ISSN 1330-3651
UDC/UDK 535.645:655.344.024

EVALUATION OF THE CHROMATIC ADAPTATION EFFECT INTENSITY BY "TUNING" THE DESATURATED ACHROMATIC REPRODUCTIONS PRINTED IN THE OFFSET

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Original scientific paper

This paper describes the interrelationships between the chromatic adaptation effects, the standard rendering methods and the perception of desaturated achromatic reproductions obtained by offset printing. In order to establish the influence of the effects of chromatic adaptation in given variables visual systems of respondents have been adapted (by observing the three types of adaptation forms: cyan, magenta and yellow) in predefined time frame. By comparing the reference sample and the prints obtained after the adaptation of the respondents – printer – the chromatic adaptation effect intensity has been measured in real terms of graphic production using the phenomenon of gray balance. The research results indicate the existence of the interdependence of the studied parameters, and further need for the research associated with the impact the effect has on certain segments of graphic production.

Keywords: *chromatic adaptation, gray balance, offset, rendering*

Evaluacija intenziteta efekta kromatske adaptacije metodom "ugađanja" na desaturiranim akromatskim otiscima produciranim u offset tisku

Izvorni znanstveni članak

U ovom radu istraživani su međuodnosi efekta kromatske adaptacije, standardnih metoda renderiranja i percepcije desaturiranih akromatskih reprodukcija dobivenih ofsetnim tiskom. U cilju određivanja utjecaja efekta kromatske adaptacije u danim varijablama adaptirani su vizualni sustavi ispitanika (promatranjem tri tipa adaptacijskih formi: zeleno-plave, purpurne i žute) u zadanom vremenskom razdoblju. Usporedbom referentnog uzorka te otisaka dobivenih nakon adaptacije ispitanika – tiskara, koristeći fenomen sivog balansa izmjeren je intezitet efekta kromatske adaptacije u realnim uvjetima grafičke proizvodnje. Rezultati istraživanja ukazuju na postojanje međuovisnosti istraživanih parametara te na dalju potrebu za istraživanjima koja su povezana s utjecajem efekta na pojedine segmente grafičke proizvodnje.

Ključne riječi: *kromatska adaptacija, sivi balans, offset, renderiranje*

1 Introduction

The central concept of seeing the colour is chromatic adaptation [1, 2]. It provides colour vision in a wide range of different illuminations [3]. Some studies from on illumination perception and adaptation are limited to the achromatic world [4, 5].

Everyday, our visual system is in situations in which it must adjust (adapt) the sensitivity of its sensory cells in these different conditions of observation [6]. The main role of adaptation mechanisms in the human organism is to make the viewer (through some nonlinear processes) less sensitive to changes in stimuli in cases where the physical stimulus intensity increases (or decreases) to a greater extent than necessary or favourable for the perception system.

When, for example, a light source has too much light intensity in a spectral region (S, M or L wavelength areas), adaptive properties of our visual system will enable the reduction of the sensitivity of cones responsible for the perception of a given spectral region [7], i.e. in the case when the cone has adapted to high intensity (his sensitivity is reduced) in a particular spectral region, due to changes in the environment, adequately to the new observation environment (in a given time period) will increase its sensitivity.

Psychophysical visual effect of chromatic adaptation is largely based precisely on the mentioned feature of our visual system that individually and independently controls the sensitivity (between) the three groups of receptor cells of our eye – L, M and S cones (which tune their sensitivity as dependent on increasing or reducing the relative radiation energy in different spectral regions).

However, in certain cases (within a certain period of time) the decrease of the sensitivity of individual receptors with regard to coloured features of a specific stimulus (compared to normal sensitivity) may result in adverse effect of a distorted interpretation of the observed stimuli features.

Within the reproductive processes of graphic technology, this problem is particularly undesirable when it comes to the processes directly related to the colour tuning or matching, such as preparation of design solutions, digitalization and correction of the original, and finally the printing process itself.

When creating a reproduction, on the corresponding machine by the means of certain elements (the position of the inkzones, ductor angle, ink-water balance, etc.), the printer interactively adjusts the interrelationships of process-based dyes based on subtractive synthesis in relation to the reference pattern or the "colour test".

Taking into consideration the fact that (except with respect to the characteristics of different illuminators) our visual system can easily chromatically adapt to a highly saturated dominant tones (primarily the colours of additive or subtractive synthesis), and taking into account the coloured characteristics of different objects and surfaces that surround us in a printing house, especially areas of prints (which are focused on over a longer period in a printing house), the possibility of manifestation of the chromatic adaptation effect can be assumed.

In everyday production process, particularly undesirable situations are when the printer, through a certain period of time without interruption, observes a surface printed in a tone colour of high impulse purity, with his visual system adapting to the observed colour. Therefore, the colour occurrence (due to reduced sensitivity of the corresponding cones) at the next "real" print is certainly changed to some extent.

2 Experimental part

2.1 Methodology

Manifestation of the chromatic adaptation effect when making achromatic reproductions in the gray balance area (with the three primary colours of subtractive synthesis) will cause a decrease in the sensitivity of our visual system for the colours that adaptation has been carried out on, and thus distortion, or the way out of gray balance areas and achromatic experience.

Evaluation methodology of the manifested chromatic adaptation intensity effect (in a given time period) is based on the determination of colorimetric size deviation (ΔE^*_{ab} color differences) between the reference print (performed through CIP3 control system and printing process management) and prints executed in the so-called "interactive visual experiment" after the performed chromatic adaptation of the visual system (on particular primary colours of subtractive synthesis).

Color differences can be expressed by the formulas [21, 22]:

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}, \quad \Delta L^* = L_0 - L_1, \Delta a^* = a_0 - a_1, \Delta b^* = b_0 - b_1 \tag{1}$$

where L_0, a_0 and b_0 physical values of perceived colour on the test sample, and L_1, a_1 i and b_1 represent the physical values of the reference colour (Fig. 1).

$$\Delta E^*_{94} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{k_H S_H}\right)^2} \tag{2}$$

$k_L = k_C = k_H = 1$ for reference conditions

$S_L = 1; S_C = 1 + 0{,}045 \cdot C^*_{ab}; S_H = 1 + 0{,}015 \cdot C^*_{ab},$

where k_L, k_C and k_H are correction parameters used to adjust the relative values of brightness, saturation and tone in terms of observation, which are different from those defined by the CIE Commission [8]. Factors S_L, S_C and S_H represent positional functions, whose role is correction of perceptual non-uniform of CIELAB colour space.

During the experiment based on the method of tuning, the examiner typically sets the device for the control of the stimulus much lower or much higher than the value that causes the targeted perceptual response. The respondents are asked to set the device at the value at which the stimuli cause the required response for them. The experiment is repeated several times (up to 10 iterations). A simple example of using the adjusting method would be a potentiometer for controlling the lights with the intensity scale for reading the intensity.

2.2 Test form design

For the purpose of evaluation of the chromatic adaptation effect intensity, the test form of size 50 × 70 cm (B2-format printing machine) is created out of four independent units (Fig. 1). Each unit is a differently rendered identical template, which can be further divided into segments for instrumental analysis and image segment designed for a visual experiment. In order to exclude the influence of the "adjacent areas" on the differently rendered test templates during the printing process and to achieve maximum independence, the printing form is derived in a manner that the distance between two tested templates is equal to the value of three inkzones width (around 10 cm). The segment for instrumental analysis (right part of Fig. 1) consists of measuring fields lined up in 7 identical columns that cover the whole area of image templates with respect to the position of the inkzones. Each column contains 9 measuring fields whose dimensions (8 × 15 mm) allow for the automatic measurement of colorimetric values by using X-Rite DTP41 device. The first three panels of each column (in relation to the position of the unit for visual assessment) are made of full tones (100 % HTV) of primary colours of subtractive synthesis; the following three fields are of identical colour derived from 80 % HTV, while the last three fields were done with 40 % HTV.

These selected values of measuring fields enable the tracking of deviations of colorimetric values of primary colours of subtractive synthesis (default HTV) between the reference print generated by the CIP3 control system (automatic print tuning using the information from the original records) and the print generated by adjusting on the side of the printing house during the manifestation of the chromatic adaptation effect.

The unit for visual assessment, or the visual interactive experiment, consists of two achromatic image templates identical in content and dimensions, deposited one above the other, with a difference that the first (reference) template is generated only in black, while the test sample is generated by printing the three primary colours of subtractive synthesis (green-blue, purple and yellow) in the area of gray balance.

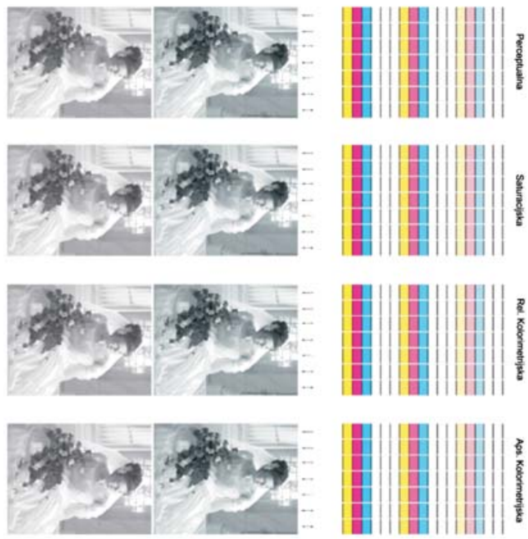

Figure 1 The review of the test form used in the experiment (rotated by 90° CCW in relation to the direction of print)

The test sample was created from an identical reference achromatic sample with a specific conversion process through a variety of colour models within Adobe Photoshop. The reference sample, originally written in the form of a bit-map greyscale (- greyscale), in the first step was converted (translated) into RGB colour space; then in the next step, the conversion of the mentioned was performed into the CMYK colour model. In the above sequence of conversions, the conversion of achromatic tone values rendered in black (reference sample) in achromatic tones that are made by combining the primary colours of subtractive synthesis in the area of gray balance (a sample intended for the evaluation of the characteristics of the tested effect) was achieved on the reproduction template.

Separate segments of the test form previously described are stored in PDF files and rasterized separately in the resolution of 2400 dpi, using various standard ICC rendering methods [9] and as such imposed at a given mutual distance (width of 3 zones) on the printing form.

2.3
The reproduction of adaptation forms and reference print

Adaptation forms intended for the stimulation of the chromatic adaptation effect manifestation are represented by the reproductions generated by printing various colours of subtractive synthesis of the full amount (100 % HTV) in accordance with the guidelines of ISO 12647-2:1996 standard (Graphic technology – Process control for manufacture of halftone colour separations, proofs and production print – part 2) where using densitometry measurements after performing the reproduction process on them (standard for coated glossy paper), the following values of integral optical density D_{iC} = 1,66; D_{iM} = 1,61; D_{iY} = 1,16 ; and D_{iK} = 1,95 are achieved.

The reference print is presented by the reproduction of test form generated by using the calibrated CIP3 control and management system, which performs automatic tuning of the print with the information derived from the original records. To adjust the printing machine, the identical information is used like for imaging printing form on the CtP device.

In order to determine the tolerant area shift of colorimetric values of the prints as a result of individual experience of certain colour printers, the prints are made where, besides the CIP3 management system, a mild correction of prints from the printers themselves (so-called "fine tuning" of inkzones) was conducted with the aim of achieving maximum correspondence between the reference sample (produced by printing only black ink) and tested samples (realised in primary colours of subtractive synthesis in the gray balance area).

The total of 8 prints was made, one for each respondent, whose values were averaged after the measurement.

The difference in values between the print created exclusively by CIP3 management system and prints derived with additional fine-tuning zones by the printer presents the tolerance movement area so that we can say that is not conditioned with the manifestation of the chromatic adaptation effect.

The reference print, adaptation forms, and the print created in the visual experiment (after applied adaptation) are derived in the same dyes on the same printing substrate (multi-coated glossy paper, grammage 170 g/m^2, whose whiteness is expressed in $L^*a^*b^*$ values has coordinates: L^*= 92,8, a^*= 1,1; b^*= 0,76). The paper was conditioned before the printing process in a period of 48 hours at ambient conditions of the printing house. The printing was carried out on 5-coloured offset printing press format B2 (Heidelberg Speedmaster 74) which at the time of the experiment was in full working condition (with new portable rubbers on all printing units and new foils in inkzones).

2.4
Adaptation of the visual system and interactive visual experiment

Immediately prior to making the reproduction on a printing machine, the visual system for each participant (printing house) has been adapted by continuous and stationary observation of the centre of adaptation forms (prints of certain primary colours of subtractive synthesis) in a period of 5 minutes. After completing the process of adaptation, the task of the printing houses was to tune, in a time-limited period of 30 seconds (default duration of the chromatic adaptation effect), a sample which is made by three primary colours of subtractive synthesis in the gray balance area for the abovementioned to assume achromatic properties, and to achieve maximum correspondence with the equivalent neighbouring sample that is generated only by printing in black.

After the initial tuning of the print, and given the time required for their making in the machine itself (mixing the colours and the journey from inkzones to print forms and eventually to the print) or the necessity of performing interactive correction with the aim of adjusting the reference and the tested sample, and for a period of whose duration the partial regeneration of the visual system's abilities can be reached, it was determined that during the performance of each of the corrections (between the two procedures of tuning the individual identical segments) the adaptation of the visual system is carried out again for a period of not less than 2 minutes (if the process of corrections is performed for the less than the specified time).

The total number of allowed corrections by the print per given segment (rendering method) is limited to four - including the initial tuning. Within this number of corrections, the respondent, according to his own experience, based on the realized perceptual reaction decides when the test sample meets the required criteria, and he marks it with the corresponding label. In case the respondent is not satisfied with the achieved degree of alignment (tuning) after a specified number of corrections, the experiment is repeated after a period of regeneration for 45 minutes.

Furthermore, with the aim of increasing the mutual independence of the segments (generated by various rendering methods), which are located on a single test form, during their reproduction, the adaptation was again repeated for each of the segments in an identical initial period of 5 minutes. For the regeneration of the visual system (on the real environment conditions) between the process of making prints of certain segments of the test form, which are generated by various methods of rendering, certain time period of 10 minutes is determined; while for the regeneration of the visual system of respondents during the change of adaptation form is a time period of 45 minutes.

Visual evaluation was conducted under the D50 light source (a standard light source of the printing machines control console) on a sample of 8 respondents (male), mean age of 28. All the respondents previously successfully met the criteria of Ishihara test (24 sampels) for the detection of potential vision defect.

2.5 Instrumental analysis

The measuring of control fields from a part for the instrumental analysis (of individual segments) of test forms (belonging to different standard rendering methods) was carried out with X-Rite DTP 41 reflex spectrophotometer, in the range of wavelengths 390-710 nm (light source D50), with a step of 10 nm and illumination geometry 45°/0°. The precision of the device, or an average deviation in terms of reflectance of up to 0,5 % per step of wavelengths (standard for calibration of the abovementioned is moderate by the Munsell's laboratory with an accuracy ΔE^*=0,25 for a light source D50 and viewing angle of 2°).

After the measurements and given the relatively large number of generated information in the abovementioned (3 adaptations × 4 standard rendering methods × 3 control colours with three different raster-tone values of measuring fields), two additional procedures of averaging results were carried out.

The first averaging data takes into account the dimensions of the template for the visual evaluation equivalent to the width of 7 measuring control fields (a unit for instrumental analysis). Therefore, the measured values of the abovementioned are averaged for each primary colour of subtractive synthesis depending on the raster-tone value (100 %, 80 % or 40 %) of the measuring field (or values of each row of an individual HTV for each primary colour of subtractive synthesis).

By the abovementioned averaging of values, in the end 7 control points are achieved within the specified HTV of each primary colour of subtractive synthesis which cover the entire width of each of the segments.

Another procedure of averaging the results relates to the calculation of average values that printers generate (8 respondents) during the reproduction of the "reference print" and various examined prints.

3 Results and discussion

The results of visual evaluation with the method of tuning are ultimately determined instrumentally, which enables a much higher degree of precision, but as is shown in the research findings presented in Tabs. 1-16, direct control over certain features of stimuli is also enabled ant

Table 1 The review of reference colour values (CIE $L^*a^*b^*$) of the measuring control fields of test form

Color rendering intent	Stimuli	HTV - HALFTONE VALUE OF THE CONTROL FIELDS								
		100 %			80 %			40 %		
		*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**
Perceptual	Cyan	67,16	-33,85	-10,36	73,38	-30,25	-17,73	77,66	-17,53	-12,31
	Magenta	59,11	53,08	-18,47	61,25	40,08	-14,47	72,65	24,08	-8,47
	Yellow	83,12	-4,71	87,02	85,41	-3,44	62,99	87,81	-3,87	35,97
Saturation	Cyan	46,61	-37,99	-35,59	47,64	-38,87	-40,17	49,30	-30,06	-51,19
	Magenta	53,68	73,84	-2,22	58,62	73,23	-2,82	63,72	49,03	-12,97
	Yellow	76,94	-0,50	84,54	78,56	-1,62	85,25	82,92	-4,96	59,65
Relative Colorimetric	Cyan	73,27	-32,28	-9,94	75,72	-24,27	-10,05	80,96	-11,60	-8,72
	Magenta	60,46	54,97	-24,72	62,20	41,63	-19,55	75,69	19,64	-13,44
	Yellow	83,99	-12,46	64,11	85,17	-11,68	65,19	87,87	-6,67	38,56
Absolute Colorimetric	Cyan	72,72	-26,47	-15,88	78,06	-24,46	-17,44	82,92	-9,31	-14,90
	Magenta	61,46	48,97	-25,48	63,28	39,39	-18,68	77,47	13,60	-13,50
	Yellow	84,31	-12,54	64,85	86,29	-12,26	64,02	87,45	-6,44	32,06

Table 2 The review of average colour values (CIE $L^*a^*b^*$) of the measuring control fields achieved under chromatic adaptation to cyan

Color rendering intent	Stimuli	HTV - HALFTONE VALUE OF THE CONTROL FIELDS								
		100 %			80 %			40 %		
		*L**	*a**	b*	*L**	*a**	*b**	*L**	*a**	*b**
Perceptual	Cyan	66,80	-36,75	-11,00	72,15	-33,99	-19,35	74,68	-23,24	-16,95
	Magenta	61,01	48,76	-18,18	63,50	35,78	-13,47	75,02	19,82	-7,38
	Yellow	83,36	-4,14	81,44	85,64	-2,95	58,07	88,18	-3,25	31,79
Saturation	Cyan	53,88	-29,64	-25,61	55,61	-29,99	-35,59	59,51	-21,25	-48,71
	Magenta	54,61	72,38	-5,82	60,59	72,42	-7,75	66,60	46,46	-11,81
	Yellow	80,32	-3,05	76,96	82,23	-4,33	79,51	85,57	-6,92	59,02
Relative Colorimetric	Cyan	69,60	-37,40	-11,24	73,31	-34,38	-10,53	74,95	-19,94	-14,31
	Magenta	62,17	50,93	-21,44	63,98	37,04	-17,42	77,76	14,96	-9,34
	Yellow	83,86	-13,32	60,22	85,41	-12,78	62,01	89,33	-8,08	35,72
Absolute Colorimetric	Cyan	69,69	-31,10	-20,88	74,48	-30,20	-23,33	75,95	-15,26	-25,69
	Magenta	65,19	44,58	-23,65	67,08	35,34	-16,41	80,28	8,80	-8,91
	Yellow	86,58	-12,75	61,58	88,08	-13,57	60,82	89,14	-5,16	6,90

together with that the possibility of observing changes in individual perceptual attributes of the abovementioned. This can be applied not only for the same stimuli with respect to which the adaptation was done on, but changes of other colours of subtractive synthesis, which the manifestation of the researched adaptation system during the creation of prints has influence on, can be observed.

Table 3 The review of average colour values (CIE $L^*a^*b^*$) of the measuring control fields achieved under chromatic adaptation to magenta

Color rendering intent	Stimuli	HTV - HALFTONE VALUE OF THE CONTROL FIELDS 100 %			80 %			40 %		
		L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*
Perceptual	Cyan	66,80	-36,75	-11,00	72,15	-33,99	-19,35	74,68	-23,24	-16,95
	Magenta	61,01	48,76	-18,18	63,50	35,78	-13,47	75,02	19,82	-7,38
	Yellow	83,36	-4,14	81,44	85,64	-2,95	58,07	88,18	-3,25	31,79
Saturation	Cyan	53,88	-29,64	-25,61	55,61	-29,99	-35,59	59,51	-21,25	-48,71
	Magenta	54,61	72,38	-5,82	60,59	72,42	-7,75	66,60	46,46	-11,81
	Yellow	80,32	-3,05	76,96	82,23	-4,33	79,51	85,57	-6,92	59,02
Relative Colorimetric	Cyan	69,60	-37,40	-11,24	73,31	-34,38	-10,53	74,95	-19,94	-14,31
	Magenta	62,17	50,93	-21,44	63,98	37,04	-17,42	77,76	14,96	-9,34
	Yellow	83,86	-13,32	60,22	85,41	-12,78	62,01	89,33	-8,08	35,72
Absolute Colorimetric	Cyan	69,69	-31,10	-20,88	74,48	-30,20	-23,33	75,95	-15,26	-25,69
	Magenta	65,19	44,58	-23,65	67,08	35,34	-16,41	80,28	8,80	-8,91
	Yellow	86,58	-12,75	61,58	88,08	-13,57	60,82	89,14	-5,16	6,90

Table 4 The review of average colour values (CIE $L^*a^*b^*$) of the measuring control fields achieved under chromatic adaptation to yellow

Color rendering intent	Stimuli	HTV - HALFTONE VALUE OF THE CONTROL FIELDS 100 %			80 %			40 %		
		L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*
Perceptual	Cyan	66,22	-32,94	-10,08	76,31	-30,65	-16,22	80,06	-15,82	-11,35
	Magenta	62,16	50,68	-18,62	64,46	37,50	-14,22	76,60	20,23	-7,71
	Yellow	84,11	-9,12	82,69	84,14	-1,92	69,78	86,78	-3,77	44,98
Saturation	Cyan	51,86	-35,71	-32,47	53,31	-35,87	-37,68	56,13	-26,70	-46,62
	Magenta	54,97	75,08	-4,57	59,94	73,77	-6,97	65,13	48,57	-9,11
	Yellow	78,85	1,49	78,71	78,39	-0,33	78,70	82,44	-3,65	64,61
Relative Colorimetric	Cyan	75,80	-30,27	-8,10	77,97	-21,67	-8,29	83,93	-9,97	-6,04
	Magenta	63,09	53,36	-23,93	65,02	39,56	-19,53	78,92	16,82	-12,51
	Yellow	84,04	-12,70	69,67	84,83	-9,53	70,36	82,21	-6,77	45,35
Absolute Colorimetric	Cyan	74,53	-23,92	-13,94	79,44	-22,07	-14,83	83,00	-8,02	-10,10
	Magenta	64,16	46,87	-24,66	66,00	37,46	-17,04	81,02	10,56	-10,97
	Yellow	83,38	-13,97	70,36	84,25	-14,14	70,16	86,79	-8,91	39,36

Table 5 The review of deviation of the measuring control fields value between the reference print and the print derived by perceptual rendering method under chromatic adaptation to cyan

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS 100 %			80 %			40 %			Average $\Delta E^*_{(100\,\%,\ 80\,\%,\ 40\,\%)}$
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	
$C_{ref.}$	69,16	-24,62	-9,63	69,89	-22,06	-9,92	77,32	-12,59	-6,47	
$C_{ev.}$	66,80	-36,75	-11,00	72,15	-33,99	-19,35	74,68	-23,24	-16,95	
ΔE^*	12,43			15,37			15,18			14,33
$M_{ref.}$	59,11	53,08	-18,47	61,25	40,08	-14,47	72,65	24,08	-8,47	
$M_{ev.}$	61,01	48,76	-18,18	63,50	35,78	-13,47	75,02	19,82	-7,38	
ΔE^*	4,73			4,96			5,00			4,89
$Y_{ref.}$	83,12	-4,71	87,02	85,41	-3,44	62,99	87,81	-3,87	35,97	
$Y_{ev.}$	83,36	-4,14	81,44	85,64	-2,95	58,07	88,18	-3,25	31,79	
ΔE^*	5,61			4,95			4,24			4,93

Table 6 Review of deviation of the measuring control fields value between the reference print and the print derived by saturation rendering method under chromatic adaptation to cyan

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									
	100 %			80 %			40 %			
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	
$C_{ref.}$	46,61	-37,99	-35,59	47,64	-38,87	-40,17	49,30	-30,06	-51,19	
$C_{ev.}$	53,88	-29,64	-25,61	55,61	-29,99	-35,59	59,51	-21,25	-48,71	Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
ΔE^*	14,91			12,78			13,71			13,80
$M_{ref.}$	53,68	73,84	-2,22	58,62	73,23	-2,82	63,72	49,03	-12,97	
$M_{ev.}$	54,61	72,38	-5,82	60,59	72,42	-7,75	66,60	46,46	-11,81	
ΔE^*	4,00			5,37			4,03			4,47
$Y_{ref.}$	76,94	-0,50	84,54	78,56	-1,62	85,25	82,92	-4,96	59,65	
$Y_{ev.}$	80,32	-3,05	76,96	82,23	-4,33	79,51	85,57	-6,92	59,02	
ΔE^*	8,69			7,33			3,36			6,46

Table 7 Review of deviation of the measuring control fields value between the reference print and the print derived by relative colorimetric rendering method under chromatic adaptation to cyan

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									
	100 %			80 %			40 %			
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	
$C_{ref.}$	73,27	-32,28	-9,94	75,72	-24,27	-10,05	80,96	-11,60	-8,72	
$C_{ev.}$	69,60	-37,40	-11,24	73,31	-34,38	-10,53	74,95	-19,94	-14,31	Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
ΔE^*	6,43			10,41			11,70			9,51
$M_{ref.}$	60,46	54,97	-24,72	62,20	41,63	-19,55	75,69	19,64	-13,44	
$M_{ev.}$	62,17	50,93	-21,44	63,98	37,04	-17,42	77,76	14,96	-9,34	
ΔE^*	5,48			5,36			6,56			5,80
$Y_{ref.}$	83,99	-12,46	64,11	85,17	-11,68	65,19	87,87	-6,67	38,56	
$Y_{ev.}$	83,86	-13,32	60,22	85,41	-12,78	62,01	89,33	-8,08	35,72	
ΔE^*	3,99			3,37			3,49			3,62

Table 8 Review of deviation of the measuring control fields value between the reference print and the print derived by absolute colorimetric rendering method under chromatic adaptation to cyan

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									
	100 %			80 %			40 %			
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	
$C_{ref.}$	72,72	-26,47	-15,88	78,06	-24,46	-17,44	82,92	-9,31	-14,90	
$C_{ev.}$	69,69	-31,10	-20,88	74,48	-30,20	-23,33	75,95	-15,26	-25,69	Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
ΔE^*	7,46			8,97			14,16			10,19
$M_{ref.}$	61,46	48,97	-25,48	63,28	39,39	-18,68	77,47	13,60	-13,50	
$M_{ev.}$	65,19	44,58	-23,65	67,08	35,34	-16,41	80,28	8,80	-8,91	
ΔE^*	6,04			6,00			7,21			6,42
$Y_{ref.}$	84,31	-12,54	64,85	86,29	-12,26	64,02	87,45	-6,44	32,06	
$Y_{ev.}$	86,58	-12,75	61,58	88,08	-13,57	60,82	89,14	-5,16	26,90	
ΔE^*	3,99			3,89			5,58			4,49

Table 9 Review of deviation of the measuring control fields value between the reference print and the print derived by perceptual rendering method under chromatic adaptation to magenta

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
	100 %			80 %			40 %			
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	
$C_{ref.}$	67,16	-33,85	-10,36	73,38	-30,25	-17,73	77,66	-17,53	-12,31	
$C_{ev.}$	70,26	-30,79	-9,52	76,63	-28,94	-14,10	80,22	-13,46	-8,40	
ΔE^*	4,43			5,05			6,20			5,23
$M_{ref.}$	59,11	53,08	-18,47	61,25	40,08	-14,47	72,65	24,08	-8,47	
$M_{ev.}$	66,25	61,46	-20,54	56,94	49,98	-17,02	67,50	34,20	-11,76	
ΔE^*	11,20			11,09			11,82			11,37
$Y_{ref.}$	83,12	-4,71	87,02	85,41	-3,44	62,99	87,81	-3,87	35,97	
$Y_{ev.}$	84,84	-3,98	82,98	87,10	-2,86	60,25	89,93	-3,35	32,14	
ΔE^*	4,45			3,27			4,41			4,04

Table 10 Review of deviation of the measuring control fields value between the reference print and the print derived by saturation rendering method under chromatic adaptation to magenta

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
	100 %			80 %			40 %			
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	
$C_{ref.}$	46,61	-37,99	-35,59	47,64	-38,87	-40,17	49,30	-30,06	-51,19	
$C_{ev.}$	52,78	-33,94	-32,89	54,17	-34,67	-35,07	55,30	-26,06	-45,19	
ΔE^*	7,86			9,28			9,38			8,84
$M_{ref.}$	53,68	73,84	-2,22	58,62	73,23	-2,82	63,72	49,03	-12,97	
$M_{ev.}$	47,18	79,30	-5,47	53,61	65,23	-5,42	60,60	46,45	-4,81	
ΔE^*	9,09			9,79			9,11			9,33
$Y_{ref.}$	76,94	-0,50	84,54	78,56	-1,62	85,25	82,92	-4,96	59,65	
$Y_{ev.}$	78,78	-0,16	78,82	80,43	-0,97	78,49	84,83	-3,21	55,90	
ΔE^*	6,02			7,04			4,56			5,87

Table 11 Review of deviation of the measuring control fields value between the reference print and the print derived by relative colorimetric rendering method under chromatic adaptation to magenta

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
	100 %			80 %			40 %			
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	
$C_{ref.}$	73,27	-32,28	-9,94	75,72	-24,27	-10,05	80,96	-11,60	-8,72	
$C_{ev.}$	76,62	-30,23	-9,65	78,69	-22,66	-8,28	84,04	-9,33	-7,92	
ΔE^*	3,94			3,81			3,91			3,89
$M_{ref.}$	60,46	54,97	-24,72	62,20	41,63	-19,55	75,69	19,64	-13,44	
$M_{ev.}$	56,09	60,84	-26,24	56,73	47,79	-22,61	69,16	27,73	-18,95	
ΔE^*	7,48			8,79			11,77			9,34
$Y_{ref.}$	83,99	-12,46	64,11	85,17	-11,68	65,19	87,87	-6,67	38,56	
$Y_{ev.}$	86,60	-12,13	63,41	87,46	-9,46	63,41	90,45	-6,08	35,79	
ΔE^*	2,73			3,65			3,83			3,40

Table 12 Review of deviation of the measuring control fields value between the reference print and the print derived by absolute colorimetric rendering method under chromatic adaptation to magenta

	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									
Color of the fields	**100 %**			**80 %**			**40 %**			
	L*	***a****	***b****	***L****	***a****	***b****	***L****	***a****	***b****	
$C_{ref.}$	72,72	-26,47	-15,88	78,06	-24,46	-17,44	82,92	-9,31	-14,90	
$C_{ev.}$	75,99	-25,24	-14,01	81,01	-22,21	-15,02	86,38	-8,83	-13,00	Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
ΔE^*	3,96			4,43			3,98			4,12
$M_{ref.}$	61,46	48,97	-25,48	63,28	39,39	-18,68	77,47	13,60	-13,50	
$M_{ev.}$	56,32	56,13	-29,17	57,82	47,72	-22,64	70,23	22,30	-20,80	
ΔE^*	9,56			10,72			13,47			11,25
$Y_{ref.}$	84,31	-12,54	64,85	86,29	-12,26	64,02	87,45	-6,44	32,06	
$Y_{ev.}$	86,94	-12,24	64,19	89,06	-11,23	63,30	90,02	-5,12	29,63	
ΔE^*	2,73			3,05			3,77			3,18

Table 13 Review of deviation of the measuring control fields value between the reference print and the print derived by perceptional rendering method under chromatic adaptation to yellow

	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									
Color of the fields	**100 %**			**80 %**			**40 %**			
	L*	***a****	***b****	***L****	***a****	***b****	***L****	***a****	***b****	
$C_{ref.}$	67,16	-33,85	-10,36	73,38	-30,25	-17,73	77,66	-17,53	-12,31	
$C_{ev.}$	66,22	-32,94	-10,08	76,31	-30,65	-16,22	80,06	-15,82	-11,35	Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
ΔE^*	1,34			3,32			3,10			2,59
$M_{ref.}$	59,11	53,08	-18,47	61,25	40,08	-14,47	72,65	24,08	-8,47	
$M_{ev.}$	62,16	50,68	-18,62	64,46	37,50	-14,22	76,60	20,23	-7,71	
ΔE^*	3,88			4,13			5,57			4,53
$Y_{ref.}$	83,12	-4,71	87,02	85,41	-3,44	62,99	87,81	-3,87	35,97	
$Y_{ev.}$	84,11	-9,12	82,69	84,14	-1,92	69,78	86,78	-3,77	44,98	
ΔE^*	6,26			7,08			9,07			7,47

Table 14 Review of deviation of the measuring control fields value between the reference print and the print derived by saturation rendering method under chromatic adaptation to yellow

	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									
Color of the fields	**100 %**			**80 %**			**40 %**			
	L*	***a****	***b****	***L****	***a****	***b****	***L****	***a****	***b****	
$C_{ref.}$	46,61	-37,99	-35,59	47,64	-38,87	-40,17	49,30	-30,06	-51,19	
$C_{ev.}$	51,86	-35,71	-32,47	53,31	-35,87	-37,68	56,13	-26,70	-46,62	Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
ΔE^*	6,52			6,88			8,88			7,42
$M_{ref.}$	53,68	73,84	-2,22	58,62	73,23	-2,82	63,72	49,03	-12,97	
$M_{ev.}$	54,97	75,08	-4,57	59,94	73,77	-6,97	65,13	48,57	-9,11	
ΔE^*	2,95			4,38			4,14			3,83
$Y_{ref.}$	76,94	-0,50	84,54	78,56	-1,62	85,25	82,92	-4,96	59,65	
$Y_{ev.}$	78,85	1,49	78,71	78,39	-0,33	78,70	82,44	-3,65	64,61	
ΔE^*	6,45			6,68			5,15			6,09

Table 15 Review of deviation of the measuring control fields value between the reference print and the print derived by relative colorimetric rendering method under chromatic adaptation to yellow

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									
	100 %			80 %			40 %			
	*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**	Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
$C_{ref.}$	73,27	-32,28	-9,94	75,72	-24,27	-10,05	80,96	-11,60	-8,72	
$C_{ev.}$	75,80	-30,27	-8,10	77,97	-21,67	-8,29	83,93	-9,97	-6,04	
ΔE^*	3,72			3,86			4,32			3,97
$M_{ref.}$	60,46	54,97	-24,72	62,20	41,63	-19,55	75,69	19,64	-13,44	
$M_{ev.}$	63,09	53,36	-23,93	65,02	39,56	-19,53	78,92	16,82	-12,51	
ΔE^*	3,18			3,50			4,39			3,69
$Y_{ref.}$	83,99	-12,46	64,11	85,17	-11,68	65,19	87,87	-6,67	38,56	
$Y_{ev.}$	84,04	-12,70	69,67	84,83	-9,53	70,36	82,21	-6,77	45,35	
ΔE^*	5,56			5,61			8,84			6,67

Table 16. Review of deviation of the measuring control fields value between the reference print and the print derived by absolute colorimetric rendering method under chromatic adaptation to yellow

Color of the fields	HTV - HALFTONE VALUE OF THE CONTROL FIELDS									
	100 %			80 %			40 %			
	*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**	Average $\Delta E^*_{(100\ \%,\ 80\ \%,\ 40\ \%)}$
$C_{ref.}$	72,72	-26,47	-15,88	78,06	-24,46	-17,44	82,92	-9,31	-14,90	
$C_{ev.}$	74,53	-23,92	-13,94	79,44	-22,07	-14,83	83,00	-8,02	-10,10	
ΔE^*	3,68			3,80			4,97			4,15
$M_{ref.}$	61,46	48,97	-25,48	63,28	39,39	-18,68	77,47	13,60	-13,50	
$M_{ev.}$	64,16	46,87	-24,66	66,00	37,46	-17,04	81,02	10,56	-10,97	
ΔE^*	3,52			3,71			5,31			4,18
$Y_{ref.}$	84,31	-12,54	64,85	86,29	-12,26	64,02	87,45	-6,44	32,06	
$Y_{ev.}$	83,38	-13,97	70,36	84,25	-14,14	70,16	86,79	-8,91	39,36	
ΔE^*	5,76			6,74			7,74			6,75

4 Discussion and conclusion

When prints are created by the respondents, due to manifestation of the chromatic adaptation effect there is decreased sensitivity of receptors responsible for the interpretation of stimuli, which the adaptation is performed on. The indicated is reflected with the respondents by the need for changing the value of stimuli to adjust the tested sample and to leave it the area of gray balance; or to annullate the influence the manifested chromatic adaptation effect.

Thus the change value in relation to the reference sample can be considered a value of intensity of the manifested chromatic adaptation effect.

If the research results are observed primarily with respect to the change value depending on the investigated adaptation system, in Tabs. 5 and 6, it is evident that the greatest changes in relation to the reference sample (Tab. 1) for the same stimuli are revealed in adaptation to cyan and in all four standard rendering methods.

The values of these changes of the same stimuli range from 8,81 at saturation rendering method (Tab. 6) to 14,33 in perceptual rendering method (Tab. 5) – expressed by ΔE^*.

Given the size of changes in the same stimuli, adaptation to magenta follows. Also in all four rendering methods applied.

The values of these changes caused by adaptation to magenta for the same stimuli range from 9,33 at saturation rendering method (Tab. 10) to 11,37 in perceptual rendering method (Tab. 9) – expressed by ΔE^*.

The smallest size changes (for the same stimuli), as compared to other adaptation systems, is observed in adaptation to yellow. Also in all four rendering methods applied.

The value of these changes caused by adaptation to yellow range from 6,09 at saturation rendering method (Tab. 4) and to 7,47 for perceptual rendering method (Tab. 13) – expressed by ΔE^*.

By analyzing the Tab. 13 it can be seen that in all three adaptation systems the greatest changes in the perception (of the same stimulus) caused by the manifestation of chromatic adaptation effect are observed when using perceptual rendering methods, while the smallest changes were observed when using the saturation rendering method.

Furthermore, with the adaptation to yellow (Tabs. 13, 14, 15, 16), it is noticeable that although there is this trend in the relationship of the size of change of the same stimuli and the application of different rendering methods, the change values among them in the end are still very close (in the narrow range from 6,67 to 7,47 – expressed by the ΔE^*).

Respectively, it is possible to conclude on the basis of the above that the selection of a rendering method for a specific adaptation has no crucial influence on the intensity of manifestation of chromatic adaptation in the case of the same stimuli.

With values of recorded changes in stimuli that are not identical with the adaptation, there is no clearly defined trend of changes with regard to the applied rendering method.

The sheer size of the value in changes in the stimuli ranges from 2,59 (Tab. 12) to 8,84 (Tab. 9). It depends on the stimulus itself, the type of adaptation, and the method of rendering applied; and given to the very size in change in relation to changes in the same stimuli, these values are clearly respectable and must be taken into consideration.

Thus it is obvious that when you tune prints, due to manifestation of the chromatic adaptation effect, caused by a single primary colour of subtractive synthesis, there is some influence of the mentioned effect not only on the same stimuli but also on the remaining colours of subtractive synthesis.

The cause of this effect is not possible to determine clearly; it is possible to assume that there is indeed a certain influence on the perception of other primary colours of subtractive synthesis (which do not match the adaptation) due to a number of mechanisms our visual system is based on (Luther's principle, Hering's theory and trichromatic theory) [10], but also the impact of these can be attributed to the desire to keep the print in the gray balance area.

Or it can be assumed that these change values on different stimuli are the result of corrections with the aim of harmonizing desaturated chromatic reproduction, which is being created in the gray balance area with the same pattern that is achieved by printing in black only.

Very favourable results achieved with the saturation rendering method, as compared to the remaining standard rendering methods (in all three experiments) are understandable because of the principles of its influence.

The increase in saturation (chromaticity), which was built in with the purpose of the colour reproduction of saturation of rendering method apparently has a beneficial effect on reducing the sensitivity of receptors which is manifested due to adaptation to a given colour, thereby reducing the impact of the effect itself on the very possibility of changing the perception of a given colour.

The explanation of the perceptual rendering method's position in the experiment should be found in the fact that in that rendering method all the colours are compressed so as to completely fit the gamut of reproduction in order to maintain the relative relations between the tones. However, this results in a decrease of the reproduction chromaticity and thus greater exposure to the impact of the effect.

Or just maintaining relationships between tones, but also preserving achromatic scale that had some impact on the research results of identical desaturated samples with the effect of retinal localized chromatic adaptation in a way that the perceptual rendering method was moved in front of colorimetric rendering methods (in terms of reducing the impact of the effect) obviously had no important influence in the experiment.

5
References

[1] Rinner, O.; Gegenfurtner, K. R. Time course of chromatic adaptation for color appearance and discrimination. // Vision Research, 40, (2000), 1823-1826.

[2] Werner, A.; Sharpe, L. T.; Zrenner, E. Asymetries in the time-course of chromatic adaptation and the significance of contrast. // Vision Research, 40, (2000), 1101-1113.

[3] Werner, A. The spatial tuning of chromatic adaptation. // Vision Research, 43, (2003), 1611-1623.

[4] Beck, J. Stimulus correlates for the judged illumination of a surface. // Journal of Experimental Psychology, 58, 4(1959), 267-274.

[5] Gilchrist, A.; Jacobsen, A. Perception of lightness and illumination in a world of one reflectance. // Perception, 13, 1(1984), 5-19.

[6] Rutherford, M. D.; Brainard, D. H. Lightness constancy: A direct test of the illumination-estimation hypotehesis. // Psychological Sciences, 13, 2 (2002), 142-149.

[7] Milković, M.; Mrvac, N.; Vusić D., Vizualna psihofizika i dizajn, Veleučilište u Varaždinu, Varaždin, 2009.

[8] CIE. Technical report: Industrial colour - difference evaluation. Central Bureau of the CIE, Vienna, 1995.

[9] ISO 15076-1:2005, Image technology colour management -- Architecture, profile format and data structure -- Part 1: Based on ICC.1:2004-10, 2005.

[10] Milković, M.; Zjakić, I.; Vusić D., Kolorimetrija u multimedijskim komunikacijama, Veleučilište u Varaždinu, Varaždin, 2010.

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