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THE NEON COLOUR SPREADING EFFECT IN VARIOUS SURROUND AMBIENT CONDITIONS

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Original scientific paper

Modern systems of visual communications, which reproduction processes of graphic technology are also based on, are permanently being improved with new findings connected with the research results of certain visual effects. In this paper, the influence of certain standard light sources to the intensity of the neon colours spreading effect in the process of graphic reproduction was studied. Also, the additive primary colours and subtractive synthesis effect in design of test samples that are based on so-called Ehrenstein model were analyzed. Test samples were printed on multiple coated glossy art paper through the machine calibrated for digital printing on the principle of liquid toner. By using visual assessment technique simultaneous binocular reconciliation evaluation of test samples was carried out. The research results prove the effect of different standard light sources and coloured characteristics of the stimulus on the intensity of neon colour spreading effect. Recommendations to expand the application of the neon colours spreading effect in order to achieve efficient designs of graphic templates in contemporary processes of graphic reproduction are proposed.

Keywords: *Ehrenstein model, intensity, light source, neon colour spreading, stimulus colour*

Efekt neonskog proširivanja boje u različitim ambijentalnim uvjetima

Izvorni znanstveni članak

Suvremeni sustavi vizualnih komunikacija na kojima se temelje i reprodukcijski procesi grafičke tehnologije permanentno se unaprijeđuju novim spoznajama vezanima uz rezultate istraživanja pojedinih vizualnih efekata. U ovom radu istražen je utjecaj određenih standardnih izvora svjetla na intenzitet efekta neonskog proširivanja boje u procesu grafičke reprodukcije. Analiziran je i utjecaj primarnih boja aditivne i suptraktivne sinteze pri konstruiranju testnih uzoraka koji su temeljeni na tzv. Ehrensteinovom modelu. Testni uzorci otisnuti su na višestruko premazanoj sjajnoj tiskovnoj podlozi za umjetnički tisak putem kalibriranog stroja za digitalni tisak na principu tekućeg tonera. Evaluacija testnih uzoraka provedena je primjenom vizualne tehnike ocjenjivanja, simultanog binokularnog usuglašavanja. Rezultati istraživanja dokazuju utjecaj različitih standardnih izvora svjetla i bojenih karakteristika stimulusa na intenzitet manifestacije efekta neonskog proširivanja boje. Predlažu se preporuke primjene efekta neonskog proširivanja boje u cilju postizanja efikasnijih dizajnerskih rješenja grafičkih predložaka u suvremenim procesima grafičke reprodukcije.

Ključne riječi: *boja stimulusa, Ehrenstein model, intenzitet, izvor svjetla, neonsko proširivanje boje*

1 Introduction
Uvod

Possibilities of a visual presentation of information through various print media and general variety of media in the graphic colour reproduction process create new relations in the relationship between physical stimuli and associated visual perceptual experience [1]. Providing conditions for the same perception of colour regardless of the medium of communication and all other parameters that affect the perception of colour, through the construction of objective psychophysical model of colour perception is the fundamental aim of colorimetric studies [2, 3].

Nonlinearity in human perception, which is noticeable in the perception of reproduced colours in terms of various influential parameters changes (printing surface, coloured characteristics of stimuli, standard light sources, the geometrical structure of the stimulus, the viewing angle), creates a need for new research that will contribute to a better understanding of the correlation of three chromatic values of coloured stimuli in graphic reproduction and all relevant influential parameters [2, 4, 5]. Achieving the correct colour appearance throughout all phases of graphic processes is doubtful in terms of occurrence of various psychophysical visual effects [6, 7, 8].

Psychophysical visual neon colour spreading effect manifests in the shifting of colour appearance by creating a virtual extension of primary stimulus colour on a background of graphic reproductions, in the size of the primary stimulus in the lattice area, but also in the process of creating design templates.

Determination of the each effect manifestation magnitude allows the application of colorimetric and psychophysical researches, with associated values of perceptual experience and the physical size of stimuli classified using standard methods of determining the threshold of visual perception. This implies joining the colorimetric values (CIE $L^*a^*b^*$) of the reference field from the atlas of colours that is identical to the perceived experience of the manifested effect on the test sample, and displaying the intensity of the effect by colorimetric colour differences ΔE^*_{94} [8, 9]

The aim of this study is to determine the impact of standard light sources and characteristics of colour stimuli on the intensity of neon colour spreading effect. Research results specify the interaction between the influencing parameters and the intensity of the neon colours spreading effect on the one side, and the impact of this effect on the human perception of colours on the other side.

2 Experimental part
Eksperimentalni dio

2.1 Problem statement
Opis problema

Significant impact in changing the colour appearance on the print media and other media in the system of graphic reproduction has different psychophysical visual effects [10].

Estimating the colour appearance of colour stimuli presented to the observer in the complex conditions of observation, is the area covered by advanced colorimetry

[11, 12]. Deviations in colour perception caused by manifestation of a specific psychophysical visual effect are possible through calculation of colorimetric colour difference ΔE^*_{94} - the difference between the Euclidean coordinates of the reference colour (the physical value of the printing substrate surface) and the coordinates of the associated colour of reference field from colour atlas to the perceived apparent colour of the test sample (physical value of the reference field from the atlas of colours) [2].

The neon colour spreading effect for the first time was analyzed under its name in the work of Van Tuija, HFJM, describing the prevalence of the effect in a situation where in a system of orthogonal grid lines - Ehrenstein model, a specific section or sections of lines are replaced with segments of different colours [13]. The effect is manifested in the creation of virtual extension of line colour of the primary stimulus (the replaced segment) on the background of the test sample in the grid area in the size of primary stimuli lines. In further studies of the neon colour spreading effect, the influences of other geometric elements within the test samples were examined [14]. It has been shown that the apparent extension of the same colour tone is the same as the hue of the primary stimuli [15]. The intensity of the neon colour spreading effect depending on the wavelength and brightness contrast [16, 17], and the influence of the contrast between primary stimuli and background on the experience of the mutual position of elements of the geometrical structure of the stimulus were investigated [18]. Previous studies have not provided a comprehensive picture of the neon colour spreading effect of the impact of certain parameters within the processes of graphic reproduction on the intensity of the effect. Therefore, it appeared evident the need of specifying and defining the impact of all relevant parameters on the intensity of the manifestation of the neon colour spreading effect in the processes of graphic reproduction.

The intensity of the manifestations of the neon colour spreading effect with respect to its known characteristics is determined by different parameters: the standard light sources, coloured stimuli characteristics, geometric characteristics of stimuli, types of media in the reproductive system of graphic products.

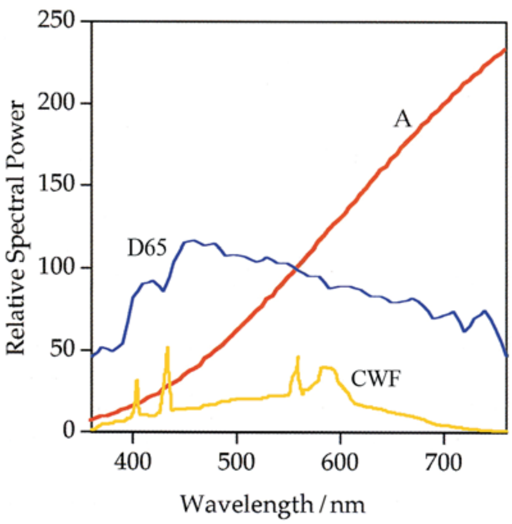

***Figure 1** The relative spectral power distributions of CIE Illuminants D65, CWF and A* [19]
***Slika 1.** Prikaz spektralne emisije standardnih CIE izvora svjetla D65, CWF i A* [19]

A light source is an important influential parameter in the process of graphic reproduction. The perception of colour stimuli largely depends on the type of light sources. Spectral emissions (distribution of radiation energy) of a particular standard CIE light source give an overview of the intensity distribution of radiation within the visible light spectrum (Fig. 1). Thus, light source D65 has a uniform intensity of radiation at all wavelengths, light source CWF has a discontinuous lower intensity radiation, and light source A has a higher intensity of radiation at higher wavelengths [19].

The results of this research will be the basis for defining the guidelines and conditions of application of investigated influence parameters in relation to effective graphic design and printing products in the circumstances of the neon colour spreading effect.

2.2 Methodology
Metodologija

The research process is methodologically divided into two parts, colorimetric and psychophysical part. Joint they form methodology for determining the physical value of the visual perception of colour stimuli due to manifestation of psychophysical visual effects. Colorimetric part of study represents spectrophotometric measurement which determined the corresponding CIE $L^*a^*b^*$ values and colorimetric values of colour differences of each field in relation to the printing surface on the formed reference fields on the printed colour atlas.

Experiment and selected variables (physical) are designed on the basis of constant stimuli method, and psychophysical part of the visual evaluation was based on the use of simultaneous binocular technique adjustments through the procedure of discrimination of visual stimuli [20] (respondents had the task to put colour from the colour atlas aside and join in the test field of the atlas, which is identical or most similar to the value of observed manifestation of the neon colour spreading effect of the studied sample test).

Based on data obtained by the research, tables show the corresponding physical values of the perceived colour resulting from the manifestation of the neon colour spreading effect. Size intensity of the neon colour spreading effect depending on the type of CIE standard light source in dependence on the colour of the primary stimulus is displayed graphically using the calculated colorimetric colour differences ΔE^*_{94}. Colour differences can be expressed by the formulas [21, 22]:

$$\Delta E^*_{ab} = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2} \quad (1)$$

$$\Delta L^* = L_0 - L_1, \quad \Delta a^* = a_0 - a_1, \quad \Delta b^* = b_0 - b_1$$

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. 2).

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

$k_L = k_C = k_H = 1$ 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 [23]. Factors S_L, S_C and S_H represent positional functions, whose role is correction of perceptual non-uniform of CIELAB colour space.

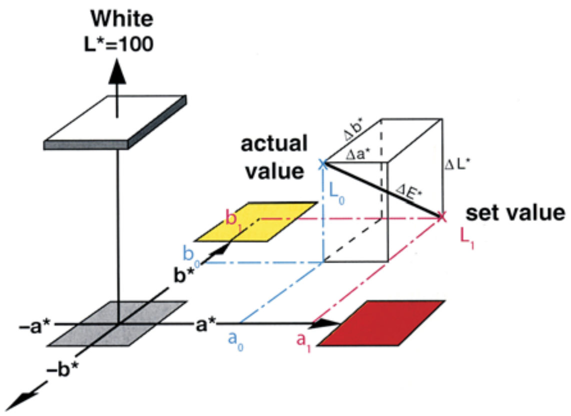

Figure 2 *Colour differences in the CIELAB colour space* [24]
Slika 2. *Prikaz razlike boja u CIELAB prostoru boja* [24]

2.3
Test samples and colour atlas design
Izrada testnih uzoraka i atlasa boja

In accordance with the methodology set, six test samples were created (Tab. 1) using Adobe Illustrator. As the basis of test samples specific geometric structure - the so-called Ehrenstein model made from the system of orthogonal grating lines formed from different combinations of overlapping tested coloured stimuli is selected. Colour of lines in each test sample is combined with additive primary colours (red, green, blue) and subtractive synthesis (cyan, magenta and yellow) as the primary stimulus, and black as a secondary stimulus (Fig. 3). Background of the test sample is a "white" colour from printing substrate, the size of A4. Size of test samples was determined according to standard ambient conditions of observation (ISO 3664:2009 standard, which specifies observation conditions for graphic technology and professional photography), viewing angle 10° and distance of respondents 50 cm according to the formula [25]:

$$\tan \frac{VA}{2} = \frac{H}{2} : D \qquad (3)$$

where VA is the viewing angle, H is the size of the test sample, and D is the distance of subjects from the test sample.

Test samples were created in CMYK colour space and stored in a vector (*.ai) format. The printing of test samples was performed on calibrated digital printing machine - Epson StylusPro 7900 HDR "on the principle of liquid toner cartridges (Epson UltraChrome HDR ink). Screening and printing were done with "GMG ColorProof" application using ICC absolute colorimetric rendering method. The accuracy of reproduction of three stimulus colours characteristics when selected a print resolution of 720×720

Table 1 *Colour combinations of test samples*
Tablica 1. *Kombinacije boja testnih uzoraka*

Tests sample	Primary stimulus colour	Secondary stimulus colour
1	red	black
2	green	black
3	blue	black
4	cyan	black
5	magenta	black
6	yellow	black

dpi is <0,5 ΔE of total colour area. As the printing substrate multiply coated art printing – GMG ProofMedia – Proof Gloss paper, grammage 250 g/m^2, high whiteness (expressed in CIE $L^*a^*b^*$ values: $L^* = 94{,}1$; $a^* = -0{,}6$; $b^* = -0{,}3$) was used. Before printing the printing substrate was in identical conditioned room during the time period of 48 hours, in the prescribed standard ambient conditions (temperature of 23 °C and a relative humidity of 55 %).

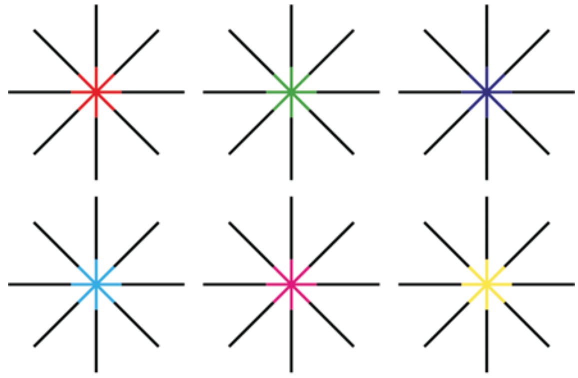

Figure 3 *Test samples*
Slika 3. *Prikaz testnih uzoraka*

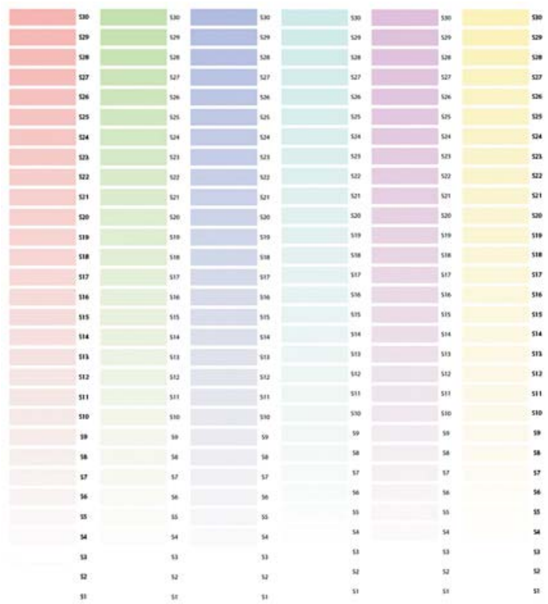

Figure 4 *The Colour Atlas*
Slika 4. *Prikaz atlasa boja*

For the purpose of visual assessment of test samples using the constant stimuli method, six reference colour atlases with the primary colours of additive and subtractive synthesis using Adobe Photoshop were created. Colour atlases are based on change of perceptual attributes of colour within the HSB colour model in a way that the value of tone (H) and brightness (B) is constant, and reference field dimensions of 4×1 cm were formed in steps of 1 % change of the value of saturation (S) colour, in the range 0-30 % (Fig. 4). Colour atlases are stored in .psd file format in the Lab colour space and printed on identical printing substrates and in identical printing conditions as the test samples.

2.4
Instrumental analysis
Instrumentalna analiza

On the Created reference fields on the printed colour atlases corresponding CIE $L^*a^*b^*$ values were measured. The measurement was carried out on "GretagMacbeth Eye-One" reflective spectrophotometer, choosing three standard CIE light sources – "Daylight" D65, "cool white fluorescent light source" CWF (F2) and "artificial light" A, and viewing angle 10°. The accuracy of the device is ΔE^*_{94} = 0,4 for the D50 light source and viewing angle 2°.

Based on the results obtained by spectrophotometric measures of reference atlas fields by the size of the corresponding colorimetric values expressed in CIE $L^*a^*b^*$ were determined and the requested colorimetric deviation ΔE^*_{94} – compared to the colorimetric values unprinted printing substrate were calculated.

2.5
Visual assessment
Vizualno ocjenjivanje

Visual evaluation of test samples in the experimental part of this paper was conducted on a sample of 15 subjects (mixed female-male population, average age 21 years). All subjects had previously successfully met the assessment criteria Ishihara test (24 samples) for the detection of potential sight defects. Psychophysical experiment, visual evaluation, was conducted under controlled ambient conditions in accordance with standard guidelines of ISO 3664:2009 – 10° viewing angle, distance of respondents 50 cm, neutral matte gray atmosphere, dim lighting (Fig. 5). For this purpose, the stationary cabin for watching test patterns, "The Judge II-S" was used. In accordance with the set experiment examined test samples and the corresponding colour atlases were evaluated under the three standard CIE light sources: D65 (6500 K) – "Sunlight", CWF (4150 K) - "cool-white fluorescent light source", and A (2856 K) – "Artificial Light, Tungsten filament lamps".

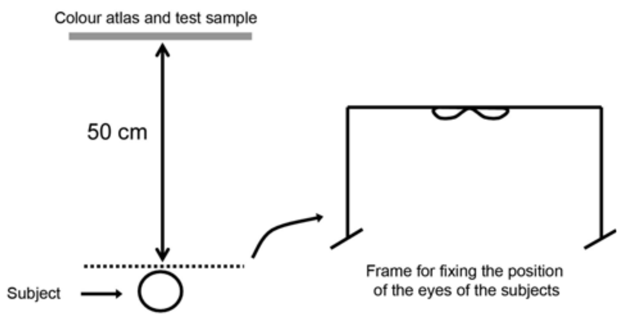

Figure 5 *The viewing field configuration*
Slika 5. *Konfiguracija vidnog polja*

The process of visual evaluation was performed using the technique of simultaneous binocular adjustments technique. Colour Atlas and test sample were placed simultaneously in an integrated visual field (next to each other). Duration of assessment of individual subject was not restricted. The task of each subject was to separate the reference field in the Colour Atlas according to his judgment of identical or most similar to the values of observed manifestations of the neon colour spreading effect of the examined test sample with the process of visual discrimination (Fig. 6). The described method is a method of constant stimuli - a random sample set of stimuli was presented to respondent with various preset fixed physical values. Physical stimulus values (reference fields on the atlas of colours) were selected in a manner that the entire area of perception threshold is potentially covered. The minimum physical value of the reference field is very slightly below the expected threshold of perception, and the highest one above the expected threshold of perception.

Equating the reference field from the colour atlas with apparently manifested colour in the test sample also means joining the colorimetric values (CIE $L^*a^*b^*$ values) and corresponding colorimetric colour differences ΔE^*_{94}. In this way, the values of deviations in colour perception caused by the manifestation of psychophysical neon colour spreading effect were obtained.

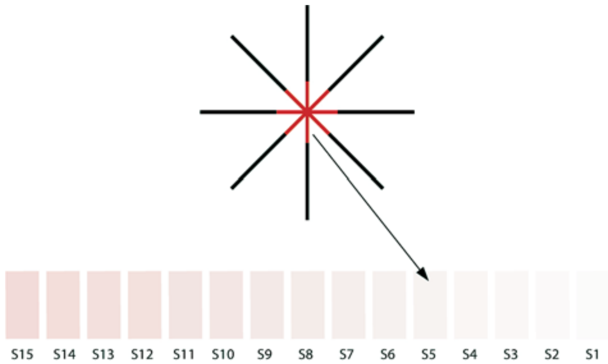

Figure 6 *Principle of visual evaluation by the colour atlas*
Slika 6. *Prikaz principa vizualnog ocjenjivanja putem atlasa boja*

3
Results and discussion
Rezultati i rasprava

Based on research results obtained in this paper by spectrophotometric measurements of reference colour atlas fields the corresponding colorimetric CIE $L^*a^*b^*$ values of individual fields were determined. Colorimetric colour difference ΔE^*_{94} for each reference field in the Colour Atlas, and in relation to colorimetric values of unprinted printing substrate were calculated. Results of visual assessment made possible to join colorimetric values (CIE $L^*a^*b^*$ values) and the corresponding colorimetric colour differences ΔE^*_{94} to the perceived colours of test samples. Tables 2-7 present the results of visual evaluation of Ehrenstein model created with primary colours of additive and subtractive synthesis under the three standard CIE light sources.

The greatest value of colorimetric colour differences ΔE^*_{94} for the red colour of the primary stimuli Ehrenstein model was 2,48 for the D65 light source, then 2,05 for the light source CWF and minimum value of 1,72 for light source A (Tab. 2).

Table 2 *The results of visual evaluation of Ehrenstein model created with red colour of primary stimulus, depending on the three standard CIE light sources - associated with colorimetric CIE L*a*b* values and the corresponding colorimetric colour difference* ΔE^*_{94}

Tablica 2. *Rezultati vizualnog ocjenjivanja Ehrenstein modela kreiranog crvenom bojom primarnog stimulusa, u ovisnosti o tri standardna CIE izvora svjetla – pridružene kolorimetrijske CIE L*a*b* vrijednosti i pripadajuće kolorimetrijske razlike boja* ΔE^*_{94}

SUBJECT	red colour of primary stimulus											
	D65				CWF				A			
	L*	a*	b*	ΔE^*_{94}	L*	a*	b*	ΔE^*_{94}	L*	a*	b*	ΔE^*_{94}
1	93,2	-0,1	0,1	1,3	93	0,3	-0,4	1,2	93,1	0,7	-0,2	1,4
2	93,2	-0,1	0,1	1,3	93	0,3	-0,4	1,2	92,3	1,3	0,5	2,6
3	93,2	-0,1	0,1	1,3	92,1	0,7	0,3	2,4	92,3	1,3	0,5	2,6
4	93,2	-0,1	0,1	1,3	94	-0,2	-0,9	0	92,3	1,3	0,5	2,6
5	89,3	2,9	1,6	6,3	92,1	0,7	0,3	2,4	91,9	2	0,7	3,4
6	91,8	0,9	0,9	3,2	92,1	0,7	0,3	2,4	94,1	-0,2	-0,8	0
7	92,3	0,3	0,8	2,5	93	0,3	-0,4	1,2	94,1	-0,2	-0,8	0
8	89,3	2,9	1,6	6,3	91,7	1,2	0,5	3	93,1	0,7	-0,2	1,4
9	93,2	-0,1	0,1	1,3	93	0,3	-0,4	1,2	92,3	1,3	0,5	2,6
10	91,8	0,9	0,9	3,2	88,9	3,4	1,5	6,6	92,3	1,3	0,5	2,6
11	94,2	-0,8	-0,4	0	94	-0,2	-0,9	0	94,1	-0,2	-0,8	0
12	90	2,1	1,5	5,4	90,7	1,7	1	4,3	92,3	1,3	0,5	2,6
13	93,2	-0,1	0,1	1,3	93	0,3	-0,4	1,2	94,1	-0,2	-0,8	0
14	94,2	-0,8	-0,4	0	93	0,3	-0,4	1,2	93,1	0,7	-0,2	1,4
15	92,3	0,3	0,8	2,5	92,1	0,7	0,3	2,4	92,3	1,3	0,5	2,6
	92,3	0,54	0,53	2,48	92,4	0,7	0	2,05	92,9	0,83	0,03	1,72

Table 3 *The results of visual evaluation of Ehrenstein model created with green colour of primary stimulus, depending on the three standard CIE light sources - associated with colorimetric CIE L*a*b* values and the corresponding colorimetric colour difference* ΔE^*_{94}

Tablica 3. *Rezultati vizualnog ocjenjivanja Ehrenstein modela kreiranog zelenom bojom primarnog stimulusa, u ovisnosti o tri standardna CIE izvora svjetla – pridružene kolorimetrijske CIE L*a*b* vrijednosti i pripadajuće kolorimetrijske razlike boja* ΔE^*_{94}

SUBJECT	Green colour of primary stimulus											
	D65				CWF				A			
	L*	a*	b*	ΔE^*_{94}	L*	a*	b*	ΔE^*_{94}	L*	a*	b*	ΔE^*_{94}
1	93,2	-1,8	1,7	2,4	93	-1,3	1,2	2,5	93	-1,2	1,1	2,3
2	92,8	-2,6	2,5	3,5	93	-1,3	1,2	2,5	93	-1,2	1,1	2,3
3	93,4	-1,4	0,6	1,3	93,2	-0,8	0,1	1,3	93	-1,2	1,1	2,3
4	93,4	-1,4	0,6	1,3	93	-1,3	1,2	2,5	94	0	-0,7	0
5	93,4	-1,4	0,6	1,3	93	-1,3	1,2	2,5	92,3	-2,6	2,4	4,1
6	91,7	-4,3	5,2	6,6	92,3	-2,5	2,8	4,4	91,4	-3,8	4	6,2
7	92,8	-2,6	2,5	3,5	93	-1,3	1,2	2,5	93,3	-0,8	0,1	1,3
8	92,5	-3,1	3,3	4,4	93	-1,3	1,2	2,5	92,6	-2	1,7	3,3
9	92,5	-3,1	3,3	4,4	92,5	-2	2	3,5	92,6	-2	1,7	3,3
10	92,8	-2,6	2,5	3,5	93	-1,3	1,2	2,5	93,3	-0,8	0,1	1,3
11	93,2	-1,8	1,7	2,4	93,2	-0,8	0,1	1,3	94	0	-0,7	0
12	92,8	-2,6	2,5	3,5	93	-1,3	1,2	2,5	93,3	-0,8	0,1	1,3
13	93,4	-1,4	0,6	1,3	93,2	-0,8	0,1	1,3	94	0	-0,7	0
14	93,2	-1,8	1,7	2,4	93	-1,3	1,2	2,5	93,3	-0,8	0,1	1,3
15	93,2	-1,8	1,7	2,4	93	-1,3	1,2	2,5	94	0	-0,7	0
	93	-2,25	2,07	2,95	93	-1,33	1,14	2,45	93,1	-1,15	0,71	1,93

Table 4 *The results of visual evaluation of Ehrenstein model created with blue colour of primary stimulus, depending on the three standard CIE light sources - associated with colorimetric CIE L*a*b* values and the corresponding colorimetric colour difference* ΔE^*_{94}

Tablica 4. *Rezultati vizualnog ocjenjivanja Ehrenstein modela kreiranog plavom bojom primarnog stimulusa, u ovisnosti o tri standardna CIE izvora svjetla – pridružene kolorimetrijske CIE L*a*b* vrijednosti i pripadajuće kolorimetrijske razlike boja* ΔE^*_{94}

SUBJECT	blue colour of primary stimulus											
	D65				CWF				A			
	L*	a*	b*	ΔE^*_{94}	L*	a*	b*	ΔE^*_{94}	L*	a*	b*	ΔE^*_{94}
1	94	-0,6	-0,4	0	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
2	93	-0,3	-1,5	1,5	93,8	-0,1	-0,9	0	91,9	0,7	-2,5	2,6
3	93	-0,3	-1,5	1,5	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
4	91,2	0	-3,2	3	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
5	94	-0,6	-0,4	0	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
6	94	-0,6	-0,4	0	91,8	0,6	-2,8	2,8	93,9	0	-0,8	0
7	94	-0,6	-0,4	0	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
8	93	-0,3	-1,5	1,5	92,8	0,3	-2	1,6	92,9	0,5	-1,7	1,4
9	93	-0,3	-1,5	1,5	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
10	93	-0,3	-1,5	1,5	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
11	92	-0,2	-2,2	2,6	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
12	94	-0,6	-0,4	0	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
13	93	-0,3	-1,5	1,5	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
14	92	-0,2	-2,2	2,6	93,8	-0,1	-0,9	0	93,9	0	-0,8	0
15	93	-0,3	-1,5	1,5	92,8	0,3	-2	1,6	93,9	0	-0,8	0
	93,1	-0,37	-1,34	1,25	93,5	0	-1,17	0,4	93,7	0,08	-0,97	0,27

Table 5 *The results of visual evaluation of Ehrenstein model created with cyan colour of primary stimulus, depending on the three standard CIE light sources - associated with colorimetric CIE L*a*b* values and the corresponding colorimetric colour difference* ΔE^*_{94}

Tablica 5. *Rezultati vizualnog ocjenjivanja Ehrenstein modela kreiranog cyan bojom primarnog stimulusa, u ovisnosti o tri standardna CIE izvora svjetla – pridružene kolorimetrijske CIE L*a*b* vrijednosti i pripadajuće kolorimetrijske razlike boja* ΔE^*_{94}

SUBJECT	Cyan colour of primary stimulus											
	D65				CWF				A			
	L*	a*	b*	ΔE^*_{94}	L*	a*	b*	ΔE^*_{94}	L*	a*	b*	ΔE^*_{94}
1	93,3	-1,6	-0,6	1,2	93,1	-0,9	-1,2	1,2	93,2	-1	-1,2	1,3
2	92,8	-2,6	-1	2,3	92,7	-1,3	-1,4	1,8	93,7	-0,5	-1,2	0,7
3	93	-2,2	-0,8	1,9	93,1	-0,9	-1,2	1,2	93,7	-0,5	-1,2	0,7
4	93	-2,2	-0,8	1,9	93,1	-0,9	-1,2	1,2	94,1	0	-0,8	0
5	92,8	-2,6	-1	2,3	92,7	-1,3	-1,4	1,8	92	-3,1	-1,9	3,7
6	91,8	-4,5	-1,4	4,4	91,7	-2,6	-2,2	3,4	91,8	-3,4	-2,2	4,1
7	93,7	-1,1	-0,7	0,7	93,5	-0,5	-1,3	0,6	93,2	-1	-1,2	1,3
8	92,6	-3,1	-1,1	2,8	92,7	-1,3	-1,4	1,8	93,7	-0,5	-1,2	0,7
9	93	-2,2	-0,8	1,9	93,1	-0,9	-1,2	1,2	92,6	-2	-1,7	2,5
10	93,7	-1,1	-0,7	0,7	93,5	-0,5	-1,3	0,6	94,1	0	-0,8	0
11	92,2	-4	-1,3	3,7	94	-0,1	-0,9	0	92,8	-1,6	-1,4	2
12	92,6	-3,1	-1,1	2,8	92,5	-1,6	-1,7	2,2	93,2	-1	-1,2	1,3
13	93,3	-1,6	-0,6	1,2	93,5	-0,5	-1,3	0,6	94,1	0	-0,8	0
14	92,8	-2,6	-1	2,3	92,7	-1,3	-1,4	1,8	93,2	-1	-1,2	1,3
15	93	-2,2	-0,8	1,9	93,1	-0,9	-1,2	1,2	93,7	-0,5	-1,2	0,7
	92,9	-2,45	-0,91	2,13	93	-1,03	-1,35	1,37	93,3	-1,07	-1,28	1,35

The greatest value of colorimetric colour differences ΔE^*_{94} for the green colour of the primary stimuli Ehrenstein model was 2,95 for the D65 light source, then 2,45 for the light source CWF and minimum value of 1,93 for light source A (Tab. 3).

The greatest value of colorimetric colour differences ΔE^*_{94} for the blue colour of the primary stimuli Ehrenstein model is 1,25 for the D65 light source, then 0,4 for the light source CWF and minimum value of 0,27 for light source A (Tab. 4).

The greatest value of colorimetric colour differences ΔE^*_{94} for cyan primary colour stimuli Ehrenstein model was 2,13 for the D65 light source, then 1,37 for the light source CWF and min. value of 1,35 for the light source A (Tab. 5).

The greatest value of colorimetric colour differences ΔE^*_{94} for the magenta colour of the primary stimuli Ehrenstein model was 3,76 for the D65 light source, then 2,3 for a light source CWF and minimum value of 2,06 for light source A (Tab. 6).

The greatest value of colorimetric colour differences ΔE^*_{94} for the yellow colour of the primary stimuli Ehrenstein model was 1,26 for the light source CWF, then 1,19 for the D65 light source and minimum value of 0,86 for light source A (Tab. 7).

In Fig. 7 is the graphic display of the intensity of the neon colour spreading effect of each test sample for CIE standard light sources D65, CWF and A through a value of colorimetric colour differences ΔE^*_{94}. The chart shows the value of colour appearance shifts caused by the manifestation of psychophysical effect of neon colour spreading.

By observing the chart in Fig. 7 it can be seen that the maximum deviation in the perception of the spreading of the primary colors of stimuli on Ehrenstein model (colorimetric deviation ΔE^*_{94} in relation to colorimetric values of unprinted substrate) due to the coloured features of the primary stimulus is in magenta and green, and at least is in

Table 6 *The results of visual evaluation of Ehrenstein model created with magenta colour of primary stimulus, depending on the three standard CIE light sources - associated with colorimetric CIE L*a*b* values and the corresponding colorimetric colour difference* ΔE^*_{94}

Tablica 6. *Rezultati vizualnog ocjenjivanja Ehrenstein modela kreiranog magenta bojom primarnog stimulusa, u ovisnosti o tri standardna CIE izvora svjetla – pridružene kolorimetrijske CIE L*a*b* vrijednosti i pripadajuće kolorimetrijske razlike boja* ΔE^*_{94}

	Magenta colour of primary stimulus											
SUBJECT	D65				CWF				A			
	L*	a*	b*	ΔE*94	L*	a*	b*	ΔE*94	L*	a*	b*	ΔE*94
1	92,5	1	-2	2,8	92,4	1,5	-2,5	2,8	93,5	1	-1,4	1,4
2	91,9	1,7	-2,5	3,8	93,3	0,8	-1,6	1,4	92,6	1,9	-2	2,7
3	92,5	1	-2	2,8	93,3	0,8	-1,6	1,4	92	2,8	-2,4	3,7
4	92,5	1	-2	2,8	93,3	0,8	-1,6	1,4	93,9	0	-0,5	0
5	92,5	1	-2	2,8	92,4	1,5	-2,5	2,8	91,4	3,8	-3	4,9
6	89,9	4,2	-4,7	7,4	93,8	-0,1	-0,5	0	91,4	3,8	-3	4,9
7	92,5	1	-2	2,8	91,7	2,2	-3	3,8	93,5	1	-1,4	1,4
8	90,5	3,3	-4,1	6,3	91,7	2,2	-3	3,8	92,6	1,9	-2	2,7
9	91,3	2,6	-3,3	5	90,3	3,8	-4,7	6,3	92	2,8	-2,4	3,7
10	92,5	1	-2	2,8	92,4	1,5	-2,5	2,8	93,9	0	-0,5	0
11	91,3	2,6	-3,3	5	93,8	-0,1	-0,5	0	93,5	1	-1,4	1,4
12	91,3	2,6	-3,3	5	91,7	2,2	-3	3,8	93,5	1	-1,4	1,4
13	92,5	1	-2	2,8	93,3	0,8	-1,6	1,4	93,9	0	-0,5	0
14	93,5	0,3	-1,2	1,5	93,3	0,8	-1,6	1,4	93,9	0	-0,5	0
15	92,5	1	-2	2,8	93,3	0,8	-1,6	1,4	92,6	1,9	-2	2,7
	92	1,69	-2,56	3,76	92,7	1,3	-2,12	2,3	92,9	1,53	-1,63	2,06

Table 7 *The results of visual evaluation of Ehrenstein model created with yellow colour of primary stimulus, depending on the three standard CIE light sources - associated with colorimetric CIE L*a*b* values and the corresponding colorimetric colour difference* ΔE^*_{94}

Tablica 7. *Rezultati vizualnog ocjenjivanja Ehrenstein modela kreiranog žutom bojom primarnog stimulusa, u ovisnosti o tri standardna CIE izvora svjetla – pridružene kolorimetrijske CIE L*a*b* vrijednosti i pripadajuće kolorimetrijske razlike boja* ΔE^*_{94}

	yellow colour of primary stimulus											
SUBJECT	D65				CWF				A			
	L*	a*	b*	ΔE*94	L*	a*	b*	ΔE*94	L*	a*	b*	ΔE*94
1	94	-0,6	-0,2	0	93,8	-0,1	-0,6	0	93,9	0,1	-0,5	0
2	93,3	-1	4,8	4,7	93,3	-1	4,8	4,7	93,2	-0,4	5,2	5,5
3	93,6	-0,6	0,7	0,9	93,5	-0,3	0,3	0,9	93,9	0,1	-0,5	0
4	93,5	-0,9	3,6	3,6	93,8	-0,1	-0,6	0	93,9	0,1	-0,5	0
5	93,6	-0,8	2,2	2,3	93,5	-0,6	1,9	2,5	93,9	0,1	-0,5	0
6	94	-0,6	-0,2	0	93,3	-1	4,8	4,7	93,9	0,1	-0,5	0
7	94	-0,6	-0,2	0	93,5	-0,3	0,3	0,9	93,9	0,1	-0,5	0
8	93,6	-0,8	2,2	2,3	93,5	-0,3	0,3	0,9	93,6	-0,2	1,7	2,2
9	94	-0,6	-0,2	0	93,8	-0,1	-0,6	0	93,6	-0,2	1,7	2,2
10	93,6	-0,6	0,7	0,9	93,5	-0,6	1,9	2,5	93,9	0,1	-0,5	0
11	94	-0,6	-0,2	0	93,8	-0,1	-0,6	0	93,6	-0,2	1,7	2,2
12	93,6	-0,6	0,7	0,9	93,5	-0,3	0,3	0,9	93,6	0	0,3	0,8
13	94	-0,6	-0,2	0	93,8	-0,1	-0,6	0	93,9	0,1	-0,5	0
14	94	-0,6	-0,2	0	93,8	-0,1	-0,6	0	93,9	0,1	-0,5	0
15	93,6	-0,8	2,2	2,3	93,5	-0,3	0,3	0,9	93,9	0,1	-0,5	0
	93,8	-0,69	1,05	1,19	93,6	-0,35	0,75	1,26	93,8	0	0,37	0,86

the blue and yellow colour. If the values of colorimetric differences are primarily observed in relation with the standard CIE light sources, it is evident that in most cases, the light source D65 gives the greatest value, while the light source A has the lowest value in all test samples.

In accordance with the discussion of research results, the intensity correlation of psychophysical visual manifestation of neon colour spreading effect with CIE standard light sources and characteristics of coloured stimuli can be set. The deviation in the perception of expansion of primary colour stimuli on Ehrenstein model is greater with respect to each primary colour of stimuli with constant black secondary stimuli on Ehrenstein model, but with respect to certain standard CIE light sources.

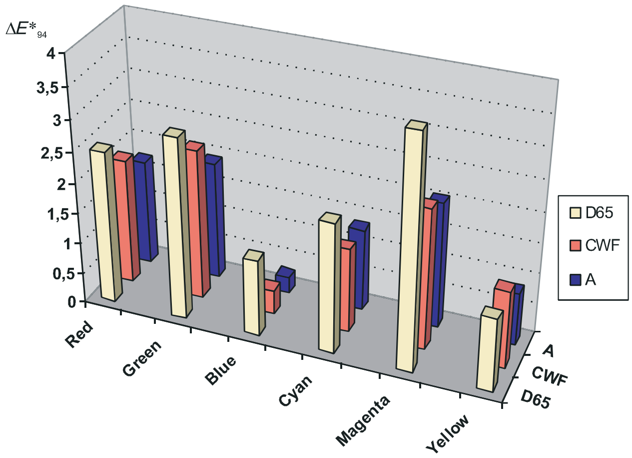

Figure 7 *Graphic display of the intensity of the neon colour spreading effect of each test sample for CIE standard light sources D65, CWF and A*

Slika 7. *Grafički prikaz intenziteta efekta neonskog proširivanja boje pojedinog testnog uzorka za standardne CIE izvore svjetla D65, CWF i A*

4 Conclusion
Zaključak

The impact of CIE standard light source to the intensity of the neon colour spreading effect is clearly demonstrated. Change of the intensity value of the effect in some standard CIE light sources ranges expressed as a percentage of up to 763 % magnitude of the effect for light source A, 612 % magnitude of the effect for CWF light source and 316 % magnitude of the effect for light source D65. It follows that the smallest change in the intensity of the effect depending on the particular primary color of stimuli on Ehrenstein model is at light source D65, and the biggest change is in the light source A. This corresponds to the spectral emission curves of standard CIE light sources in which the distribution of radiation energy per wave lengths is mostly consistent of light source D65, unlike the other two sources which have pronounced unevenness of distribution of radiation energy. Large deviations output the allowable recommendations regarding the accuracy of reproduction of the graphic technology (Tab. 8) [24].

Table 8 *Evaluation of colorimetric colour differences for the standard observer* [24]

Tablica 8. *Vrednovanje kolorimetrijske razlike boja za standardnog promatrača* [24]

$\Delta E^*_{94} < 1$	in general, this deviation cannot be perceived
$\Delta E^*_{94} = (1\text{-}2)$	very small deviation; only perceivable by an experienced eye
$\Delta E^*_{94} = (2\text{-}3{,}5)$	medium deviation; perceivable even by an unexperienced eye
$\Delta E^*_{94} = (3{,}5\text{-}5)$	large deviation
$\Delta E^*_{94} > 6$	massive deviation

Change of ΔE^*_{94} for each stimuli primary colour individually on Ehrenstein model and in relation to the light source ranges expressed in percentages of 144 % magnitude effect for red, 152 % for green, 462 % for blue, 158 % of cyan, magenta and 182 % to 138 % for the yellow color.

It is evident that there is traceability and predictability in the manifestation of the effect which is found in almost all tested stimuli (5 out of 6 or more than 83 % of all cases), and on the basis that it is possible to predict that the impact of selecting the primary colour of stimuli on Ehrenstein model for manifestation of effect is more important than changes in the light source. It is possible to predict that the vast majority of situations regardless of the light source intensity of the neon colour spreading effect will be stronger in the purple (magenta) than in the blue colour. For the yellow colour of the primary stimulus impact of the light source on the effect intensity was not proven. The change of the value of the intensity of the effect of the yellow color for each CIE standard light source moves up to 138 % magnitude of the effect itself. This result can be attributed to the result of a statistical error of the experiment, but also to the fact that the amount of radiation energy at yellow wavelength is similar for all three light sources.

If the fact that the RGB and CMYK colour (tested in this paper) are also the synthesis of primary colours for a number of transmitters (digital) or reflexive (print) media is taken into account, the need to perceive the results obtained with the aim of predicting and calculating the potential inconsistencies in reproducing image information on them is understandable. It is necessary in situations where the corresponding colour reproduction has to be achieved [26], and in which the appearance of the study of geometric structures (Ehrenstein model) and different environmental conditions can be predicted, to conduct linearization. Also, these colours are primary colours in most of the design creations, first in the selection of design solutions for a range of additive and subtractive media and cross-media reproduction system in general. In the creation of design it is therefore necessary to avoid these types of geometric structures or to predict these discrepancies caused by the neon colour spreading effect.

Inclusion of other influential parameters in the graphic reproduction process in exploring the intensity of the neon colour spreading effect will provide better definition of the conditions of application of investigated parameters that will contribute to the optimal design of graphic products and printing under the same circumstances of neon colour spreading effect manifestation.

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