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Objective Colour Evaluation and the Visual Threshold

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A B S T R A C T

The science of colour is concerned with developing theories and establishing facts about colour which help us understand the perception of colour and provide the means for objective colour specification. Scientific research in this FIELD must consider different factors that affect colour perception such as the observer's experience and behaviour. Spectrophotometric colour measurement methods are based on the tristimulus values (X, Y and Z) and describe colour by three psychological attributes: chroma (C), hue (H) and lightness (L). These values are objective and are not affected by observer characteristics and their environment. By using an instrumental, i.e. spectrophotometric method, a threshold is identified in order to predict the area in which the visual perception of colour, i.e. the psychological (subjective) experience matches the C to L* ratio. The experiment is carried out using complementary colours - red and green, based on the opponent colour theory. 182 subjects aged 20-50 participated in the experiment in which objective spectrophotometric method is compared against the psychophysical, i.e. subjective perception of colour. Psychophysical methods, i.e. the method of constant stimuli and Stevens' magnitude estimation are used to measure the subjective perception of colour influenced by different backgrounds (white, grey and black).Among the subjects aged 30 and over, higher inaccuracy is observed in rating the position of the sample for the parameter lightness (L). For the parameter chroma (C), all subjects, irrespective of their age, displayed uncertainty in rating the position of the sample. Descriptive statistics and appropriate nonparametric tests (the Mann-Whitney U test, the Kruskal-Wallis test and the Median test) show significant differences in inaccurate visual perception of colour depending on the surround colour, in particular for the parameter lightness (L) and for the red hue.*

Key words: *spectrophotometric measurements, red and green hues, visual perception, descriptive statistics, psychological colour attributes*

INTRODUCTION

The history of colour theory dates back to the time of the Greek philosophers Plato and Aristotle, who sought to explain the nature of colour, define human perception of colour, and provide a uniform and systematic definition of colour. The earliest scientific studies on the psychophysical experience of colour conducted by Aubert, Exner, Newton, Helmholtz, Hering, Land, Munsell and Ostwald provided the basis for understanding of the phenomenon of colour[1,2]. They demonstrated that the perception of colour is affected by changes in viewing conditions and parameters such as the observer, light source, background colour, energy level of the illuminant, and the like.

Light is essential to object colour perception. This is a fact that has been established and confirmed in many works in the FIELD of colour science. Hunt asserts that colour perception requires "three essential components: a source of light, an illuminated objects and an observer". Based on experimental facts, Isaac Newton demonstrated that white light is not a homogeneous entity but a mixture of all the colours in the spectrum. This marked the beginning of the theory of colour[1,3,4,5].

The colour system, which was recognized by the *Commission Internationale de l'Eclairage* (CIE) in 1931, was standardized only in 1976. The system of objective colour measurement is based on the CIE principles [5,6].

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Colour vision

According to the theory of colour vision, which explains how the human eye perceives colour, there are two types of light-sensitive photoreceptors in the human retina: rods and cones. In 1867, Hermann von Helmholtz proposed the Trichromatic colour theory based on the assumption of three primary hues: red, green and blue. The Zone theory of colour vision, which combines Hering's theory, i.e. the Opponent Process Theory, and the Trichromatic theory, explains the experience of colour in the brain[2,9,10].

The structure of the human eye (Figure 1) enables the sense of sight and colour vision.

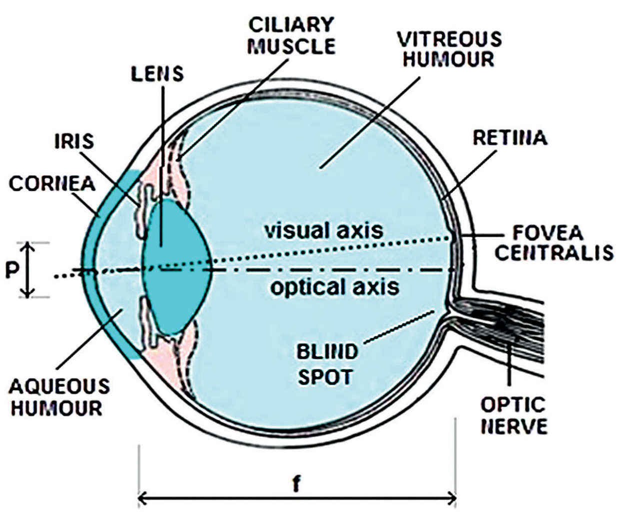


Fig. 1. The structure of the human eye

According to the current colour vision theory, which explains how the human eye perceives colour, there are two types of light-sensitive cells in the human eye (retina) known as rods and cones. They convert the energy of light (electrical and chemical signals) into nerve impulses, enabling an observer to perceive a hue. (Figure 1)

Fairchild explains colour vision by maintaining that the human eye works like a camera. The cornea and the lens work together as a camera lens which focuses on a visual image of the retina located at the back of the eye acting like a film or another image sensor of the camera. These and other structures have an important effect on human perception of colour[2,5,11].

Rods and cones are retinal photoreceptors. Cone vision provides clearer and sharper image than rod vision but it only functions at relatively high light levels. At low and very low light levels, we see an almost monochrome low-resolution image[2,3,5,12,13].

The method of constant stimuli and Stevens' magnitude estimation were used to measure the psychophysical (subjective) perception of colour.

An experiment was carried out to explore the effect of achromatic backgrounds (white, gray, black) on the subject's psychological experience of different lightness levels for green and red hues[2,8,11]. The subjects were aged 20-50. Descriptive statistics and deductive statistics were used to determine the differences in distributions between different groups. To test the hypothesis proposing that there are statistically significant differences in inaccurate colour perception depending on the surround colour, non-parametric statistical tests were used, that is the Mann-Whitney U Test, the Kruskal-Wallis ANOVA and the Median test. The results of subjective colour evaluation were analysed using Statistica software (StatSoft) and SAS (SAS Institute).

Research Methodology

For each hue (green - H = 173° and red - H = 12°), the samples were set against achromatic backgrounds (white, gray and black), arranged by chroma (C*) and lightness (L*) and ranked from I to VIII (Figure 2).

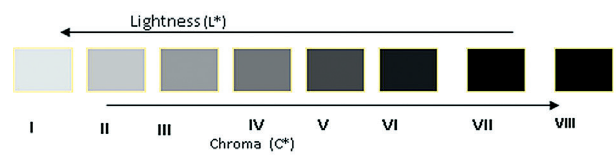


Fig. 2. Schematic representation of the positions of samples ranked from I to VIII.

Objective evaluation

Objective colour evaluation was carried out by means of DataColour 600 + CT, D_{65}, d/8° remission spectrophotometer in the visible spectrum (400 - 700 nm) measured at wavelength interval of 10 nm.

The colouristic attributes of each hue for each position are expressed by the C*/Y and C*/L* ratios. The obtained values are shown in Figures 3-6.

Subjective analysis

The test samples measuring 2x2 cm were evaluated using a D65 illuminant (xenon lamp) at a distance of 60 cm and a 45°viewing angle.

The subjects were asked to rate the position of each hue against the background based on the level of lightness (L) and chroma (C). The Method of constant stimuli and Stevens' magnitude estimation were used to measure the effect of background on the psychological experience of red and green hues.

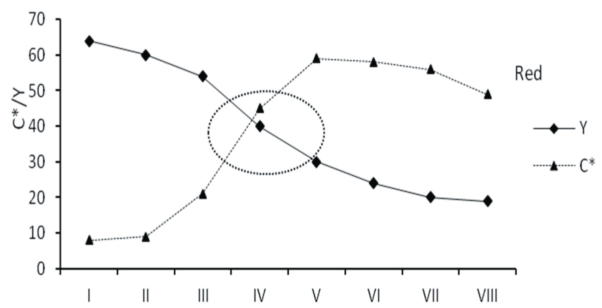


Fig. 3. C(Y) ratio for the red hue samples (H*= 12 degrees).*

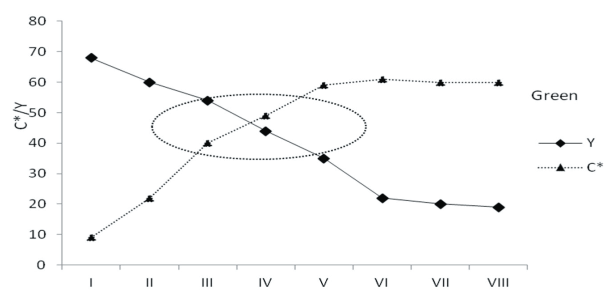


Fig. 4. C(Y) ratio for the green hue samples (H*= 173 degrees).*

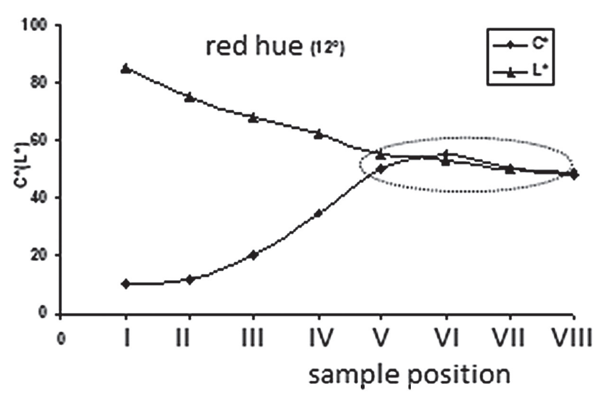


Fig. 5. C(L*) ratio for the red hue samples (H*= 12 degrees).*

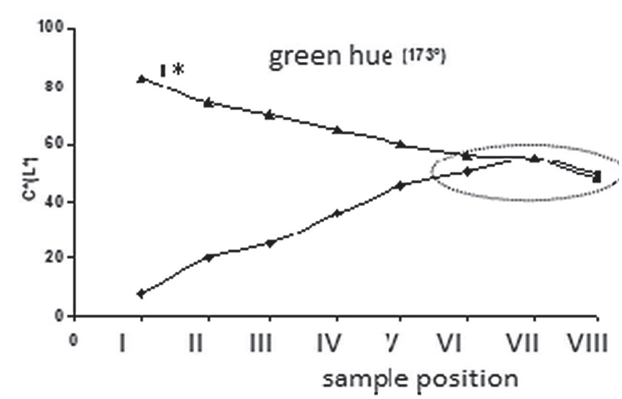


Fig. 6. C(L*) ratio for the green hue samples (H*= 173 degrees).*

182 subjects (N=182) aged 20-50 participated in the experiment. The majority of the subjects (60%) were aged 20-30. The sample was drawn from student population of University North from Varaždin, Koprivnica, Zagreb and Čakovec. Older subjects were employees of University North. The experiment was conducted from September to October 2017.

The subjects were classified into three groups according to their age:

I: 20-30

II: 31-40

III: 41-50

The subjects were asked to rate the position of the colour set against three different backgrounds in terms of its lightness (L) and chroma (C). The following instructions were given:

Using the schematic representation (Figure 2), rate the samples from 1-8, according to your perception of lightness and chroma of individual hues (red and green), on each of the backgrounds (white, gray, and black.)

Following the above instructions, the subjects rated each hue (I-VIII) according to their own perception.

A statistical analysis was conducted of the subjects' ratings for each position and each background.

Statistical analysis of visual evaluation data

The data obtained were analysed using Statistica software (StatSoft) and SAS (SAS Institute). Descriptive statistics and deductive statistics were used to determine the differences in distributions between groups of variables. As the data were not normally distributed, appropriate nonparametric statistical tests were used (the Kruskal-Wallis ANOVA and the Median test) to test the hypothesis proposing that there are statistically significant differences in inaccurate perception of colour attributes (L and C) caused by the surround colour[14].

The range of perception of each hue by its attributes (L and C) and the effect of the surround on the perception of red and green hues relative to their actual position (from I to VIII) is rated from 0 to 7 in position I, from -1 to 6 in position II, from -2 to 5 in position III, from -3 to 4 in position IV, from -4 to 3 in position V, from -5 to 2 in position VI, from -6 to 1 in position VII, and from -7 to 0 in position VIII. Statistical analysis was performed for each position separately[15,16,17].

Results and Discussion

Given the complexity and interdisciplinarity of colour science, the paper aims to determine whether there is a correlation between objective computer-based evaluation and the psychological (subjective) perception of colour depending on the subjects' age.

An experiment was conducted to determine the effect of the surround colour (white, gray and black) on the subjects' psychological perception of the red ($H^* = 12°$) and the green hue ($H^* = 173°$) The method of constant stimuli and Stevens' magnitude estimation method were used. The experiment involved comparing the results of objective spectrophotometric methods with psychophysical colour perception. Statistical analysis was carried out using the Mann-Whitney U test, the Kruskal-Wallis test and the Median test.

Objective analysis

Objective analysis involves accurate and precise colour evaluation. Spectrophotometric colour measurement methods are based on the tristimulus values (X, Y and Z) and describe colour by its psychological attributes: chroma (i.e. saturation) (C), hue (H) and lightness (L). These values are objective and are not affected by the observer and their environment, whereas the psychological (subjective) experience of colour is the result of interaction between the environment and colour.

The colouristic attributes of each hue for each position are expressed by C*/Y and C*/L* ratios (see Figures 3-6).

Figures 3 and 4 show the colouristic characteristics and the C*/Y ratio for the red and green hue for each position. Based on the colorimetric definition of each hue, value Y is often assumed to be a direct indicator of lightness. It has been confirmed, for each hue, that as chroma, i.e. saturation (C *) reaches its maximum, value Y, which represents lightness, becomes less dominant. It is therefore to be assumed that the smaller the difference between values Y and C*, the lower the observer's visual sensitivity will be to the psychological (subjective) experience. For example, it is to be expected that the observer's visual sensitivity to a hue will be lower when the differences between values Y and C* are smaller. Thus, a low threshold of sensitivity was found/observed for both red (Figure 3) and green (Figure 4) colours at positions above III, IV, and V.

However, value Y, which represents lightness, is not correlated with the psychological experience of colour. The transformation of the CIE system in 1974 is the result of an effort to develop a uniform system in which colour by lightness (mathematical formula: $L^*=116(Y/Yn)^{1/3}-16$) becomes closer to its visual perception when observed in the environment. It is to be assumed that, depending on the hue, when values L* and C* become equal, distinguishing between samples will be more difficult, that is, the subjective colour experience of colour over the entire FIELD will depend on the evaluation of the observer and the colour of the background.

Figures 5 and 6 show the C* to L* ratio for each sample position of the red and green hues.

For the red hue, the observer's sensitivity shifts towards position V, while for green hue, it shifts towards position VI. Although these values are objective, it is to be expected that the subjective experience of colour in the area with the maximum saturation of hue will depend on the subject's age.

Subjective analysis

The psychological (subjective) experience of colour is the result of interaction between the environment and the colour. It depends on the source of light, energy, viewing angle, and in particular the observer and their mental health. Information on the intensity of light is obtained through the rods (there are about one hundred million of these cells in one eye), whereas cones are responsible for colour vision. The cones are most sensitive to the wavelengths of 420, 534 and 564 nm, which is why complementary colours red and green were chosen for this experiment[2,3]. The fact that the same physical stimulus (wavelength) causes different experience of colour in different people proves that colour perception is indeed a psychological experience.

The experiment was carried out under constant conditions, as described in Chapter 2.2. The subjects were aged 20-50.

The method of constant stimuli was used in the experiment. This method is considered to be one of the most accurate psychophysical methods for determining visual threshold. Subjects were asked to rate the samples set against different background colours, according to their psychological (subjective) experience of lightness (L) and chroma (C).

The data obtained were analysed using descriptive statistics, the Mann-Whitney U test, the Kruskal-Wallis ANOVA and the Median test. The results are shown graphically in Figures 11-12.

Method of constant stimuli and Stevens' magnitude estimation method

In the method of limits, ascending and descending limits are used to estimate the most frequently perceived hue. Threshold is considered the average of the threshold points estimated by several ascending and descending limits. Ascending and descending limits is a quick method of determining the threshold. Stevens proved that magnitude adjustment can provide an effective tool for measuring subjective experience of metathetic and prothetic stimuli.

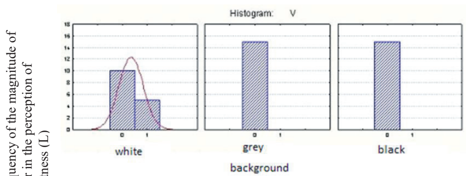
The subjects were given the following instructions: Using the schematic representation (Figure 2), rate the samples from I to VIII, according to your perception of lightness and chroma of each hue (red and green), on each of the backgrounds (white, gray, and black).

The effect of the stimulus lightness (L)

The amount of light energy reflected from an object will affect the perception of hue. It is often equated with the stimulus lightness. The rating according to the schematic diagram (Figure 2) will depend on the overall intensity of light of the surround colour and the sample colour, as well as the age of the subjects.

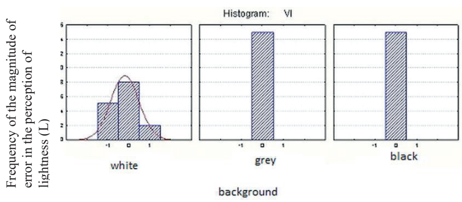
On achromatic backgrounds (Figures 7 and 8), where, as already mentioned, the lightness is measured with a magnitude scale from 14 to 100, where 14 is black, 50 is

red hue
- samples in the fifth position



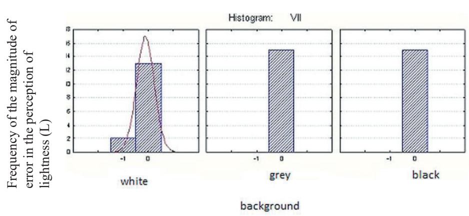
Subjects' psychological experience of the position (age group 20-30)

- samples in the sixth position



Subjects' psychological experience of the position (age group 31-40)

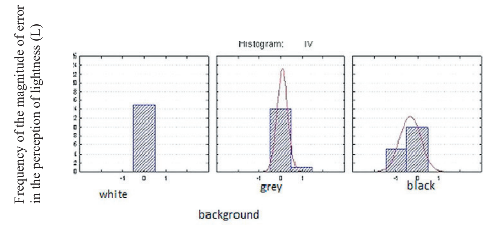
- samples in the seventh position



Subjects' psychological experience of the position (age group 41-50)

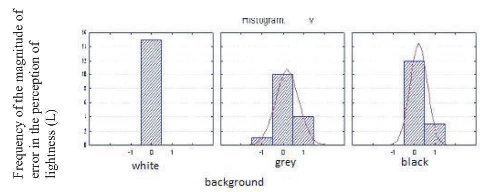
Fig. 7. The effect of the surround colour on the perception of red hue related to stimulus L.

- green hue
- samples in the fourth position



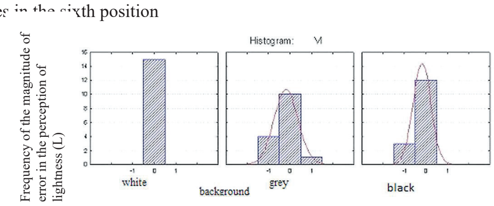
Subjects' psychological experience of the position (age group 20-30)

- samples in the fifth position



Subjects' psychological experience of the position (age group 31-40)

- samples in the sixth position



Subjects' psychological experience of the position (age group 41-50)

Fig. 8. The effect of background colour on the psychological experience of the green hue related to stimulus L

gray and 100 is white, the perceived position of the samples is in correlation with the objective CIE L* value (Figures 3 and 4) and depends on the hue. In the case of an objective evaluation of the C*/L* ratio according to the CIE system, it was assumed that the samples in which the values L* and C* are equal, the perception of colour in the whole area would depend on the observers' subjective assessment and the surround colour.

The results are graphically depicted in Figures 7 and 8. The figures show the frequency of the psychological experience from lower to higher lightness for each position of the hue, depending on the surround colour.

The obtained results are shown graphically only for positions in which significant deviations have been observed.

The above figures show the effect of background colour and lightness (L) of the red hue from V to VII position, for all three age groups. The said positions were graphically illustrated because of the significant deviations found in them. The deviations are found on the white background in positions V, VI and VII.

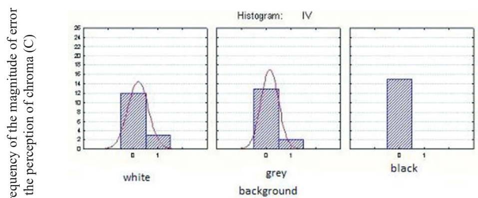
The above figures show the effect of background colour and lightness (L) of green hue in positions IV-VI, for all three groups of subjects. The said positions were graphically illustrated because of the significant deviations found in them. The deviations are found for grey and black backgrounds in positions IV to VI.

Based on objective evaluation, it is to be assumed that, depending on the hue, when values L* and C* become equal, distinguishing between samples will be more difficult, that is, the experience of colour over the entire area will depend on the observer's subjective evaluation and the background colour.

The data on subjective experience of the position of samples confirm that the subjects were uncertain about samples in positions IV, V and VI. The smallest deviations in the perceived position were observed for red hue.

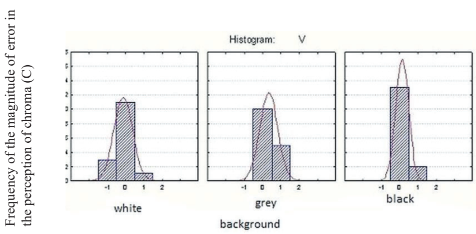
Due to its high level of lightness, experience on the white background is less affected by the influence of other hues than neutral gray. The most neutral colour (i.e. non-colour) is medium gray, which makes it most sensitive to all possible influences. An isolated medium gray is the

- ***red hue***
- samples in the fourth position



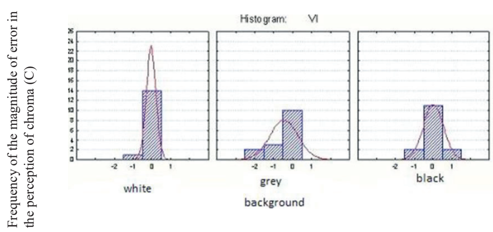
Subjects' psychological experience (age group 20-30)

- samples in the fifth position



Subjects' psychological experience (age group 31-40)

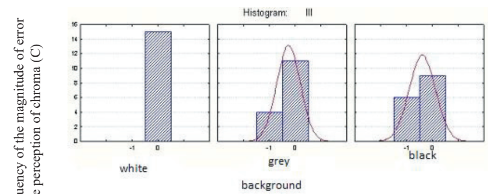
- samples in the sixth position



Subjects' psychological experience (age group 41-50)

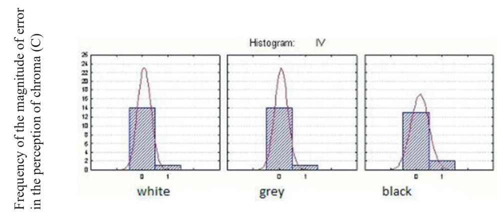
Fig. 9. The effect of the surround colour on the psychological perception of the red hue related to stimulus C

green hue
- samples in the third position



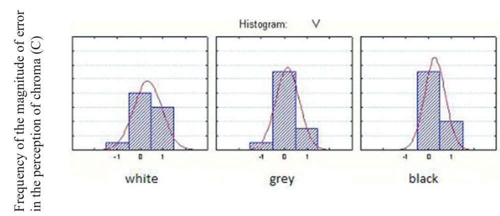
Subjects' psychological perception (age group 20-30)

- samples in the fourth position



Subjects' psychological perception (age group 31-40)

- samples on the fifth position



Subjects' psychological perception (age group 41-50)

Fig. 10: The effect of surround colour on the psychological perception of the green hue related to stimulus C

least conspicuous; however, when put next to another colour, it instantly acquires brightness and hues complementary to its neighbour, whose colour then weakens. This phenomenon is known as the simultaneous colour contrast. Inaccurate judgments were observed in subjects aged 31-40. The deviations were more pronounced in the case of green hue on gray and black backgrounds. Significant errors in colour judgement were observed for red colour on the white background. The higher level of uncertainty about their judgment of the colour of the samples on the white background is attributed to a larger amount of light reflected from the background and the red hue itself.

The effect of chroma (C):

A colour changes its effect depending on the background. As a rule, when set against a light background, a colour loses its lightness, becomes darker and less saturated, softer and more muted. Conversely, when set against a dark background, colours become brighter, stronger and seem purer, which makes psychological evaluation more difficult.

On *achromatic backgrounds* (Figure 9 and 10), for the red and green hue values with low dispersion in the area of higher saturation, sd <1, it is confirmed that, when colours have the same lightness, the perception of colour is dependent on saturation.

The graphs for red hue show only the positions IV to VI because of the significant deviations found in these positions. The deviations for the red hue are found on white and grey backgrounds in position IV. In positions V and VI, deviations are observed on all backgrounds. Fewer inaccurate ratings, i.e. subjective evaluations by subjects aged 40 and over are consistent with the smaller effect of lightness of the background colour and these values are attributed entirely to the age factor. (Figure 10)

The graphs illustrating the results for the green hue show only the positions III to V because of the significant deviations from objective evaluation observed in these positions. The deviations were found on all backgrounds. The subjects displayed uncertainty.

Figure 10 shows the effect of the surround colour and the chromaticity (C) of green hue in positions III to V. The graphs show only the positions indicated because visible deviations were observed there. Deviations occurred on all backgrounds in position V relative to objective position of the green hue. Increased saturation (C) decreases hue lightness, and the observer is uncertain in rating the position.

Figure 9 shows the effect of the surround colour and the chromaticity (C) of red hue in positions IV to VI. The graphs show only the positions indicated because visible deviations were observed there. Deviations were observed in position IV on white and gray backgrounds. In positions V and VI, deviations were found on all backgrounds. Red hue has the highest energy which causes inaccurate rating of the sample position due to the energy of the background colour.

Analysis by means of

Descriptive statistics and deductive statistics were used to determine the differences in distributions between different groups. Appropriate nonparametric statistical tests were used (the Kruskal-Wallis ANOVA and the Median test) to test the hypothesis proposing that there are statistically significant differences in the error in perception of colour caused by the surround colour. The obtained values for lightness (L) indicate the difference between the perceived position of the sample and the actual position depending on the surround colour.

The results of subjective colour perception are shown in the Box-and-Whisker plot (Figures 11-12).

The effect of the stimulus lightness (L)

The intensity of colour perception depending on the surround colour can also be estimated based on the magnitude of inaccurate perception of lightness (L). Values ranging from -1 to 1 were assigned to the differences for red and green hues in each of the positions, as shown graphically in Figures 7 and 8. The results are provided for the green hue only for positions in which visible deviations were observed. The deviations for the green hue are observed on gray and black backgrounds in positions IV to VI. The graphs for the red hue show the indicated positions only because of significant deviations found in these positions. The deviations for the red hue are found on the white background in positions V, VI and VII.

The results of the Kruskal-Wallis test and the Median test indicate that there are significant differences in the perceived lightness (L) which occur due to the surround colour. For the red hue (A), significant differences in the perceived sample positions were found in groups II and III (aged 31-50). For the green hue (B), no statistically significant differences were found in the perceived sample position in any of the positions (Figure 11).

The effect of stimulus chroma (C)

Figure 12 shows that there are significant differences in the perceived sample position for red hue (A) in all subject groups, in particular in groups II and III (31-50). For the green hue (B), no statistically significant differences were found in the perceived sample position in any of the positions.

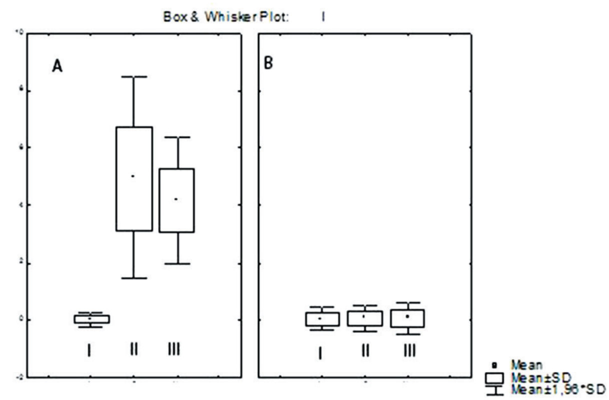


Fig. 11. Perceived lightness (L) (f-frequency); ***A****-red and* ***B****-green (age groups: I: 20-30, II: 31-40 and III: 41-50)*

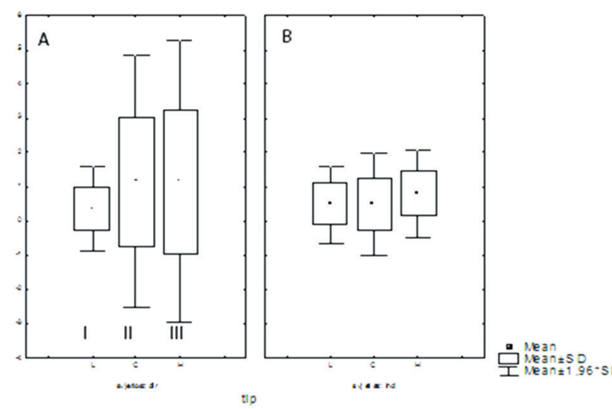


Fig. 12. Perceived saturation (C) (f-frequency); ***A****-red and* ***B****-green (I: 20-30, II: 31-40, III: 41-50).*

Comparison of samples of subjective (psychological) experience and the actual position of the sample according to the template

The psychological perception of colour is the result of interaction between the environment and the colour. It depends on the source of light, energy of the hue, and in particular on the observers and their mental health[5,8]. The method of constant stimuli was used in the experiment. The subjects were classified into three groups according to their age; I: 20-30, II: 31-40 and III: 41-50. Green and red were selected as sample colours, according to the Opponent Process Theory of colour vision developed by Ewald Hering which suggests that color perception is controlled by the activity of two opponent systems: a blue-yellow mechanism and a red-green mechanism.

The subjects were instructed to rate the position of a particular hue set against white, gray and black backgrounds. The answers varied depending on the subjects' age and the hue itself. In evaluating the perceived lightness of the red colour set against a particular background, group I subjects confirmed that the red colour was less noticeable and they were indifferent to it (Figure 11, A, subject group I (aged 20-30). Subjects from groups II and III (aged 31-50) displayed ambiguity and uncertainty and were more inaccurate in their evaluations. Their answers indicate that green hue (B) was less noticeable and that they were indifferent to it. This confirms that the energy of each hue is, in fact, the energy of light.

In the case of red colour, as shown in Figure 12 (A), the level of uncertainty amongst the subjects increased with the level of saturation (C) in particular in groups II and III which led to higher inaccuracy in rating the position of the sample. The high specific energy of the red colour stimulates the subjects' visual reaction and captures their attention.

This experiment has confirmed that the red colour will stay in the memory relating to the psychophysical visual phenomenon the longest of all colours. Perception is the impression that an individual obtains based on a group of individual stimuli that the human mind receives and the mental processes in which these stimuli are processed in order to form a certain opinion, attitude and behaviour.

Conclusion

Through objective evaluation, using spectrophotometric methods and the CIE C*/L* ratio, the subjects threshold is obtained for each hue. At the moment when the spectral values of L* (lightness) and C* (chromaticity) become equal, distinguishing between sample colours is more difficult, that is, the subjective experience of colour over the entire area depends on the evaluation of the individual observer and the surround colour.

Descriptive statistics and appropriate non-parametric statistical tests (the Mann-Whitney U test, the Kruskal-Wallis test and the Median test) show significant differences in the visual perception of colour depending on the surround colour.

Subjects aged 31 and over made inaccurate judgements due to lightness (L), in particular in the case of the green hue on gray and black backgrounds. When it comes to the red hue, significant errors in rating were found on the white background. The subjects' uncertainty over the position of the red hue samples on a white background is attributed to a larger amount of reflected light from the background and the light of the red hue itself. Red hue has the highest energy which causes inaccurate rating of the sample position due to the energy of the white background colour.

Increased saturation (C) decreases hue lightness, and the observer is uncertain in rating the position. This is particularly evident in the case of the red hue.

The intensity of colour perception depending on the surround colour was also estimated using the frequency of error magnitude. The results indicate significant errors in judging lightness (L), which are affected by the background colour. For the red hue, significant differences in the frequency of errors in the rating of sample positions were found in subjects aged 31 and over. For the green hue, no statistically significant differences were found in errors in the rating of sample position in any of the positions and the subjects were indifferent to it.

For the red hue, significant differences in the frequency of error in the rating of sample position based on saturation (C) were found in all subject groups, in particular in subjects aged 31 and over. No statistically significant differences in any of the positions were found in errors in the perception of sample position for the green hue.

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OBJEKTIVNA PROCJENA BOJE I VIZUALNI PRAG

SAŽETAK

Nauka o boji bavi se razvijanjem teorija i utvrđivanjem činjenica o boji koje nam pomažu razumjeti percepciju boje i pružaju sredstva za objektivno specificiranje boje. Znanstvena istraživanja u ovom znanstvenom polju moraju uzeti u obzir različite čimbenike koji utječu na percepciju boje kao što su promatračevo iskustvo i ponašanje. Spektrofotometrijske metode mjerenja boje temelje se na tri vrijednosti (X, Y i Z) i opisuju boju s tri psihološka svojstva: zasićenost (C), ton (H) i svetljivost (L). Te su vrijednosti objektivne i na njih ne utječu promatračke karakteristike i njihovo okruženje. Korištenjem instrumentalne, tj. spektrofotometrijske metode, identificira se prag kako bi se predvidjelo područje u kojem vizualna percepcija boje, tj. psihološko (subjektivno) iskustvo odgovara omjeru C * prema L *. Eksperiment se provodi pomoću komplementarnih boja - crvene i zelene, temeljene na kontrastnoj teoriji boja. U eksperimentu, u kojem je sudjelovalo 182 ispitanika u dobi od 20-50, objektivna spektrofotometrijska metoda se uspoređuje s psihofizičkom, tj. Subjektivnom percepcijom boje. Psihofizičke metode, tj. metoda stalnih podražaja i Stevensova procjena veličine koriste se za mjerenje subjektivne percepcije boje pod utjecajem različitih pozadina (bijele, sive i crne). Među ispitanicima u dobi od 30 i više godina primjećuje se veća netočnost u ocjeni uzorka za parametar svjetline (L). Za parametar zasićenosti (C), svi su ispitanici, bez obzira na dob, pokazali nesigurnost u ocjeni položaja uzorka. Opisna statistika i odgovarajući neparametrijski testovi (Mann-Whitney U test, Kruskal-Wallisov test i Medijan test) pokazuju značajne razlike u netočnoj vizualnoj percepciji boje ovisno o okolnoj boji, posebno za parametar svjetline (L) i za crvenu nijansu.