented visual evaluation was based on the estimated differences between the stimulus of internal lines of the Munker-White's grid with the method, which would by its classification and criteria match the method of constant stimuli – to the participant a random set of different stimuli with fixed predefined values was presented.

Stimulus values are selected to cover the whole potential area of threshold of perception, so that the minimum value of stimulus is very slightly below the expected threshold of perception, and the largest is barely just above the expected threshold of perception. Aspiration is in the selection of the values that are considered to be the closest to the assessed stimulus [11].

For the purposes of evaluation an atlas with different variations of primary colors of additive and subtractive synthesis was created. Each primary color was represented in the atlas with a total of 120 of its variations. Samples of colors in the atlas for each tested color were selected to include all anticipated values of the area of the tested stimulus.

The first 26 samples of each primary color in the atlas (Fig. 2 - viewed from the left) were designed as linearly decreasing values of brightness (HSB color model) in steps of 3 % (ranging from 100 % to 22 %). The last four fields of each color were not defined by values of brightness, but as a linear falling raster values in steps of 5 % (ranging from 95 % to 80 % halftone values). In other words, each primary color of the variations of 30 different samples was given in variations of 30 different samples (26 + 4).

The reason for the design of the atlas with described characteristics in the field will be made understandable if the minutely created Munker-White's samples (Fig. 1) are observed. It is evident that the changes in color appearance caused by chromatic assimilation in the given samples are perceived more as the change in brightness of the primary stimulus (lines that assimilate), and less like the hue or saturation.

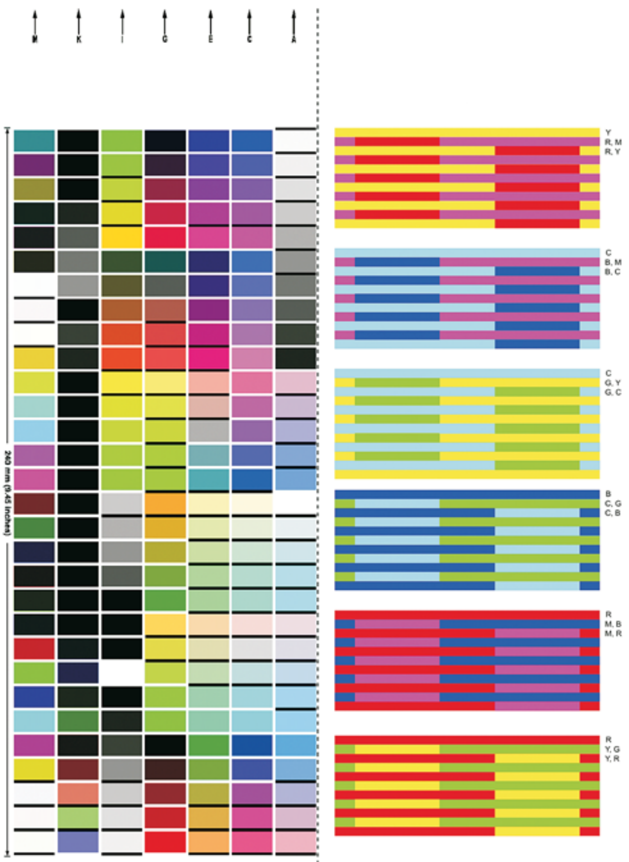

Figure 1 *The test form used in research of the chromatic assimilation effect on Munker-White samples*
Slika 1. *Prikaz testne forme korištene u istraživanju efekta kromatske asimilacije na Munker-White uzorcima*

The described atlas is printed on the same substrate base with the same digital printing machine as the examined samples.

Corresponding CIE $L^*a^*b^*$ values for each of the color samples from the atlas are determined with Spectrophotometric measurements (X-Rite DTP41 device).

The procedure of the assessment of relations between stimuli is based on the process of visual detection and recognition.
Each participant had the task to perform identification of samples in the color Atlas (constant stimulus) and decide which one, according to his assessment, was the most similar (or identical) to the tested sample represented with lines of the Munker-White's grid (Fig. 3).

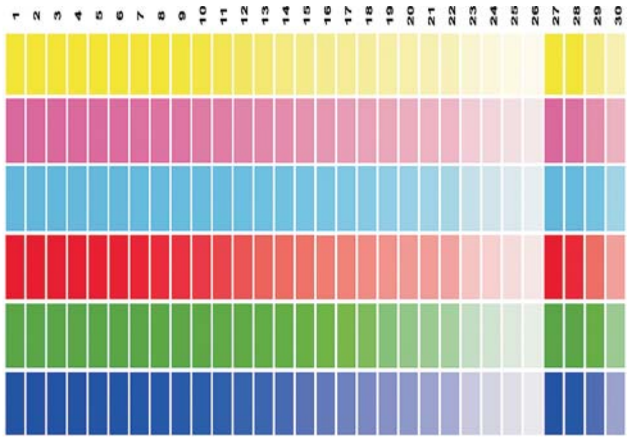

Figure 2 *Atlas segment*
Slika 2. *Prikaz segmenta Atlasa*

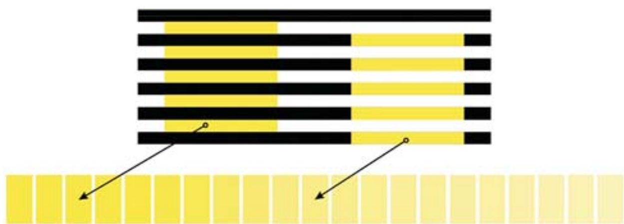

Figure 3 *Principle of visual evaluation by the Atlas*
Slika 3. *Prikaz principa vizualnog ocjenjivanja putem Atlasa*

Assigning the reference sample from the color atlas (implemented for both systems of internal lines with respect to the background and surrounding) to the tested sample in the basis colorimetric perceived values are joined (CIE $L^*a^*b^*$ sizes).

If, after conducted visual evaluation from the relevant associated colorimetric values three-dimensional geometric color difference - ΔE^*_{ab} is calculated, the deviation of differences in the color perception that is caused by manifestation of chromatic assimilation effect will be gained.

With the second series of visual evaluation assessments between the stimuli of internal lines of the Munker-White's grid were conducted using the procedure that would fit the criteria for its psychophysical method of tuning (setting). With such experiment the examiner set the device for control of stimulus to a specific initial value. The task of each participant was to set the same device to a value that caused the desired perceptual response - for example, equality [12].

Such a process of visual evaluation in the second series was chosen because these methods allow direct interactive

Table 2 *Reference physical values of primary stimuli of the Munker-White's samples measured on reproductions depending on the applied rendering methods*
Tablica 2. *Referentne fizikalne vrijednosti primarnih stimulusa Munker-White-ovih uzoraka izmjerene na reprodukcijama u ovisnosti o primijenjenim metodama renderiranja*

stimulus color	perceptual			saturation			relative colorimetric			absulute colorimetric		
	*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**
yellow	84	-5	69	75	0	85	85	-12	64	85	-13	65
magenta	59	28	-15	47	74	-2	60	35	-25	61	30	-25
cyan	69	-25	-10	37	-38	-40	76	-28	-9	78	-26	-16
red	49	54	15	47	73	20	52	59	33	51	61	34
green	60	-41	29	49	-67	19	73	-42	41	73	-42	40
blue	47	-6	-32	29	-8	-50	47	5	-39	49	-2	-39

assessment of stimulus features by subjects and is therefore considered the most accurate.

Visual evaluation, i.e. its treatment, is based on a research study of the Institute of Physics (Stockholm University) led by Pehr Sällström from the year 1998. [13]. This study describes the possibility of using personal computers and their calibrated screens in order to determine the colors using the process which is identical to visual colorimetric experiment.

For using the computer screen in visual colorimetric experiment as a medium one condition must be fulfilled, i.e. that the gamut of the screen is larger than the gamut of the medium with which colors are compared.

The visual evaluation of inner lines of the Munker-White's samples on the calibrated computer screen using the "Visual colorimeter" from application X-Rite ColorShop is conducted as well.

Before the start of the visual evaluation, the examiner sets the initial value of colorimeter depending on the primary color of the stimulus which is evaluated. Initial values of colorimeter are the values of the stimulus measured at the corresponding patterns reproduced by the tested rendering methods.

Apart from the classic visual colorimetric experiment on a computer screen using the "Visual colorimeter", participants had the task to set the values of three primary additive synthesis of R, G and B so that the color experience gained from their overall values gives the perception equivalent to the tested sample on print.

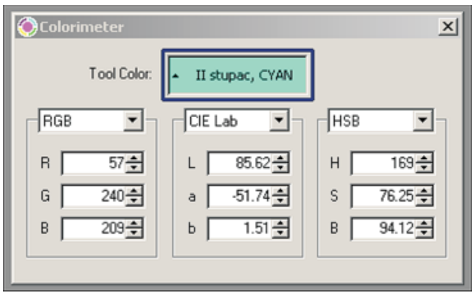

Figure 4 *Interface of working tool "Colorimeter" from application X-Rite ColorShop*
Slika 4. *Prikaz radnog sučelja alata "Colorimeter" iz aplikacije X-Rite ColorShop*

When by adjusting primary R, G and B on the colorimeter the participant acquires the experience equal to the one that he gets by looking at reproductions of the tested stimulus of the Munker-White's samples, then the obtained values are entered in a table of the measured survey results as CIE $L^*a^*b^*$ sizes.

Comparing the instrumentally measured values of primary colors in the reproduction with the values obtained with descriptions of Sällström's visual colorimetric experiment the intensity of the manifested chromatic assimilation effects is determined depending on the applied method of rendering.

The values obtained by the second series of visual evaluation are not absolute because the process of visual colorimetric evaluation via PC is not entirely reliable and because the process of visual evaluation is based on "cross – media" verification (computer screen – print).

However, the obtained results allow determining the magnitude of the examined effects on each sample (depending on the selected combination of colors and/or with respect to the applied rendering method). The obtained results of the second series of visual evaluation were expected to enable the verification of results of determining the examined effects collected in the first series of visual evaluation as well.

The use of two separate, and by the principle of determining the intensity of the effects, different methods of visual evaluation also allows the perceiving of characteristics of the studied effects during their manifestation in everyday design solutions in the technological processes that are performed in graphic technology on different media (changes caused by applying of various media).

4 Results
Rezultati

After the corresponding conversions, based on the results obtained by spectrophotometric measurements from the segment of the test forms intended for instrumental analysis, through application of Monaco GamutWorks the volumes of gamut prints achieved by certain standard rendering methods were calculated.

Tables 5 to 10 show the results of visual estimation.

5 Discussion and conclusions
Diskusija i zaključci

With classic colorimetric visual experiment based on psychophysical customizing method for the sake of interactivity and the possibility of control over the individual attributes in the process of evaluation of the target characteristics more accurate results in relation to marking over the atlases that are based on the method of constant stimulus, and thus predetermined possible values

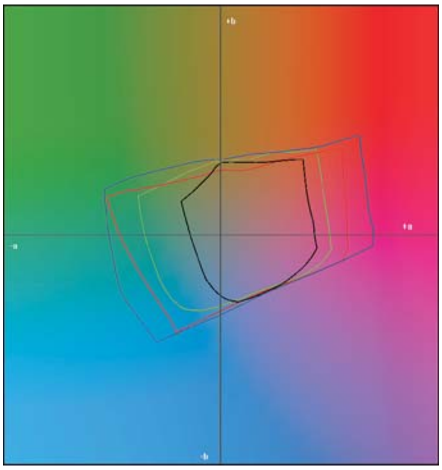

Figure 5 *Two-dimensional view of gamut and the corresponding calculated reproduction volumes achieved by using standard rendering methods in CIE L*a*b* color space (for the brightness value L*= 50)*
Slika 5. *Dvodimenzionalni prikaz gamuta i pripadajućih izračunatih volumena reprodukcija ostvarenih primjenom standardnih metoda renderiranja u CIE L*a*b* prostoru boja (za vrijednost svijetline L*=50)*

Table 3 *Colorimetric color differences (ΔE*) between the value of the primary stimuli of the original non-reproduced file and belonging values generated on reproductions depending on the applied rendering methods*
Tablica 3. *Prikaz kolorimetrijske razlike boja (ΔE*) između vrijednosti primarnih stimulusa originalnog ne-reproduciranog zapisa i pripadajućih vrijednosti ostvarenih na reprodukcijama u ovisnosti o primijenjenim metodama renderiranja*

rendering method	gamut volume
Perceptual - black	384923
Saturation - green	412182
Relative colorimetric - red	561883
Absulute colorimetric - blue	583172

Table 4 *Relationship of colorimetric color differences between the values of the primary stimuli of the original not printed file and the printed file belonging values depending on the applied rendering methods*
Tablica 4. *Odnos kolorimetrijskih razlika boja između vrijednosti primarnih stimulusa originalnog nereproducranog zapisa i pripadajućih vrijednosti ostvarenih na reprodukcijama u ovisnosti o primijenjenim metodama renderiranja*

stimulus color	original file			ΔE * reproductions			
	*L**	*a**	*b**	perceptual	saturation	rel. colorimetric	abs. colorimetric
yellow	87	-12	73	9	30	9	8
magenta	61	39	-20	12	42	6	11
cyan	73	-29	-18	10	43	10	6
red	50	63	29	17	14	6	6
green	68	-46	37	12	34	7	7
blue	46	0	-36	8	23	6	5

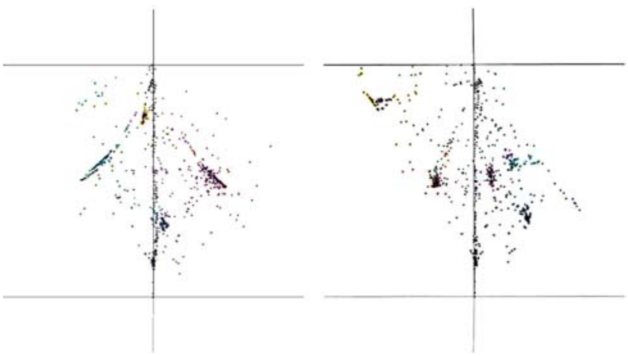

Figure 6 *Three-dimensional view of position of the characteristic colors of the original test forms (not printed) in the CIE L*a*b* color model, for viewing angles of 0° (left figure) and 90° (right figure)*
Slika 6. *Trodimenzionalni prikaz položaja karakterističnih boja originalnog zapisa testne forme (ne-reproduciranog) u CIE L*a*b* modelu boja, za kutove gledanja od 0° (lijeva slika) i 90° (desna slika)*

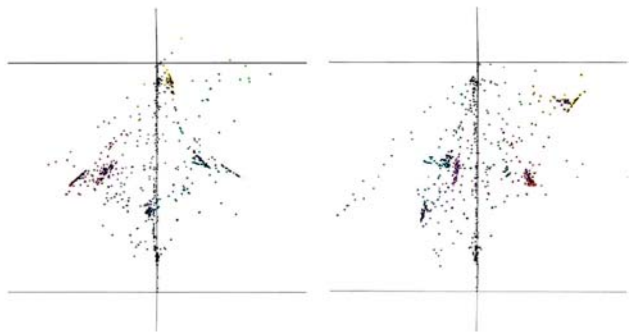

Figure 7 *Three-dimensional view of position of the characteristic colors of the original test forms (not printed) in the CIE L*a*b* color model, viewing angles of 180° (left figure) and 270° (right figure)*
Slika 7. *Trodimenzionalni prikaz položaja karakterističnih boja originalnog zapisa testne forme (ne-reproduciranog) u CIE L*a*b* modelu boja, za kutove gledanja od 180° (lijeva slika) i 270° (desna slika)*

of results, are realized [12].

At the chromatic assimilation effect there is no distinctive dominance in the change of certain perceptual attributes, but the same varies depending primarily on the type of the stimulus.

Discrepancies in perception between the examined stimulus vary from 1,34 to 4,16 for the evaluation with atlas or 2,43 to 4,91 for visual Colorimetric experiment - expressed through colorimetric color difference (Δ*E**).

The greatest differences in the perception of stimulus are noticed with the saturation rendering method and with almost all examined stimuli, i.e. colors.

Considering the value of chromatic assimilation, they are very similar in all the remaining rendering methods, with the slight advantage in strength of intensity manifested effect for perceptual rendering method for primary colors of subtractive synthesis in relation to colorimetric rendering method. It is also evident that the intensity is somewhat

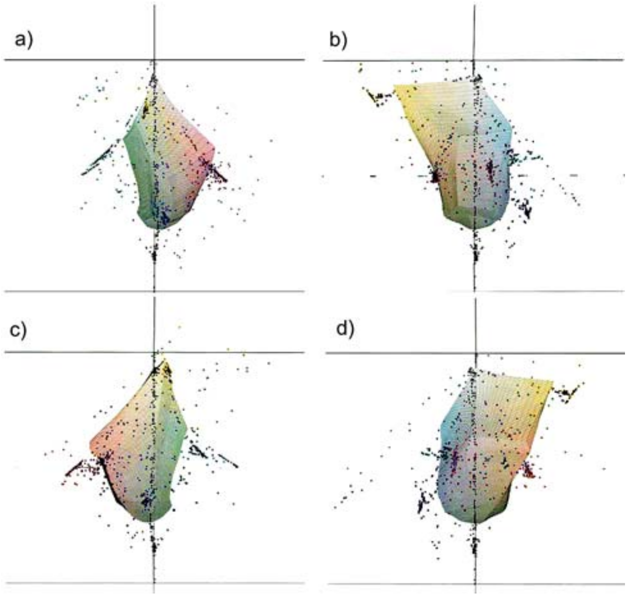

Figure 8 *Projection of three-dimensional position of the characteristic colors of the original test form in relation to the reproduction gamut made by perceptual rendering method in the CIE L*a*b* color model (for viewing angles of a = 0°, b = 90°, c = 180° and d = 270°)*
Slika 8. *Projekcija trodimenzionalnog prikaza položaja karakterističnih boja originalnog zapisa testne forme u odnosu na reprodukcijski gamut ostvaren perceptualnom metodom renderiranja u CIE L*a*b* modelu boja (za kutove gledanja od a=0°, b=90°, c=180° i d=270°)*

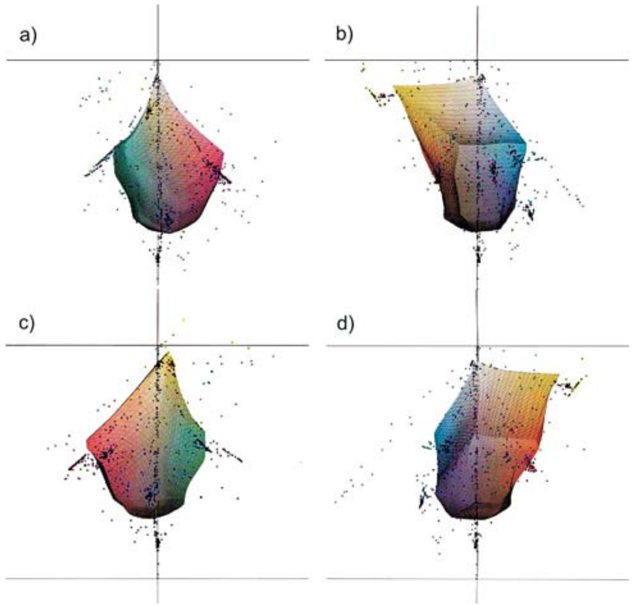

Figure 9 *Three-dimensional view of position of the characteristic colors of the original test form in relation to the reproduction gamut made by the saturation rendering method (in the CIE L*a*b* color model, the viewing angles of a = 0°, b = 90°, c = 180° and d =270°)*
Slika 9. *Trodimenzionalni prikaz položaja karakterističnih boja originalnog zapisa testne forme u odnosu na reprodukcijski gamut ostvaren saturacijskom metodom renderiranja (u CIE L*a*b* modelu boja, za kutove gledanja od a=0°, b=90°, c=180° i d=270°)*

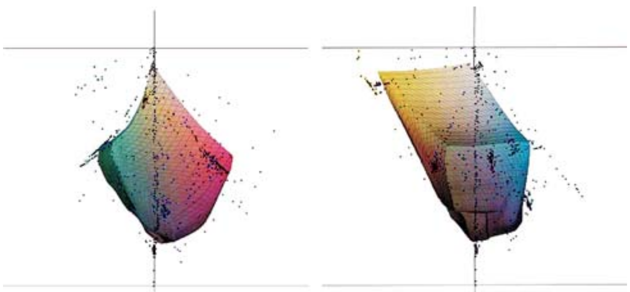

Figure 10 *Three-dimensional view of position of the characteristic colors of the original test form in relation to the reproduction gamut made by relative colorimetric rendering method (in the CIE L*a*b* color model, the viewing angles of 0° - left and b = 90° - right)*
Slika 10. *Trodimenzionalni prikaz položaja karakterističnih boja originalnog zapisa testne forme u odnosu na reprodukcijski gamut ostvaren relativnom kolorimetrijskom metodom renderiranja (u CIE L*a*b* modelu boja, za kutove gledanja od 0° - lijevo i b=90° - desno)*

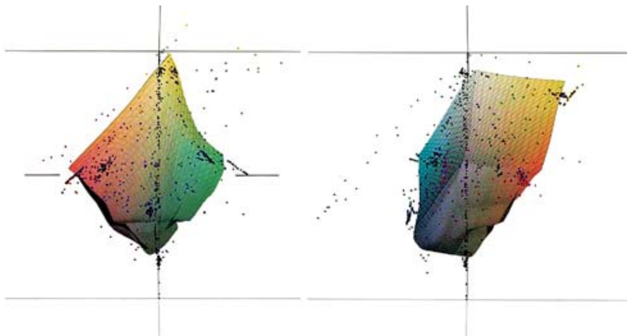

Figure 11 *Three-dimensional view of position of the characteristic colors of the original test form in relation to the reproduction gamut made by relative colorimetric rendering method (in the CIE L*a*b* color model, the viewing angles of 180° - left and 270° - right)*
Slika 11. *Trodimenzionalni prikaz položaja karakterističnih boja originalnog zapisa testne forme u odnosu na reprodukcijski gamut ostvaren relativnom kolorimetrijskom metodom renderiranja (u CIE L*a*b* modelu boja, za kutove gledanja od 180° - lijevo i 270° - desno)*

Table 5 *Average values (ΔE*) of results of visual assessment of the Munker-White's sample created with the red lines that are induced by the colors of external grid (yellow - magenta) which by subtractive synthesis build the assessed stimulus in different rendering methods*
Tablica 5. *Prosječne vrijednosti (ΔE*) rezultata vizualnog ocjenjivanja Munker-White-ovog uzorka kreiranog s crvenom bojom linija koje se induciraju bojama vanjske rešetke (žuta - magenta) koje suptraktivnom sintezom izgrađuju ocijenjeni stimulans kod različitih metoda renderiranja*

	Perceptual						Saturation						Relative colorimetric						Absulute colorimetric					
	Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas		
Stimulus	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
R_M	52,12	50,19	19,54	50,44	50,76	13,99	48,86	68,22	23,48	47,04	73,18	20,48	52,37	58,81	34,85	51,67	59,24	33,01	52,11	59,12	36,45	51,11	60,99	34,32
R_Y	49,34	52,42	17,33	49,33	53,88	15,07	50,06	64,31	20,76	48,9	72,44	16,83	54,7	56	36,73	52,92	56,91	30,12	54,59	56,23	33,44	52,59	58,23	31,78
	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*
R_M	52,12	53,86	21,28	50,44	52,65	15,41	48,86	72,15	18,99	47,04	75,99	15,63	52,37	68,36	30,65	51,67	67,81	29,13	52,11	69,45	31,66	51,11	69,98	29,37
R_Y	49,34	55,21	18,3	49,33	55,95	15,62	50,06	67,58	17,89	48,9	74,37	13,08	54,7	66,97	33,26	52,92	64,39	27,89	54,59	65,43	30,74	52,59	66,34	28,62
	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*
	2,78	-1,35	2,98	1,11	-3,3	-0,21	-1,2	4,57	1,1	-1,86	1,63	2,55	-2,33	1,39	-2,61	-1,25	3,42	1,24	-2,48	4,03	0,92	-1,48	3,64	0,74
$ΔE^*(R_w,R_c)$	4,19			3,49			4,91			4,16			4,11			3,91			4,85			4,03		

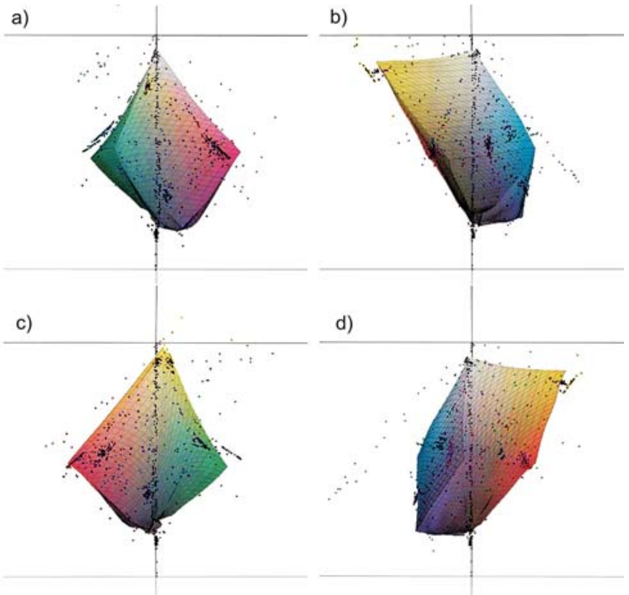

***Figure 12** Three-dimensional view of position of the characteristic colors of the original test form in relation to the reproduction gamut made by absolute colorimetric rendering method (in the CIE L*a*b* color model, the viewing angles of a = 0°, b = 90°, c = 180° and d = 270°)*
***Slika 12.** Trodimenzionalni prikaz položaja karakterističnih boja originalnog zapisa testne forme u odnosu na reprodukcijski gamut ostvaren apsolutnom kolorimetrijskom metodom renderiranja (u CIE L*a*b* modelu boja, za kutove gledanja od a=0°, b=90°, c=180° i d=270°)*

stronger with the absolute colorimetric rendering method in relation to the relative rendering method.

If the relationship between the standard rendering method and the given stimulus on the manifestation of the chromatic assimilation effect is analyzed it shows that higher intensities of the above effect with all rendering methods achieve the primary colors of additive synthesis in relation to their secondary colors.

This means that the primary colors of subtractive synthesis to a greater extent influence the assimilation of its complementary colors at the same time changing their occurrence as it is when the primary colors of additive synthesis assimilate its complementary colors.

Considering the samples it can be noticed that in the first three samples, but at the other three samples as well, there are the same stimuli of the same physical characteristics in order. The only difference is the estimated size of the stimuli - which is smaller in relation to the stimuli that form the external grid.

If the intensity of manifestation of investigated effect and the characteristics of reproduction gamut with respect to a particular rendering method are compared. The obtained relations are given in the Tab. 11.

As the mentioned order of intensity of the manifested effects does not follow the realized size of gamut it can be concluded that for the size of the intensity of examined effects to select a combination of line colors of the Munker-White's grid is more important than the physiological characteristics of the gamut.

To obtain a more general picture about the possibilities of defining the situation that would facilitate the selection of some standard rendering methods in terms of predictions of the manifestation of individual psychophysical effects on concrete samples this research is planned to be expanded to other psychophysical effects.

***Table 6** Average values (ΔE*) of results of visual assessment of the Munker-White's sample created with the blue lines that are induced by the colors of external grid (cyan - magenta) which by subtractive synthesis build the assessed stimulus in different rendering methods*
***Tablica 6.** Prosječne vrijednosti (ΔE*) rezultata vizalnog ocjenjivanja Munker-White-ovog uzorka kreiranog s plavom bojom linija koje se induciraju bojama vanjske rešetke (cyan - magenta) koje suptraktivnom sintezom izgrađuju ocijenjeni stimulans kod različitih metoda renderiranja*

	Perceptual						Saturation						Relative colorimetric						Absulute colorimetric					
	Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas		
Stimulus	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
B_C	48,4	-5,32	-27,65	47,98	-4,21	-30,35	34,47	-6,88	-50,18	31	-7,68	-52,83	50,51	7,11	-35,91	48,78	6,89	-38,1	52,75	7	-35,3	51,75	-4,93	-37,61
B_M	45,27	-7,47	-29,48	46,66	-6,47	-31,81	31,31	-8,18	-46,98	29,01	-7,91	-49,85	47,11	4,44	-37,07	46,59	4,68	-39,07	49,31	4,55	-36,56	48,98	-2,39	-38,63
	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*
B_C	48,8	28,15	-100,89	47,98	30,64	-97,9	34,47	50,65	-97,81	31	53,38	-98,27	50,51	36,61	-78,8	48,78	38,72	-79,74	52,75	35,99	-78,78	51,75	37,93	-97,47
B_M	45,27	30,41	-104,22	46,66	32,46	-101,5	31,31	47,69	-99,87	29,01	50,47	-99,02	47,11	37,34	-83,17	46,59	39,35	-83,17	49,31	36,84	-82,9	48,98	38,7	-93,55
	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*
	3,13	-2,26	3,32	1,32	-1,83	3,6	3,16	2,96	2,07	1,99	2,92	0,74	3,4	-0,73	4,37	2,19	-0,63	3,43	3,44	-0,86	4,12	2,76	-0,77	-3,93
$ΔE^*(B_C,B_M)$	4,22			3			4,68			3,59			4,47			3,26			4,4			3,89		

***Table 7** Average values (ΔE*) of results of visual assessment of the Munker-White's sample created with the green lines that are induced by the colors of external grid (cyan - yellow) which build the assessed stimulus by subtractive synthesis in different rendering methods*
***Tablica 7.** Prosječne vrijednosti (ΔE*) rezultata vizalnog ocjenjivanja Munker-White-ovog uzorka kreiranog s zelenom bojom linija koje se induciraju bojama vanjske rešetke (cyan – žuta) koje suptraktivnom sintezom izgrađuju ocijenjeni stimulans kod različitih metoda renderiranja*

	Perceptual						Saturation						Relative colorimetric						Absulute colorimetric					
	Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas		
Stimulus	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
G_Y	56,23	-35,47	26,95	58,88	-37,72	29,48	53,32	-64,13	22,19	51,2	-66,51	20,77	69,53	-45,04	41,4	72,26	-43,02	42,97	69,37	-45	43,04	71,29	-42,73	41,81
G_C	58,64	-38,42	28,77	60,44	-40,77	29,43	49,88	-66,54	20,33	48,67	-68	18,85	72,22	-42,78	39,61	73,1	-41,97	40,23	73,05	-43,78	41,75	72,71	-41,46	39,57
	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*
G_Y	56,23	44,55	142,78	58,88	47,88	141,99	53,32	67,86	160,92	51,2	69,68	162,65	69,53	61,18	137,41	72,26	60,81	135,03	69,37	62,27	136,28	71,29	59,78	135,63
G_C	58,64	48	143,17	60,44	50,29	144,17	49,88	69,58	163,01	48,67	70,56	164,5	72,22	58,3	137,2	73,1	58,14	136,21	73,05	60,5	136,36	72,71	57,31	136,33
	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*
	-2,41	-3,45	-0,39	-1,55	-2,41	-2,18	3,44	-1,71	-2,1	2,53	-0,88	-1,85	-2,7	2,88	0,21	-0,84	2,67	-1,18	-3,68	1,77	-0,08	-1,42	2,47	-0,7
$ΔE^*(G_Y,G_C)$	4,23			3,42			4,59			3,5			3,95			3,06			4,09			2,94		

Table 8 *Average values (ΔE*) of results of visual assessment of the Munker-White's sample created with the cyan color lines that are induced by the colors of external grid (blue - green) which build the assessed stimulus by subtractive synthesis in different rendering methods*
Tablica 8. *Prosječne vrijednosti (ΔE*) rezultata vizalnog ocjenjivanja Munker-White-ovog uzorka kreiranog s cyan bojom linija koje se induciraju bojama vanjske rešetke (plava - zelena) koje suptraktivnom sintezom izgrađuju ocijenjeni stimulans kod različitih metoda renderiranja*

	Perceptual						Saturation						Relative colorimetric						Absulute colorimetric					
	Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas		
Stimulus	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
C_G	68,89	-24,06	-12,09	69,89	-22,06	-9,92	40,43	-38,18	-38,95	38,41	-39,78	-40,85	73,76	-27,68	-10,76	75,76	-25,85	-9,61	75,11	-28,11	-18,33	78,36	-25,02	-16,94
C_B	66,92	-26,82	-11,64	69,16	-24,62	-9,63	38,71	-35,79	-36,65	36,61	-37,99	-39,59	71,7	-29,76	-9,58	75,7	-27,58	-8,8	72,32	-30,41	-17,44	78,19	-26,47	-15,88
	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*
C_G	68,89	26,93	-153,32	69,89	24,19	-155,78	40,43	54,54	-134,43	38,41	57,02	-134,24	73,76	29,7	-158,76	75,76	27,57	-159,61	75,11	33,58	-146,92	78,36	30,22	-145,9
C_B	66,92	29,24	-156,54	69,16	26,44	-158,64	38,71	51,23	-134,32	36,61	54,87	-133,82	71,7	31,26	-162,15	75,7	28,95	-162,3	72,32	35,06	-150,17	78,19	30,87	-149
	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*
	1,97	-2,31	3,22	0,73	-2,25	2,86	1,72	3,32	-0,1	1,8	2,15	-0,42	2,06	-1,56	3,4	0,06	-1,38	2,69	2,79	-1,48	3,25	0,16	-0,65	3,14
$\Delta E^*(C_G,C_B)$	3,42			2,68			3,74			2,84			3,15			1,91			3,71			1,8		

Table 9 *Average values (ΔE*) of results of visual assessment of the Munker-White's sample created with the magenta lines that are induced by the colors of external grid (red - blue) which build the assessed stimulus by subtractive synthesis in different rendering methods*
Tablica 9. *Prosječne vrijednosti (ΔE*) rezultata vizalnog ocjenjivanja Munker-White-ovog uzorka kreiranog s magenta bojom linija koje se induciraju bojama vanjske rešetke (crvena - plava) koje suptraktivnom sintezom izgrađuju ocijenjeni stimulans kod različitih metoda renderiranja*

	Perceptual						Saturation						Relative colorimetric						Absulute colorimetric					
	Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas		
Stimulus	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
M_B	60	30,18	-24,25	61,25	27,68	-14,28	50,1	71,44	-4,62	48,62	73,13	-2,82	63,07	36,02	-22,65	61,94	33,82	-23,93	63,21	36,26	-22,72	62,92	28,53	-24,13
M_R	59,77	33,39	-23	59,4	28,39	-14,7	47,75	73,33	-2,52	46,68	73,84	-2,22	61,14	37,47	-24	60,46	34,97	-24,72	61,3	38,37	-24,23	61,24	29,93	-25,48
	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*
M_B	60	38,72	-38,79	61,25	31,14	-27,3	50,1	71,59	-3,7	48,62	73,19	-2,21	63,07	42,55	-32,16	61,94	41,43	-35,29	63,21	42,79	-32,07	62,92	37,37	-40,23
M_R	59,77	40,54	-34,56	59,4	31,97	-27,38	47,75	73,37	-1,97	46,68	73,87	-1,72	61,14	44,49	-32,64	60,46	42,82	-35,26	61,3	45,38	-32,27	61,24	39,3	-40,41
	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*
	0,23	-1,83	-4,23	1,85	-0,83	0,08	2,35	-1,78	-1,74	1,94	-0,69	-0,49	1,94	-1,94	0,48	1,48	-1,39	-0,02	1,91	-2,59	0,2	1,68	-1,94	0,19
$\Delta E^*(M_B,M_R)$	3,45			2,03			3,68			2,15			2,77			2,03			3,23			2,57		

Table 10 *Average values (ΔE*) of results of visual assessment of the Munker-White's sample created with the yellow lines that are induced by the colors of external grid (red - green) which build the assessed stimulus by subtractive synthesis in different rendering methods*
Tablica 10. *Prosječne vrijednosti (ΔE*) rezultata vizalnog ocjenjivanja Munker-White-ovog uzorka kreiranog s žutom bojom linija koje se induciraju bojama vanjske rešetke (crvena - zelena) koje suptraktivnom sintezom izgrađuju ocijenjeni stimulans kod različitih metoda renderiranja*

	Perceptual						Saturation						Relative colorimetric						Absulute colorimetric					
	Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas			Classical visual colorimetric experiment			Evaluation by atlas		
Stimulus	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
Y_G	83,02	-5,28	68,35	83,52	-4,08	67,51	78,48	-5,04	86,16	75,78	-1,14	85,62	86.67	-7,84	69,26	85,17	-11,68	65,19	87	-8,13	69	85,46	-11,14	64,69
Y_R	82,58	-6,83	70,65	83,88	-4,71	69,05	76,74	-3,3	85,22	74,94	-0,5	84,54	85,79	-9,82	68,15	84,99	-12,46	64,11	85,54	-9,85	68	85,31	-12,54	64,05
	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*	L*	C*	h*
Y_G	83,02	68,55	94,42	83,52	67,63	93,46	78,48	86,31	93,35	75,78	85,63	90,76	86,67	69,7	96,46	85,17	66,23	100,16	87	69,48	96,72	85,46	65,64	99,77
Y_R	82,58	70,98	95,52	83,88	69,22	93,9	76,74	85,29	92,21	74,94	84,54	90,34	85,79	68,86	98,2	84,99	65,31	101	85,54	68,71	98,24	85,31	65,27	101,08
	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*	ΔL*	ΔC*	Δh*
	0,44	-2,43	-1,11	-0,36	-1,58	-0,44	1,74	1,02	1,13	0,84	1,09	0,43	0,89	0,85	-1,74	0,19	0,92	-0,84	1,46	0,77	-1,52	0,15	0,37	-1,31
$\Delta E^*(Y_G,Y_R)$	2,81			1,7			2,64			1,51			2,43			1,34			2,47			1,55		

Table 11 *Comparison of the relationship of gamut sizes and the intensity of manifested effects*
Tablica 11. *Usporedba odnosa veličina gamuta i intenziteta manifestiranih efekata*

	chromatic assimilation	order of gamut sizes
1	Saturation	Abs. Colorimetric
2	Perceptual	Rel. Colorimetric
3	Abs. Colorimetric	Saturation
4	Rel. Colorimetric	Perceptual

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