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Statistic Analyses of the Color Experience According to the Age of the Observer

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ABSTRACT

Psychological experience of color is a real state of the communication between the environment and color, and it will depend on the source of the light, angle of the view, and particular on the observer and his health condition. Hering's theory or a theory of the opponent processes supposes that cones, which are situated in the retina of the eye, are not sensible on the three chromatic domains (areas, fields, zones) (red, green and purple-blue), but they produce a signal based on the principle of the opposed pairs of colors. A reason of this theory depends on the fact that certain disorders of the color eyesight, which include blindness to certain colors, cause blindness to pairs of opponent colors. This paper presents a demonstration of the experience of blue and yellow tone according to the age of the observer. For the testing of the statistically significant differences in the omission in the color experience according to the color of the background we use following statistical tests: Mann-Whitnney U Test, Kruskal-Wallis ANOVA and Median test. It was proven that the differences are statistically significant in the elderly persons (older than 35 years).

***Key words**: color experience, statistic analyses, yellow and blue tone, observer*

Introduction

The experience of color changes depending on the conditions of observation of color environment, energy level of brightness, viewing angle, and the observer and his health.

The colors we see depend on the light that enters our eyes from the outside world. The experience of color in the brain is given a »zonal theory of color vision« that connects trichromatic theory and the theory of opposing processes. According to this theory in the retina of the eye, behind the layer of cones of different chromatic sensitivity (S, M and L), lies another layer of receptors.

The absorption and reflection of certain wavelengths from the entire spectrum takes place on the principle of complementary relationship. The opposite pairs of colors are complementary colors: purple-yellow, green-red and white-black. The amount of light energy reflected from an object will affect the psychological experience of color and is often identified with the brightness of a color stimulus. The experience will depend on the total intensity of the ambient light color (background) and color pattern. Looking at the world we never see just one color, but each color in its complex characteristics in tone (H), luminance (L) and saturation (C) under the influence of the colors that surround it and form its background.

The Color and its Visualization

Color plays an important role in human life in many areas. One of the major areas of research is the vision of colors, i.e. the mechanisms involved in the perception of color with Helmholtz and Herring being pioneers in this field. Also important are the experiments conducted by Land and his associates as well as development of his theory of retinal color vision. The study of color is an interdisciplinary activity that includes many arts and sciences. Light is a fundamental requirement when watching colors on/in buildings. Human perception of illuminated objects, along with the effects of the human brain, results in color experience. These facts were established in many works in the science of color such as in Hunt's ar-

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gument that the perception of color includes »three basic color components: light source, the illuminated objects and observers.« Isaac Newton found, based on experimental facts, that white light is not only a homogeneous entity but a mixture of all colors of the spectrum. Since then the understanding of the mechanism of color vision and color progressed.

The colors we see depend on the light that enters our eyes from the outside world. What we perceive as red or green is actually created in our brains. Many definitions of colors are given, of which the following will be used in this paper: Color is a psychophysical experience caused by electromagnetic radiation of wavelength 380–750 nm. That it really is a psychological experience is proven by the fact that the same physical stimulus causes in different people a different color experience[1].

Trichromatic theory of vision

The structure of the human eye (Figure 1) allows the sense of sight and color. According to accepted theory of visualization and interpretation of how the human eye detects color, there are two types of photosensitive elements in the eye (retina): rods and cones, which convert light energy (electrical and chemical signals) into nerve impulses, and allows observers to register tone color.

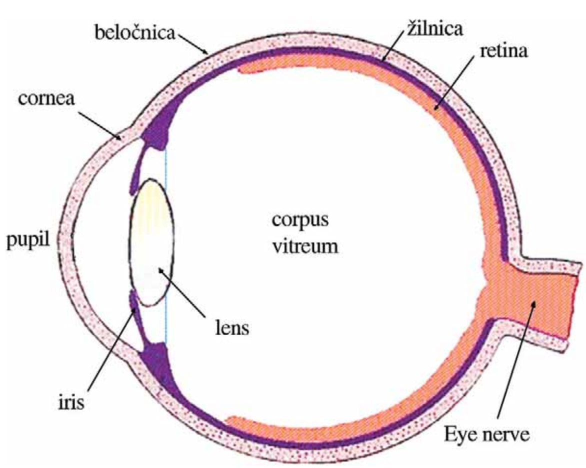

Fig. 1. The section of the human eye 1.

The perception of color is based on the fact that »the human eye works like the camera. The cornea and lens act together as a lens of the camera when it focuses the image of the visual world of retina, which is located on the back of the eye, and works as a film or other image sensor on the camera. These and other structures have an important impact on our perception of color,« as described by Fairchild[2].

The rods are arranged in the eye outward toward the edge of the retina and mediate at lower light levels and are able to experience the brightness of each color, while cones are responsible for the experience of color tone and mediate vision at higher light levels. Cones are concentrated in a small central area of the retina, the yellow spot (fovea centralis), and are able to distinguish colors[3].

Rods and cones are the retinal photoreceptors. Looking with the cones is clearer and sharper than with the rods, but they only operate at relatively high light levels. At low and very low light levels, we see almost a monochrome picture of low-resolution[4,5]. There are three types of cones, each with a different kind of sensitivity to different ranges of the visible spectrum and are used for color vision. According to Fairchild, appropriate names of cones are L (Long), M (medium) and S (Short). Names are related to the long wavelength, high and short sensitivity of the cones. Spectral sensitivity of the S cones is the highest at approximately 440 nm, M cones at 545 nm and L cones at 565 nm, after correction of loss of light in front of the retina[6–9].

In contrast to cones there is only one kind of rods that have a role in seeing colors in the visible spectrum (from 380 nm to 780). Sometimes they are referred to as RGB (Red, Green, Blue) cones, what is wrong based on the colors in the spectrum, Figure 2.

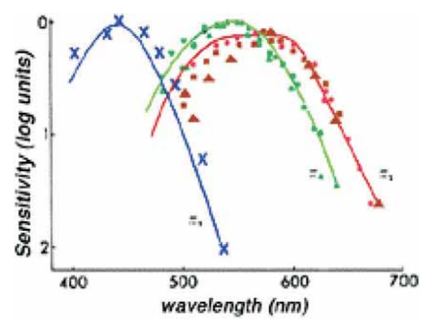

Fig. 2. The sensitivity spectrum of S, M an L cones 10.

Explanation of sensation and color perception in the brain is given by »zonal theory of color vision,« which combines theory of opposing processes and trichromatic theory.

Trichromatic theory is based on papers (Maxwell, Helmholtz and Yung) considering that the fundamental basis of all considerations of visibility perception of colors is the fact that the human eye has three types of independent »sensors« for colors that are approximate to red, green and purple-blue end of the spectrum. Any color one wants to reproduce can be obtained by mixing three kinds of pigments, Figure 3.

The experience of color depends on several factors and stems from different levels. Although observers tend to ignore the color variations, they are nevertheless important in considering the identity of color. »Elasticity« of color can be a useful tool for designers and users in understanding the results which will occur by choosing a color. The area of expected »elasticity« together with the expected appearance of colors can give a good conception of color[12–14].

Besides the physiological reasons for defective color vision, there are physical and psychological causes. As a cause of psychological reasons of incorrect color vision

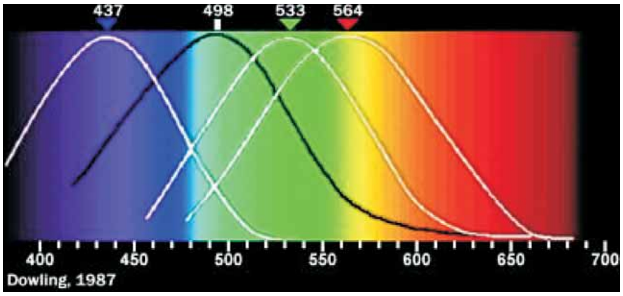

Fig. 3. The eye sensitivity to colors.

the impact of color in the environment, especially simultaneous and successive contrast, is considered[15–18].

A cause of psychological reasons of incorrect color vision might be the impact of color in the environment, as well as simultaneous and successive contrast[15–18].

Hering's theory of opposite colors

In the mid 19th century it was believed that only three receptors are required for mixing colors and create the basis for the experiments conducted by James Maxwell in 1867 and Herman Helmholtz in 1859. Modern psychologists can confirm that there are three types of molecules and that each species is especially sensitive to the short, medium or long waves of light. Although this review may help explain why some areas of the light wave cannot be separated from others and why many mixtures result in the same color, this still cannot explain the shades of color that we see.

Helmholtz was the one who suggested that there must be three receptors that directly indicate the different colors and he named them blue, green and red, believing that the blue receptor produces the sense of blue, green of green, etc. He was aware that the spectral sensitivity of receptors must overlap so that different wavelengths can result in different colors. Between 1872 and 1874 the physiologist Ewald Hering discovered six communicators as published in the theory of light sensitivity at the Academy of Sciences in Vienna, thus opposed to Helmholtz Hering's view of color phenomenons. Although he spent a significant amount of time exploring the visual perception of three-dimensional space, Hering dedicated more to introspective aspect of color. His work on colors refers to a problem such as the yellow color in the three-color system. According to Helmholtz the yellow color is necessarily a product of a mixture of red and green, or, like Hering noted, it was not in accordance with the human experience. The sense the yellow color is basic and not the result of a mixture. Hering further argues that the mixture of red and green never appear but eliminate one another. Hering concluded that there are not three, but four elementary color sensations or physiological pyramids that encode our perception of so called opposite processes.

In 1878 Hering wrote that yellow may contain red or green tint, but not blue. Blue may contain only red or only green tint, and red only yellow or blue. The four colors can be described as basic, as Leonardo Da Vinci said. In the case of opposite color tones that explain all the colors of the visible spectrum, Hering too speaks of the antagonistic sorts of light that make up white light. White is for him a sense of his own nature itself, as well as black, red, green, yellow or blue. Hering takes out the black-white opposite process to care of the brightness. In such an analysis the six basic tones were obtained. Hering distinguishes his theory of light from the world of physics. According to Hering's claim that red and green or blue and yellow together give white it would make sense only if the red and green were interpreted as fluctuations in the air, and not as red and green sensation. Four expressions red, green, yellow and blue were available to the pioneers in this area and they were able to describe each color using a combination of these concepts. There are four basic color tones, not three. Neuropsychological evidence for this exist since 1966. These four basic color tones are set against one another in Hering's system that represents a circle of opposing rings and ellipses. This system is shown using the four basic colors: yellow, red, blue and green, laid at right angles opposite each other.

Hering's color sequence, which describes the system as a natural color perception, forms the basis for a system that we know today as the NCS system. The success of this circle of color shows the locations of the four basic colors and proportions with which any two colors can create a basic mix. Hering's theory of opposite colors was not accepted. It has been fiercely criticized by Helmholtz's students who claimed that Hering's claims make sense only if there are different processes in the nervous system, naming them stimulating and streamlined processes. In Hering's time the knowledge that is today regarded as normal was not yet accepted and proved. Our perception of color is not clearer, but should not be allowed to spoil our enjoyment of them[17–20].

Hering's theory or the theory of opponent process assumes that cones that are found in the retina of the human eye are not sensitive to the three chromatic fields (red, green and purple-blue), but produce a signal based on the principle of opposing pairs of colors. The opposite pairs of colors are purple-yellow, green-red and white-black. The support for this theory lies in the fact that some defects, including blindness to certain colors, causes blindness in pairs of opposite colors. So a person who does not see the red color also loses the sense of its opposite: green. The same goes for the blue color, with a lost sense of recognition of yellow[21,22].

Zone theory of color vision links the trichromatic theory and the theory of opponent processes by which in the retina of the eye, behind a number of cell layers of cones of different chromatic sensitivity (S, M and L), there is another layer (zone) of receptors. It is considered that there are three types of bipolar sensory receptors. Each of the receptors from the second zone is associated with the three neighboring cones of different chromatic sensitivity. These receptors may receive conflicting information from each of the cones (such as + and –) and act as opposing cells and transmit conflicting information. It is assumed that information about the opposite senses occur when the cones of opposite colors (purple, blue and yellow or green and red) are reached by identical positive signals (+ and +), while in the case of receiving different signals (+ and – or – and +) a positive signal is transmitted to the brain. In this way, different information can be transferred by the same nerve[23].

The psychology of colors

One has but to perceive the objects around him to know that the properties of color need to be seen. The characteristic of the psychology of perception is that it is associated with the physiology and the science of communication. Visually we perceive shapes and colors. How we see shapes depends on the information how we visually recollect three-dimensionality as well as the processing of such information. The perception of color will not only be influenced by blooming and saturation, color of environment, but also by the observer's information about objects. According to Hering, the color which is often seen in an outward thing, indelibly affects our memory and becomes a fixed feature of remembered images[16,17,24].

Methodology

The research on the yellow and blue tones was done for the purpose of defining the relation between the color and background (environment color). The yellow (H= 089) and blue (H=271) tones were presented according to saturation (C) on the basis of the following color characteristics background: achromatic (white; L=100, grey; L=50 and black; L=10), yellow (H= 089, L= 50 and C= 50) and blue (H=271, L=50 and C= 45), Figure 4.

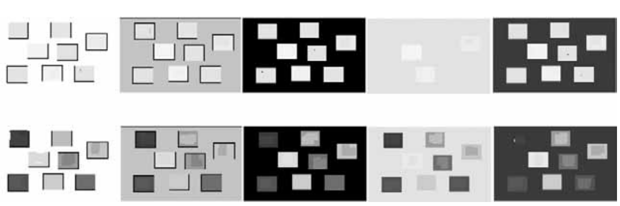

Fig. 4. Schematic representation of the set positions of samples from I to VIII

The visual assessment

The psychophysical analysis (visual assessment) of the colored samples was conducted on 30 observers in two groups (first group: 21 to 25 years of age and second group: 35 to 40 years of age), with the light source D_{65}, the distance between the observer and the sample being 60 cm and the angle being 10^0.

All the observers were submitted to the Ishihara test for the purpose of choosing the participants in the assessment i.e. in order to choose the observers capable of normal color defining.

The observers were asked the following questions:

Sort and rank the equivalent color tone of yellow and blue on the media, (white, gray, black, yellow and blue), Figure 5. a) according to the psychological experience of the luminance (L attribute color) – from lighter to darker? b) according to the psychological experience of the saturation with its own tone (color attribute C) – less than saturation and higher? c) according to the psychological experience of the color tone?

Statistical analysis of visual data evaluation

The placement of every position of every observer depending on the background has been analyzed statistically and the resulting experienced position of the color yellow and blue is shown, with the values of standard deviation, on Figures 5, 6, 7 and 8.

The statistical analysis of the visual assessment is conducted by an application program (StatSoft). The corresponding non-parameter statistical tests, the Kruskal-Wallis ANOVA and the Median test, were used. The results are the values shown graphically in Figures 5 to 14[25,26].

The range of differences of experience obtained from the actual values for each color to the color attributes (H, L and C) and the influence of the substrate than the actual position of each color (1–8) is given by:

from 0 to 7 on 1. position

from –1 to 6 on 2. position

from –2 to 5 on 3. position

from –3 to 4 on 4. position

from –4 to 3 on 5. position

from –5 to 2 on 6. position

from –6 to 1 on 7. position

Results and Discussion

The absorption and reflection of certain wavelengths from the entire spectrum takes place on the principle of a complementary relationship. The amount of light energy reflected from an object will affect the psychological experience of color and is often identified with the brightness stimulus of a color. The experience will depend on the total intensity of the ambient light color (background) and the color of the pattern as well as the conditions of observation, the color of the environment, energy level of the illumination, the viewing angle, and the observer and his health.

Method of adjustment – ranking is considered to be the simplest, as the examinee himself interactively controls the value of stimuli and with most direct method of evaluation »threshold« sets the visual perception. The examinee is also indirectly affected by questions. The observer gives a position code for each color according to his viewing sequence – perception – from position 1 to 8.

The aim of the statistical analysis of the quantitative data is to enable as correct as possible a description of the

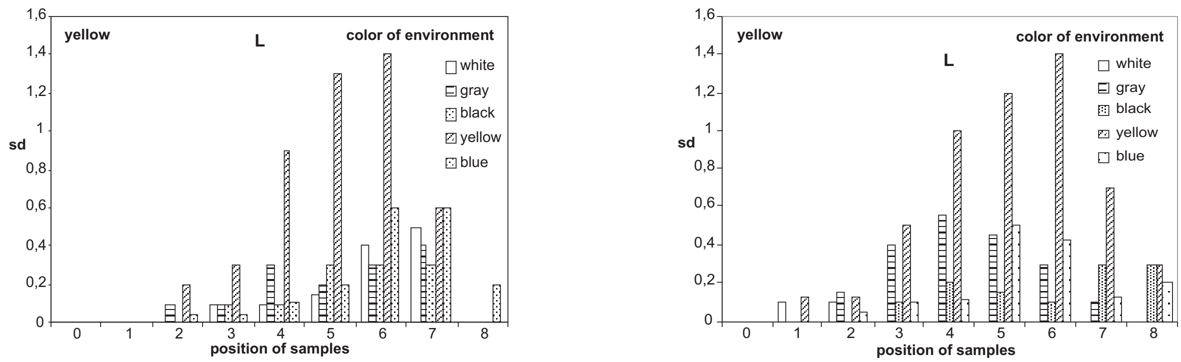

Fig. 5. The standard deviation of background color influence (environment) on the psychological experience of yellow tones per luminence stimulus (L) (a – observers younger than 25 years and b – older than 35 years)

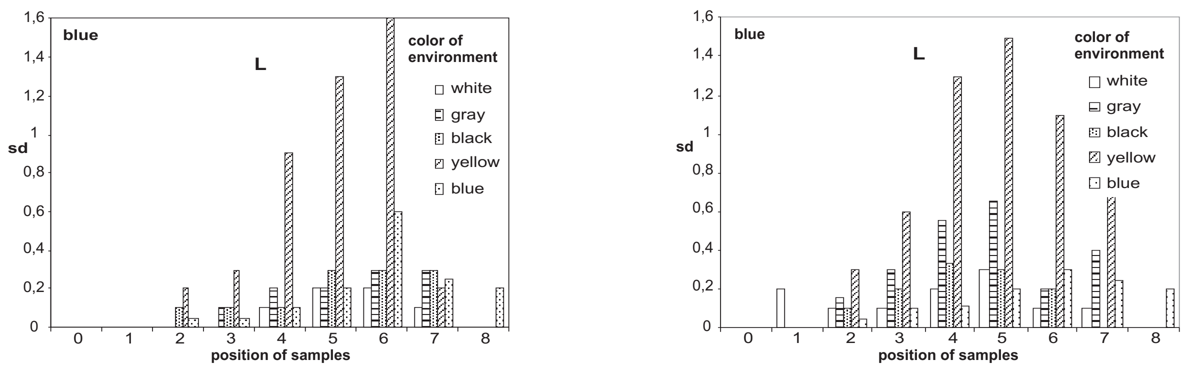

Fig. 6. The standard deviation of background color influence (environment) on the psychological experience of the blue tone per luminance stimulus (L) (a – observers younger than 25 years and b – over 35 years).

examinees' answers. The standard deviation in the mathematical sense demonstrates the scatter of results.

The amount of light energy reflected from an object will affect the psychological experience of the color and is often identified with the brightness of the stimulus, some color. The experience will depend on the total intensity of the ambient light color (background) and color pattern.

On the graphics 5–10, the values defined by the standard deviation of each position are given as a confirmation of the accuracy of the viewer's experiences by both the influence of background color (the environment) and the observer's age.

By parameter of brightness (L), Figures 5 and 6, all the examinees insecure ranked positions of yellow and blue tones on a yellow background. Generally we can talk about the effect of achromatic and chromatic induction based on the difference in luminance (L) between the background and position on the template.

However, in Figure 6b for the blue color tone, in examinees older than 35 years we can also see a greater uncertainty in the ranking of the other tested backgrounds, and higher values of standard deviation (SD) are obtained. This uncertainty in ranking the level of illumination confirms a reduced adaptation of the human eye to brightness can be observed with an increase in age.

Based on the Figures 7 and 8 it is not possible to make a uniform explanation on the basis of the standard deviation value of the psychological experience of sample position saturation C. The value of the standard deviation, SD>1, confirms that the color saturation correlates with the color lightness, i.e. the spectral characteristic of the yellow color. The insecurity of the experience of the color yellow confirms that the yellow color is confusing with its own high level of lightness.

The insecurity in ranking is more obvious in elder people, Figure 7b.

The fact that the saturation of the tone (C) by its own tone (deeper color) is correlated with brightness. The lower values of standard deviation that were obtained for the blue color tone confirm that the brightness of the color is an energy that is smaller in blue than in yellow, and with increasing chromaticity – saturation of color tone – reduces the ability of assessment in the older people, Fig. 8b.

If the results are viewed from the point of color tone (H) as an attribute of visual sensation, according to which each color is defined with a dominant wavelength of light and has no quantitative meaning of brightness, the maximum saturation of the color tone obtained »confuses« the psychological experience of color, Figs. 9 and 10.

When speaking generally about the color tone which is seen, it is confirmed that the experience of tones combines all the three attributes of color (H, L and C); there-

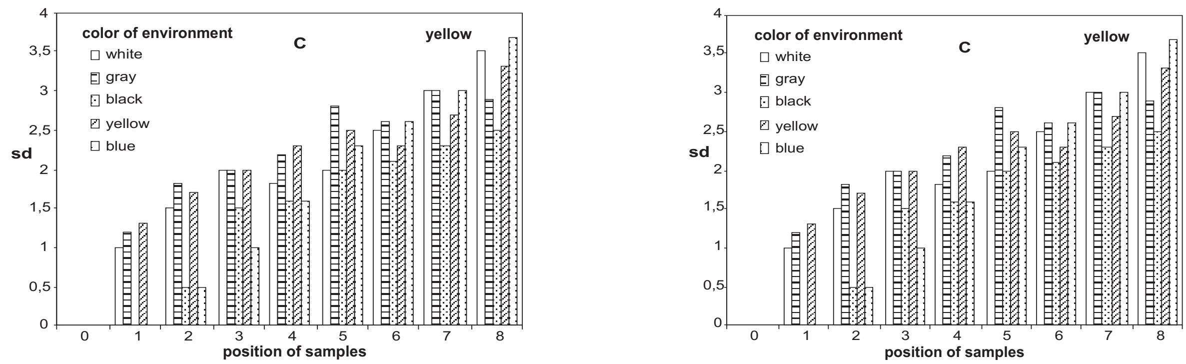

Fig. 7. The standard deviation of background color influence (environment) on the psychological experience of yellow tones per saturation stimulus (C) (a – observers younger than 25 years and b – over 35 years).

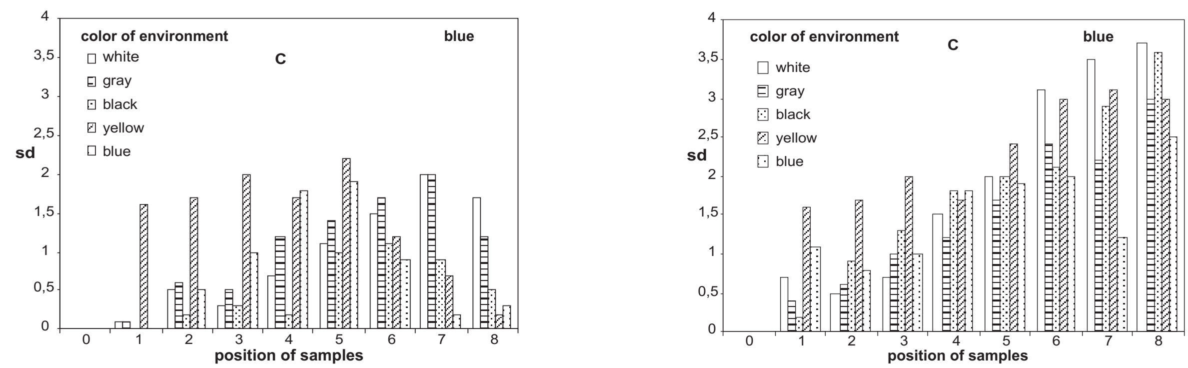

Fig. 8. The standard deviation of background color influence (environment) on the psychological experience of the blue tone per saturation stimulus (C) (a – observers younger than 25 years and b- over 35 years).

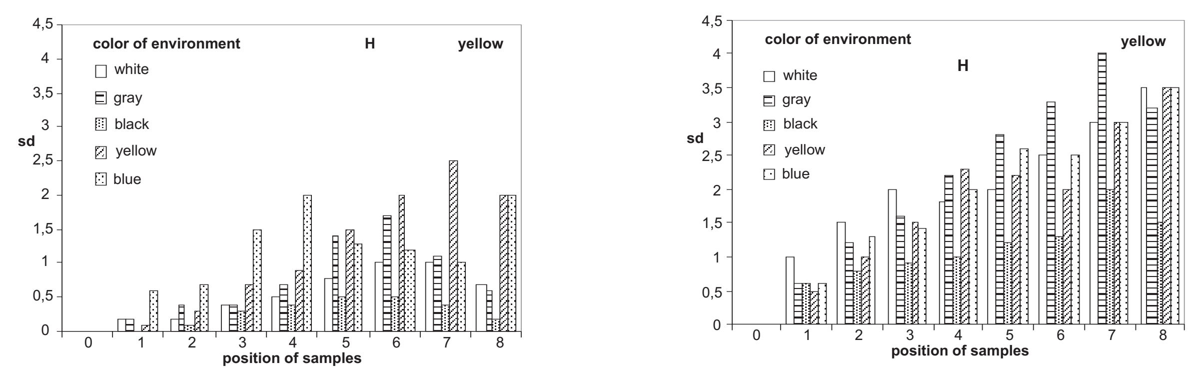

Fig. 9. The standard deviation of background color influence (environment) on the psychological experience of the yellow tone per tone stimuli (H) (a – observers younger than 25 years and b – over 35 years).

fore the higher values of standard deviation obtained for the elderly, fig. 9b and 10b, confirm that over the years the eye becomes slower and the assessments are more confusing.

In the further statistical analysis the methods of descriptive statistics and methods of statistical inference about differences in distributions between groups have been used. To test the hypothesis of the existence of statistically significant differences in color perception error as a function of background color (color temperature), appropriate non-parametric statistical tests: Mann-Whitnney U Test, Kruskal-Wallis ANOVA and Median Test have been used. The obtained values for the color brightness (L), saturation (C) and tone (H), give the difference of the total experience of yellow and blue colors and are given for the positions I, IV, V and VIII, depending on the color environment, Figures 11, 12, 13 and 14.

The Kruskal-Wallis and Median Test indicate that errors of perception of yellow and blue color on all surfaces are less in the experience of the dimensions of brightness (L). However, significant differences obtained for both colors, on the 4th and 5th position, Figures 12 and 13, confirm that the differences in the experience of dimension of brightness (L) are correlated with saturation (C)

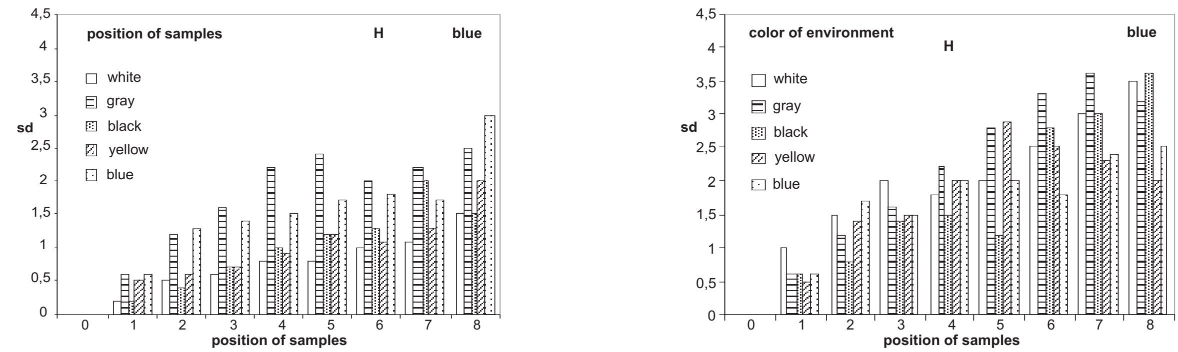

Fig. 10. The standard deviation of background color influence (environment) on the psychological experience of the blue tone per saturation stimulus(C) (a – observers younger than 25 years and b – over 35 years).

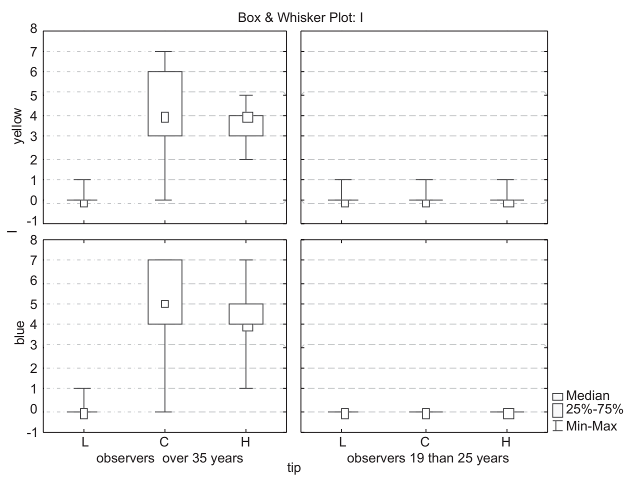

Fig. 11. Sample on the first position

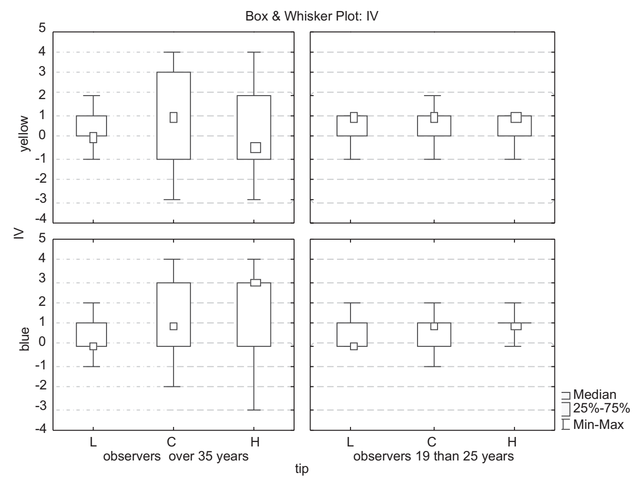

Fig. 12. Sample on the fourth position

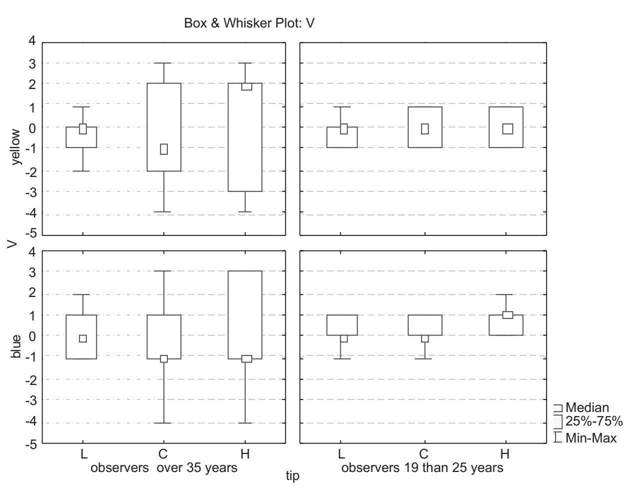

Fig. 13. Sample on the fifth position

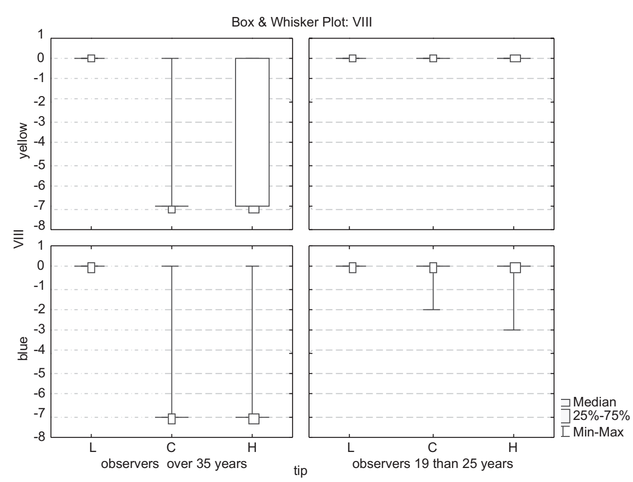

Fig. 14. Sample on the eighth position

of color tone, the saturation increases with the increase in the inertia of the eye to brightness, Figure 14.

However, on the same graphics, Figures 11, 12, 13 and 14, significant deviations in the parameters of color, saturation (C) and tone (H), were obtained for people older than 35 years. This confirms that the experience of color combines all three attributes of color (H, L and C), and over the years the eye becomes slower and the assessments are more confusing. Larger values of standard deviation are also obtained for the older examinees, Figures 8b, 9b and 10b.

The foregoing analysis confirms that there are, due to chromatic induction of yellow color with increased intensities, different psychological experiences depending on the observer, which is more pronounced in the older respondents.

Conclusion

Subjective experience of color analysis is based on the »zonal theory of color vision,« which combines theory and opposing processes and the three chromatic theory. Therefore, as psychological primary colors blue and yellow, and black and white, were selected in this work, which by Hering's theory of perception allow the receptors of the eye to produce the movements of complementary stimuli, blue, yellow, light, dark. In the method of ranking with constant stimuli it is taken that the observer's experience is not limited, but allows him to estimate the threshold for luminance (L) and saturation (C) and tone (H) of each position, consistent with the zonal theory of color vision.

The color tone is a psychological experience that defines the color by the dominant wavelength of light colors and intensities has no quantitative meaning.

It is proven that in defining of psychological accuracy of the position, standard deviation gives the maximum deviation, and also that the greatest uncertainty of assessment of saturation (C) *per* color tones (H) occurs in the observers older than 35 years. The greatest uncertainty has been confirmed in estimating the yellow tone.

The values obtained for the brightness of the color parameters (L), do not give the different position of the sample experienced than of the actual position depending on the color of the substrate when it comes to subjects-observers, students from 19 to 25 age, while the difference is statistically significant in subjects older than 35 – the age that has been proven that the sensitivity of the eye depends on the age of the observer.

From a psychophysical point of view, the inertia of the eye for the blue color is large and in cases where it bursts with its own color, the brightness has been reduced and independently of the color of the background minor errors in the perception of color have been obtained.

This work describes the experience of blue and yellow color tone depending on the substrate and shows that the brightness parameter and the parameter of tone are balanced in young adults creating a sense of well-being, while the differences are statistically significant in the elderly, i.e., the sense of sight is slower.

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STATISTIČKA ANALIZA DOŽIVLJAJA BOJE OVISNO O STAROSNOJ DOBI PROMATRAČA

S A Ž E T A K

Psihološki doživljaj boje je realno stanje komuniciranja okoline i boje i ovisit će o izvoru svjetlosti, kutu gledanja, a posebno o promatraču i njegovom zdravstvenom stanju. Heringova teorija ili teorija suprotnih procesa pretpostavlja da čunjići koji se nalaze u mrežnici ljudskog oka nisu osjetljivi na tri kromatska područja (crveno, zeleno i ljubičasto-plavo), već da proizvode signal na osnovi principa suprotnih parova boja. Razlog ovoj teoriji ovisi o činjenici da pojedini poremećaji vida boja koji uključuju sljepoću za pojedine boje uzrokuju sljepoću na parove suprotnih boja. U radu dat je prikaz doživljaja plavog i žutog tona boje ovisno o starosnoj dobi promatrača. Za testiranje statistički značajnih razlika u pogrešci doživljaja boje u ovisnosti o boji podloge korišteni su statistički testovi: Mann-Whitnney U Test, Kruskal-Wallis ANOVA i Medijan test. Dokazano je da su razlike statistički značajne kod starijih.