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THE EFFECT OF EXPANSION AND SIMULTANEOUS CONTRAST IN MODIFICATED FIGURAL DOTTED AND GROUNDAL DOTTED ILLUSIONS

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Original scientific paper

The appearance of colour is based on different parameters and observation conditions. Taking into account that the research of certain visual psychophysical effects is updated daily, such a phenomenon presents a challenge for researchers of modern visual communication systems. Effects of psychophysical expansion and simultaneous contrast belong to this group. This paper researches the influence of those effects using method of visual tuning. Those effects cause the shifting of colour appearance of stimuli (different combinations of primary and secondary colours) on test samples. Test samples are based on White's illusions (*groundal dotted illusion and figural dotted illusion*).

Keywords: *colour, expansion, figural dotted illusion, groundal dotted illusion, simultaneous contrast*

Efekt proširivanja i simultanog kontrasta kod modificiranih figural dotted i groundal dotted iluzija

Izvorni znanstveni članak

Pojavnost boje uvjetovana je raznim parametrima i uvjetima promatranja. Takav fenomen predstavlja izazov u suvremenim sustavima vizualnih komunikacija koji se svakodnevno unapređuju novim spoznajama vezanim uz istraživanje pojedinih psihofizikalnih efekata. Jedni od takovih efekata su i psihofizikalni efekti proširivanja i simultanog kontrasta.U radu je provedeno istraživanje utjecaja navedenih efekata koji izazivaju pomak pojavnosti boje (različite kombinacije primarnih boja aditivne i suptraktivne sinteze) stimulusa na testnim uzorcima baziranim na Whiteovim iluzijama *(groundal dotted i figural dotted illuzije)* primjenom vizualne tehnike metode ugađanja.

Ključne riječi: *boja, figural dotted iluzija, groundal dotted iluzija, proširivanje, simultani kontrast*

1 Introduction

Ever since its publication in 1979 White's illusion is known as the strongest illusion of lightness [1]. The illusion itself shows the lightness change between grey elements and black and white lines. Grey elements are assimilated with the colour of unbroken lines. In the combination with grey-black lines the grey elements are perceived darker. Grey-white lines lighten the same element. Illusion is based on design by Susan Hirth published in the book "Optical Art: Theory and Practice" [2]. This design is described as illusion of change of different contrast of lightness and assimilation.

In the papers [1, 3, 4, 5] and his doctoral thesis [6] White describes the grey elements assimilating with the colour of lines surrounding them. Wider research based on lightness was made by Bressan [7]. Chubb, Sperling and Solomon researched contrast-contrast illusion [8].

In their theories [9, 10] Gilchrist and Anderson state that assimilation can be found in grey-black and grey-white White's illusion.

Spotted White's illusion was first published in 1982 [4] as the assimilation of lightness found in the centre part of the test area. In the original illusion T-junctions appear on line ends. Those junctions do not exist in this version. Since then only Bressan and Kramer have researched the influence of colour and lightness [11].

Spotted White's illusion can be described as merger of simultaneous contrast and expansion effects.

Simultaneous contrast or induction is an effect which causes the shift in colour perception, caused by the change of background colour. Light background causes darker perception of observed coloured stimuli. Achromatic induction is based on the difference in lightness between background and the observed stimuli. Chromatic induction is based on the difference between chromatic colour pairs [12, 13, 14].

Increasing the frequency of the appearance of certain stimuli, or reducing the stimuli in size or shape in the visual field, causes the diminishing of simultaneous contrast effect and its replacement with the expansion effect [15, 16].

2 Experimental part

2.1 Research description

This research attempts to determine the influence of psychophysical effects of simultaneous contrast and expansion in different combinations of primary and secondary colours, specifically their influence on the quality of final printed product. In relation to those problems researches were made on illusions based on White's illusions ((groundal dotted illusion (Fig. 1a) and figural dotted illusion (Fig. 1b)).

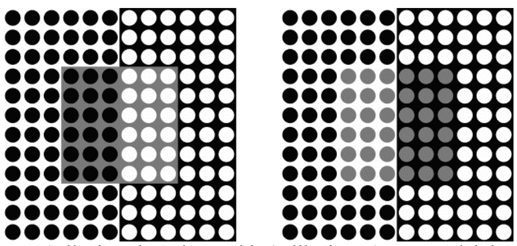

Figure 1 Illusions based on White's illusions (a - groundal dotted illusion, b - figural dotted illusion)

Experimental part consists of two parts. Tuning method [17] was used for visual experiment. Visual experiment also determines the fields for instrumental measurements. Second part is instrumental. It encompasses visualisation of CIE L*a*b values and calculations of ΔE_{00} colorimetric values and difference in lightness, chroma and hue.

This research enables the information upgrade needed for prediction of appearance of colour in variable realistic conditions of printing industries using objective colour models [18].

Difference in perception is caused by certain appearance of visual effect. It can be shown with colorimetric colour difference ΔE_{00}, lightness difference ΔL_{00} , chroma ΔC_{00} and hue ΔH_{00} [19, 20, 21].

Colour difference ΔE_{00} is calculated with the formula [20]:

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{k_L S_L} \right)^2 + \left(\frac{\Delta C'_{ab}}{k_C S_C} \right)^2 + \left(\frac{\Delta H'_{ab}}{k_H S_H} \right)^2 + R_T \left(\frac{\Delta C'_{ab}}{k_C S_C} \right) \left(\frac{\Delta H'_{ab}}{k_H S_H} \right) \right]^{0,5}, \quad (1)$$

and difference in lightness ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} with the formula [22]:

$$\Delta L' = L'_b - L'_s, \quad (2)$$

$$\Delta C'_{ab} = C'_{ab,b} - C'_{ab,s}, \quad (3)$$

$$\Delta H'_{ab} = 2 \left(C'_{ab,b} \, C'_{ab,s} \right)^{0,5} \sin \left(\frac{\Delta h'_{ab}}{2} \right). \quad (4)$$

2.2 Creation of test samples

Test samples were created in Adobe Photoshop CS6 in L∗a∗b colour system (Fig. 2) in accordance with research methodology.

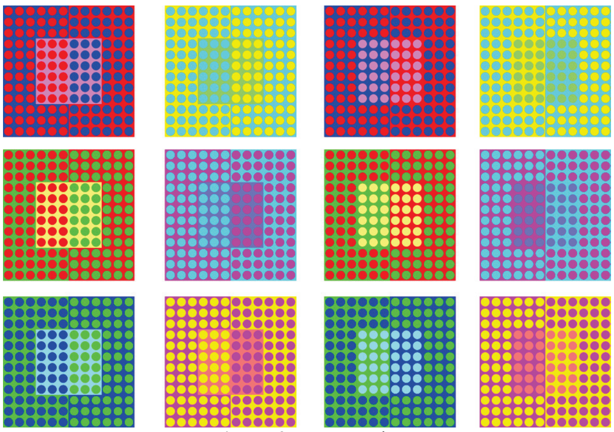

Figure 2 Test samples

Size of the test samples is determined according to standard observation conditions (ISO 3664:2009). They determine observation conditions for printing industry and professional photography as viewing angle of 10° and distance between the observer and sample of 60 cm according to the formula [23]:

$$\tan\left(\frac{\theta}{2}\right) = \frac{H}{2}, \quad (5)$$

where θ is the viewing angle, H is the test sample size.

Coverage within test samples is defined so that the dots cover 50 % of smaller square, and the small square covers 50 % of larger square.

Colours and surface of specific samples is defined so that the research encompasses all basic primary and secondary colours (Fig. 2, Tab. 1). This enabled the determination of expansion effect and simultaneous contrast effect on the basic colours in printing industry process.

Table 1 Combination of test sample pairs

Test sample	Colour of primary stimulus	Colour of secondary stimulus
1	magenta	red / blue
2	yellow	red / green
3	cyan	blue / green
4	green	cyan / yellow
5	blue	cyan / magenta
6	red	yellow / magenta

2.3 Reproduction of the test samples

Test samples were printed on calibrated digital printer Canon iPF6100, which uses liquid toner (ink). 180 g/m^2 Canon matt coated paper 7125 was used as the print substrate. Paper was conditioned in the room for 48 hours in prescribed standard ambiental conditions (23 °C and 55 % moisture) prior to printing. Test samples were printed in 10 pieces run.

2.4 Instrumental analysis

Measurement of the samples was made with X-Rite DTP 41 reflex densitometer, within wave length range from 390 to 710 nm, light source of 2850 K, 10 nm steps and lightning geometry 45°/0°. Values of control fields were measured on the whole run of 10 samples to increase statistical accuracy. Each sample was measured five times after which average values were calculated (Tab. 2).

Device accuracy is up to 0,5 % per wave length step. Calibration strip was made by Munsell lab (RIT) with accuracy ΔE^*=0,25 for D50 light source and viewing angle of 2°.

Table 2 Referent physical values of primary stimuli measured on reproductions

Colour of stimulus	*L*	*a*	*b*
magenta	72,57	45,94	1,1
yellow	91,34	3,26	62,66
cyan	83,14	−21,97	−11,58
green	85,4	−24,41	32,2
blue	63,26	8,81	−34,57
red	70,39	46,75	30,65

2.5 Visual analysis

Visual analysis of the test samples was made on 20 subjects of mixed population 21 years of age on average. Prior to the testing all subjects took Ishihara test for sight deficiency. Only those that passed Ishihara test participated.

Visual evaluation of psychophysical part of experiment was performed in realistic conditions of print production. Test settings were 10° viewing angle, 60 cm distance from viewer to sample, natural matte grey environment, 150 lux with 5400 ÷ 6000 K and in standardized ISO 3664:2009 environment (10° viewing angle, 60 cm distance from observer to sample, matte gray environment and CIE D50 lighting).

Characteristics of reference LCD screen HP DreamColor LP2480zx used in controlled ambient conditions are as follows: diagonal 24" (61 cm), display resolution 1920×1200, bandwidth of colour space in the internal processing is within min 10 bits to max 12 bits, IPS panel, RGB LED backlighting, while the volume of colour space for display is about 133 % NTSC. In real conditions of graphic arts productions characteristics of reference are iMac diagonal 24" (61 cm), display resolution 1920×1200, bandwidth of colour space in the internal processing is within 10 bits, RGB LED backlighting.

Procedure is based on research study of Stocholm University Physics department. Study was made by team led by Pehra Sällströma in 1998. *(P. Sällström, "Using a Personal Computer as a Visual Colorimeter")*. Visual assessment was made by grading smaller square on test sample on calibrated screen using Adobe Photoshop CS6. The assignment was for the subject to match L*a*b* values using Colour picker tool in Adobe Photoshop to the sample colour of the smaller square on test sample.

3 Results

Based on the difference in results gained from spectrophotometric measurement of reference fields with Lab values determined on monitor it is possible to calculate colorimetric difference between colours ΔE_{00}. ΔL_{00}, ΔC_{00} and ΔH_{00} were calculated from ΔE_{00}. Calculations were also made for absolute lightness $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$ between left and right side of test sample for each colour in both laboratory and realistic conditions.

Differences in colour $\Delta E_{00,}$ lightness ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} and also absolute lightness $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$, between left and light side depending on observation conditions and kind of White's illusion are given in Tabs. 3 ÷ 8.

Table 3 Difference in colour ΔE_{00}, lightness ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} and also absolute lightness $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$ for colours primary stimulus magenta and secondary stimulus red and blue on left and right side

	Ambient conditions				Real conditions			
Colour of primary stimulus / colour of secondary stimulus	Groundal dotted illusion		Figural dotted illusion		Groundal dotted illusion		Figural dotted illusion	
magenta / red, blue	left side	right side	left side	right side	left side	right side	left side	right side
ΔE_{00}	15,72	15,72	13,43	13,43	7,50	8,13	7,89	7,96
ΔL_{00}	1,01	1,01	1,71	1,71	−0,49	−0,31	−1,09	−0,55
aps. difference ΔL_{00}	0,00		0,00		0,18		0,54	
ΔC_{00}	5,18	5,18	2,48	2,48	−2,27	−3,48	−2,04	−2,71
aps. difference ΔC_{00}	0,00		0,00		1,21		0,67	
ΔH_{00}	−13,29	−13,29	−12,32	−12,32	−2,19	−1,14	−1,30	−1,66
aps. difference ΔH_{00}	0,00		0,00		1,04		0,36	

Table 4 Difference in colour ΔE_{00}, lightness ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} and also absolute lightness $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$ for colours primary stimulus yellow and secondary stimulus red and green on left and right side

	Ambient conditions				Real conditions			
Colour of primary stimulus / colour of secondary stimulus	Groundal dotted illusion		Figural dotted illusion		Groundal dotted illusion		Figural dotted illusion	
yellow / red, green	left side	right side	left side	right side	left side	right side	left side	right side
ΔE_{00}	9,23	9,23	9,28	9,28	7,23	7,01	6,56	6,96
ΔL_{00}	1,60	1,60	2,44	2,44	0,09	0,10	−0,53	−0,38
aps. difference ΔL_{00}	0,00		0,00		0,01		0,15	
ΔC_{00}	2,19	2,19	1,14	1,14	−2,59	−1,20	−1,09	−1,61
aps. difference ΔC_{00}	0,00		0,00		1,39		0,51	
ΔH_{00}	7,37	7,37	7,55	7,55	5,18	5,01	4,70	5,51
aps. difference ΔH_{00}	0,00		0,00		0,17		0,80	

Table 5 Difference in colour ΔE_{00}, lightness ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} and also absolute lightness $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$ for colours primary stimulus cyan and secondary stimulus blue and green on left and right side

	Ambient conditions				Real conditions			
Colour of primary stimulus / colour of secondary stimulus	Groundal dotted illusion		Figural dotted illusion		Groundal dotted illusion		Figural dotted illusion	
cyan / blue, green	left side	right side	left side	right side	left side	right side	left side	right side
ΔE_{00}	7,73	7,73	6,99	6,99	8,01	7,55	7,47	7,54
ΔL_{00}	2,63	2,63	2,56	2,56	−1,82	−1,91	−1,50	−1,78
aps. difference ΔL_{00}	0,00		0,00		0,09		0,29	
ΔC_{00}	4,12	4,12	3,00	3,00	−1,79	−0,63	−0,74	−1,18
aps. difference ΔC_{00}	0,00		0,00		1,16		0,44	
ΔH_{00}	−2,15	−2,15	−0,34	−0,34	4,13	4,86	4,08	3,07
aps. difference ΔH_{00}	0,00		0,00		0,73		1,01	

Table 6 Difference in colour ΔE_{00}, lightness ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} and also absolute lightness $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$ for colours primary stimulus green and secondary stimulus cyan and yellow on left and right side

	Ambient conditions				Real conditions			
Colour of primary stimulus / colour of secondary stimulus	Groundal dotted illusion		Figural dotted illusion		Groundal dotted illusion		Figural dotted illusion	
green / cyan, yellow	left side	right side	left side	right side	left side	right side	left side	right side
ΔE_{00}	11,85	11,97	13,74	13,74	9,28	9,90	10,01	10,36
ΔL_{00}	2,02	1,77	1,45	1,45	−1,90	−3,84	−4,30	−3,50
aps. difference ΔL_{00}	0,26		0,00		1,94		0,80	
ΔC_{00}	−1,83	−1,79	−2,90	−2,90	−2,19	−1,84	−2,79	−3,28
aps. difference ΔC_{00}	0,04		0,00		0,35		0,49	
ΔH_{00}	9,94	10,09	12,40	12,40	0,72	2,23	3,93	3,14
aps. difference ΔH_{00}	0,15		0,00		1,52		0,80	

Table 7 Difference in colour ΔE_{00}, lightness ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} and also absolute lightness $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$ for colours primary stimulus blue and secondary stimulus cyan and magenta on left and right side

	Ambient conditions				Real conditions			
Colour of primary stimulus / colour of secondary stimulus	Groundal dotted illusion		Figural dotted illusion		Groundal dotted illusion		Figural dotted illusion	
blue / cyan, magenta	left side	right side	left side	right side	left side	right side	left side	right side
ΔE_{00}	12,31	11,68	11,72	11,72	10,73	10,21	9,81	10,94
ΔL_{00}	−2,37	−1,25	1,25	1,25	−6,52	−4,61	−2,92	−4,72
aps. difference ΔL_{00}	1,12		0,00		1,91		1,80	
ΔC_{00}	5,36	4,96	5,60	5,60	2,55	1,59	1,35	1,75
aps. difference ΔC_{00}	0,40		0,00		0,96		0,40	
ΔH_{00}	6,37	6,29	8,31	8,31	5,10	5,43	5,79	6,56
aps. difference ΔH_{00}	0,07		0,00		0,33		0,77	

Table 8 Difference in colour ΔE_{00}, lightness ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} and also absolute lightness $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$ for colours primary stimulus red and secondary stimulus yellow and magenta on left and right side

	Ambient conditions				Real conditions			
Colour of primary stimulus / colour of secondary stimulus	Groundal dotted illusion		Figural dotted illusion		Groundal dotted illusion		Figural dotted illusion	
red / yellow, magenta	left side	right side	left side	right side	left side	right side	left side	right side
ΔE_{00}	17,27	17,26	17,40	17,40	9,27	10,08	10,85	9,07
ΔL_{00}	0,69	1,08	2,50	2,50	−2,65	−1,33	−0,42	−2,96
aps. difference ΔL_{00}	0,40		0,00		1,31		2,54	
ΔC_{00}	1,90	1,60	−0,58	−0,58	−2,95	−3,81	−4,28	−2,60
aps. difference ΔC_{00}	0,30		0,00		0,86		1,68	
ΔH_{00}	4,62	4,55	1,16	1,16	2,23	3,63	4,89	2,26
aps. difference ΔH_{00}	0,07		0,00		1,40		2,63	

4 Discussion and conclusions

Results of the visual grading (Tabs. 3 ÷ 8) show shift in the colour perception. They clearly demonstrate the influence of psychophysical effects of expansion and simultaneous contrast on illusions based on White's illusions *(groundal dotted illusion, figural dotted illusion)*. It changes on different colour pairs.

When the results considering difference in colours were observed, effects were more pronounced when stimuli coloured with primary colours were used. The appearance of illusion is not relevant. Differences in lightness, chroma and hue confirm this.

It is also visible that expansion effect is most visible in hue difference in all observation conditions coloured in secondary colours. In primary colours change is greatest in lightness.

When comparing viewing conditions, psychophysical effects are more exposed in realistic conditions with all colours.

Looking at illusions separately confirms they exist independently of viewing conditions. Laboratory results show first detection of effect based on figural dotted illusion. Samples based on primary colours are also more pronounced. They are highest in red colour which can be attributed to the influence of yellow as secondary stimuli.

Results show that the quality values (effect intensity) are different with different colour pairs. By linking the influence of psychophysical effects of expansion and simultaneous contrast with colorimetric colour difference (ΔE_{00}), lightness difference ΔL_{00}, chroma ΔC_{00} and hue ΔH_{00} and absolute lightness difference $|\Delta L_{00}|$, chroma $|\Delta C_{00}|$ and hue $|\Delta H_{00}|$ between left and right side, taking viewing conditions in account, influence is smallest when primary stimulus is coloured with secondary colours (yellow, magenta, cyan). Differences are smallest in yellow which can be attributed to the nature of yellow.

It can also be concluded that the secondary colours (yellow, magenta, cyan) affect their counterparts more than the other way around.

Looking at the spatial frame of illusions it is visible that effects are more pronounced at figural dotted illusion than in groundal dotted illusion. This leads to the conclusion that secondary stimulus on test samples degrades perception of the sample.

Considering that today's market requires original design, which in turn requires usage of more effects in printing industry, results of this paper can help in better description and standardization of certain prepress and press processes linked with above stated.

In order to gain wider image of the possibilities of selection of standard rendering models in regard to appearance of specific psychophysical effects on practical samples, further widening of this research on other psychophysical effects is probable.

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