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# Quantitative analysis of the von Bezold effect in graphic communication

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***Abstract**: The paper analyzes the Von Bezold effect, in which chromatic assimilation is manifested, which shifts the appearance of the color of the sample according to the color of the surrounding background. The effect was first discovered and described by the German physicist and meteorologist Wilhelm von Bezold (1837-1907), who noticed that changing just one color in a sample containing several colors can completely change the perception of the entire composition as well as the experience of all colors. This paper presents the results of a psychophysical visual experiment in which the effect of the Von Bezold effect was tested on originally designed samples of graphic characters. 30 subjects of both sexes took part in the experiment and evaluated the strength of the Von Bezold effect on the given samples. On the samples, the letters of the letter T are constructed, which are located on two bases of different colors. The letters are covered with thin stripes that are painted in the color of the opposite background. The experiment determined a very strong effect of the Bezold effect on the described samples, which was also confirmed by statistical analysis.*

***Keywords**: Von Bezold effect, chromatic assimilation, statistical analysis, machine learning*

## 1. Introduction

Often due to the action of various factors that influence it, human perception is not aligned with the physical value of the stimulus. This means that our perception can deviate from the "normal" perception that is following the physical values of the stimulus that causes the stimulus [1]. Thus, in many situations, there is a "wrong" perception of color, which means that the perception of color as seen by the human visual system can be significantly different from the "normal" perception that is aligned with the physical values of color as the wavelength of a light ray that is reflected from a colored surface. The phenomena of "wrong" color perception are called psychophysical visual effects [2,3]. There are numerous psychophysical visual effects, the most important of which are simultaneous contrast, chromatic assimilation, Von Bezold effect, Munker White effect and neon color expansion [4-6]. The described psychophysical phenomena are of great importance in the field of all visual arts, including graphic design. Visual effects can be used as a means by which designers can increase the quality of the design. Still, they can also cause unwanted phenomena such as reduced text readability, as well as various types of noise in a composition that contains colored elements.

This paper presents the results of a psychophysical visual experiment of the manifestation of the Von Bezold effect in the graphic design of letters, that is, in the field of typography. The experiment was conducted on originally designed samples of colored letters within which the Von Bezold effect is very strongly manifested, as shown by the results of the conducted research.

## 2. Theoretical part

### 2.1. The history of the discovery of the Von Bezold effect.

Below is a brief history of the discovery of the Von Bezold effect of chromatic assimilation. Namely, the history of art is full of examples of great artists who managed to combine their theoretical and practical knowledge and thus create valuable works of art. Michel Eugéne Chevruel (1786-1889) was a leading French scientist of his time and as a scientist, he tried to combine the science of colors with art and thus connect theory and its application [7]. It is worth mentioning that he was a natural scientist who dealt with chemistry and was twice elected president of the French Academy of Sciences and Arts, and his name is written in golden letters on the Eiffel Tower among the seventy-two leading French scientists of that time. He became acquainted with the problem of visual perception of colors by accident when in 1824, by Royal Decree, he was appointed director of the Gobelins tapestry factory in Paris [8]. He published his observations on the perception of complementary colors interacting with each other as well as other discoveries about colors in as the general public.

Addressing climate and environmental challenges requires natural scientific knowledge as well as engineering expertise concerning the various technical solutions that can be adopted to mitigate the negative impacts (e.g., carbon-free energy technologies). However, pursuing sustainable technological change is also a societal, organizational, political, and economic endeavor that involves several non-technical challenges. For instance, the so-called transitions literature recognizes that many sectors, such as energy generation, water supply, etc., can be conceptualized as socio-technical systems and/or innovation systems [24, 40]. These systems consist of networks of actors (individuals, private firms, research institutes, government authorities, etc.), the knowledge that these actors possess as well as the relevant institutions (legal rules, codes of conduct, etc.). In other words, the development of, for instance, new carbon-free technologies may often require the establishment of new value chains hosting actors that have not necessarily interacted in the past; this necessitates a relatively long process that can alter society in several ways, e.g., through legal amendments, changing consumer behavior, distributional effects, infrastructure development and novel business models. In other words, beyond technological progress, economic and societal adjustment is necessary to achieve sustainable technological change. History is full of examples that illustrate the need to address the organizational and institutional challenges associated with technological change and innovation. In hindsight, the societal impacts of electricity in terms of productivity gains were tremendous during the twentieth century. Still, while electrical energy was discovered in the late 1870s, in the year 1900, less than 5% of mechanical power in American factories was supplied by electric motors and it took yet another 20 years before their productivity soared [14]. An important reason for the slow diffusion of electric power was that to take full advantage of the new technology, existing factories had to change the entire systems of operation, i.e., the production process, the architecture, the logistics as well as howworkers were recruited, trained and paid.1 A similar story emerges when considering the impact of computers on total productivity during the second half of the twentieth century. For a long, many companies invested in computers for little or no reward. Also in this case, however, the new technology required systemic changes for companies to be able to take advantage of the computer. This meant, for instance, decentralizing, outsourcing, and streamlining supply chains as well as offering more choices to consumers [9]. This key argument that the adoption of new technology has to be accompanied by systemic changes, applies both to the company as well as the societal level. Any novel solutions being developed must consider the complexity of the interdependencies between different types of actors with various backgrounds, overall market dynamics, as well as the need for knowledge development and institutional reforms. In fact, the need for systemic changes may be particularly relevant in the case of green technologies, such as zero-carbon processes in energy-intensive industries (see further below). (1839) [9]. The mentioned book as well as Chevruel's numerous scientific works strongly influenced the art of the 19th century. Through his scientific works on colors, many painters became familiar with visual effects. In the aforementioned book, Chevreul specifically interpreted the visual effect of simultaneous contrast and explained how to use colors in the painting, but also in tapestries, mosaics, typography, and even clothing design. Thus, painters discovered new possibilities provided by the visual effect of simultaneous contrast and used it in their paintings. A good example is the works of Vincent van Gogh (1853-1890), which are characterized by strong lines and frequent use of complementary colors, which achieves a very strong effect of simultaneous contrast [10]. For example, in the painting Cafe Terrace (Figure 1), which was created in Arles in 1888, the simultaneous contrast is most strongly expressed in the places where red and green colors and violet-blue and yellow colors touch [11]. The purple-blue sky is a background that enhances the lightness of the stars in the night sky, making it appear as if the stars are twinkling.

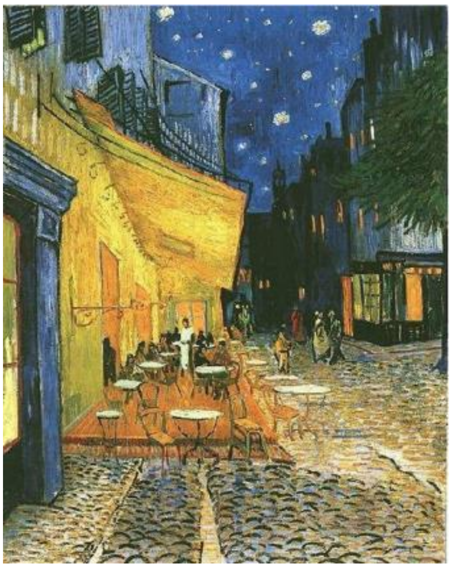

***Figure 1** Vincent van Gogh, Coffee Terrace at the Forum, Arles, 1888 [12]*

The Swiss and German painter Arnold Böcklin (1827-1901), like many of his contemporaries, was strongly influenced by Chevreul's color theories. Like many painters of his time, he tried to explore the properties of simultaneous contrast to be able to use it as effectively as possible. At the same time, the German professor of physics and meteorology Vilhelm von Bezold (1837-1907), who lived in Munich, moved in the circle of visual artists who lived in that city and thus became familiar with the problem of visual perception of colors that are in mutual interaction

[13]. Böcklin and Bezold knew each other personally and shared similar research interests related to the application of scientific results about colors to painting practice. Von Bezold contributed to scientific debates about colors by interpreting the relationships between warm and cold colors, and in 1874 he created the famous color circle that is still studied today, he also discovered a new visual effect called the Von Bezold effect in his honor. He came to the discovery of the visual effect by accident while he was engaged in his favorite hobby - designing carpets [14]. While arranging colors on his carpets, he accidentally noticed that changing just one color on the carpet strongly affects the overall perception of all other colors. The effect is most pronounced if the colored area is inside black or white frames. If the colored area is inside a black frame, it will be perceived as darker than its physical value, and if it is framed by a white line, it will be perceived as lighter. The effect observed by von Bezold is the effect of chromatic assimilation and is the opposite of the effect of simultaneous contrast. The effect is described in Bezold's book Die Farbenlehre im Hinblick auf Kunst und Kunstgewerbe [15], which was published in 1874, where you can find samples on which it manifests itself (Figure 2).


***Figure 2*** *The Von Bezold effect manifests itself in the patterns published in his book Die Farbenlehre im Hinblick auf Kunst und Kunstgewerbe [14]*

Figure 2 shows Bezold's colored patterns with red and blue ornaments bordered by white and black lines. The structure of the samples causes a very strong manifestation of the Von Bezold effect. In a white environment, tones of red and blue are perceived much brighter than tones of identical colors on samples that are in a black environment, which happens due to the manifestation of the Von Bezold effect. Very soon the Von Bezold effect attracted the attention of Munich painters. The German painter, sculptor and printmaker Franz Von Stuck (1863-1908) got acquainted with Bezold's research results on colors. One of Stuck's students was the American mathematician and painter of German origin Jozef Albers (1888-1920). This is how Albers became familiar with the Von Bezold effect and described it along with other visual effects in his famous work on art theory, The Interaction of Color [16], which was published in 1963. The aforementioned work is a manual for artists and designers that contains Albers' color theory and is one of the most influential books on art and design of the 20th century. Thus, the Von Bezold effect became part of the classic literature on art theory, which inspired numerous famous painters and designers for decades.

### 2.2. Measuring the intensity of visual effects

With the development of modern color science, methods were found to measure the intensity of psychophysical visual effects [17]. There are several verified visual assessment techniques in graphic communication [18-20]. Visual evaluation techniques are carried out through a psychophysical visual experiment that is conducted on subjects or observers. One of the assessment methods is simultaneous binocular matching [21,22]. As the name suggests, simultaneous binocular matching is a method of simultaneous or simultaneous comparison of test and reference stimuli. Test and reference stimuli are simultaneously placed in the examinee's field of vision. The subject evaluates the test stimulus by directly comparing the test stimulus with the reference stimulus. Visual experiments are performed on printed test samples or on a calibrated computer screen. In recent times, data is increasingly collected from the Internet [23-25]. The Internet enables the collection of a large amount of data in a short time, which also enables the application of machine learning as the most modern method of constructing mathematical models [26]. The results obtained by the visual experiment are statistically analyzed [27], where the arithmetic mean of the sample of colorimetric differences in lightness and color in the CIEDE 2000 [22] color system ($\Delta L_{00}$ and $\Delta E_{00}$) is most often taken as a measure of the intensity of the effect, and in some cases also the median sample.

## 3. Experimental part

This paper presents the results of a psychophysical visual experiment involving 30 subjects or observers who evaluated the intensity of the effect. The test samples were displayed on the computer screen. The psychophysical experiment was performed using the method of simultaneous binocular matching. For the experiment, original test samples were made in the form of a letter T dotted with thin lines. The design was realized with the graphic drawing tool Adobe Photoshop.

### 3.1. Design and tools for creating test samples

Two test samples were designed, each of which has two different sides, in which there are letter characters of the letter T through which horizontally placed thin stripes pass (Figure 3 and Figure 4). Each test sample is made of the left side marked with the letter A and the right side marked with the letter B. Both sides are square and their backgrounds are colored with different pairs of colors. In the left and right squares, there are nine letter characters (3x3) of the letter T. The letters T are filled with the same color on all the samples made, which is the cyan color of the Pantone P 133 – 12 C type (x3, Figure 3 and Figure 4. ) which has values $L^*=61$, $a^*=-15$, $b^*=-28$.

The first test sample (Figure 3.) has on the left side (which is marked with the letter A) a black base (mark 1A), and on the right side which is marked with the letter B, a magenta base (mark 1B). All letters T are colored with an identical shade of cyan (Pantone P 133 – 12 C). Thin horizontal lines colored in magenta pass through the letter T on the left side, while thin horizontal lines colored black pass through the letter T on the right. Specifically, the magenta shade of the thin horizontal stripes inside the letter T in sample A is identical to the magenta shade of the background in sample B. Conversely, the letters T in sample B are punctuated by thin lines of black color identical to the black color used on the background of sample A.

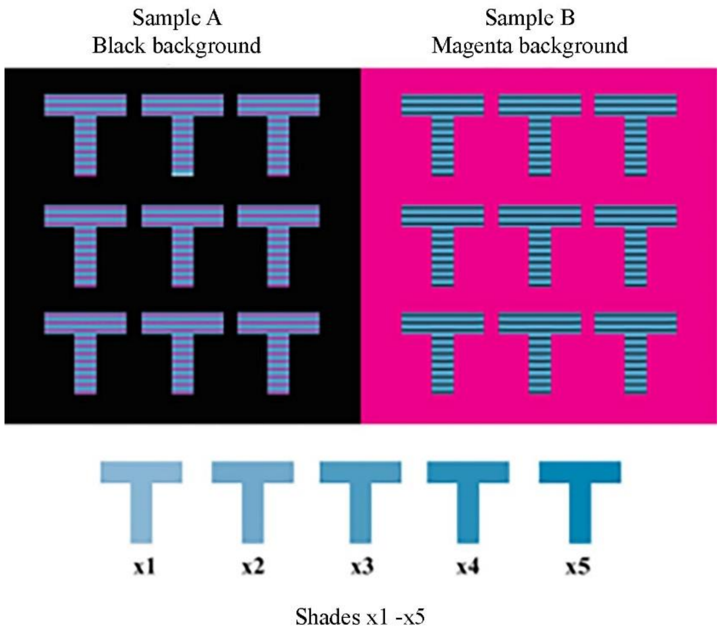


***Figure 3*** *Samples A and B in black-magenta combination*

In the second test sample (Figure 4), the left square is labeled A (label 2A) and its background is colored red, while the right square is labeled B (label 2B) and its background is colored yellow. The letters T in the left square (2A) intersect thin lines painted in yellow, which represents the background color of the right square, while the letters T in the right square (2B) intersect thin lines painted red, which is the background color of the left square.

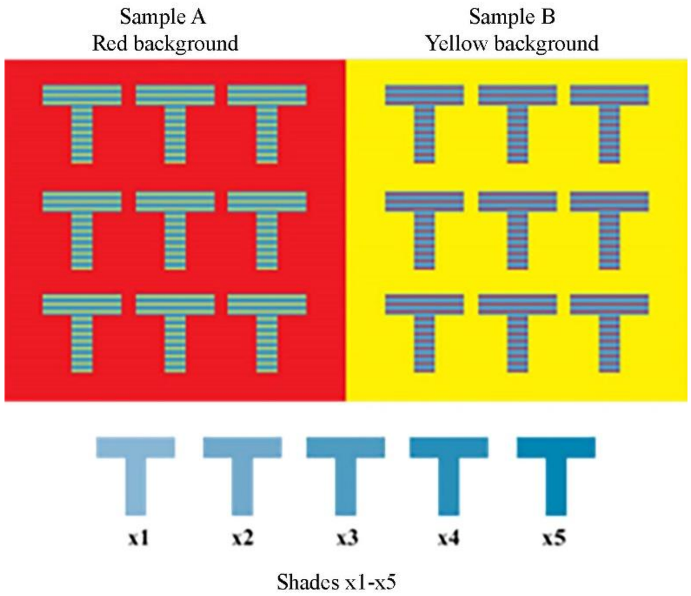


***Figure 4*** *Samples A and B in red-yellow combination*

In both samples, a reference color atlas of the shape of the letter T was made in five different shades of cyan whose L*a*b* values are presented in the following Table 1.

***Table 1.*** *L*a*b* value of the cyan color used in the reference color atlas*

| | ***Shades of cyan x1-x5*** | $L^*$ | $a^*$ | $b^*$ |
|---|---|---|---|---|
| ***X1*** | ***Panteone P 113-10C*** | *72* | *-10* | -21 |
| ***X2*** | ***Panteone P 113-11C*** | *67* | *-13* | -24 |
| ***X3*** | ***Panteone P 113-12C*** | *61* | *-15* | -28 |
| ***X4*** | ***Panteone P 113-13C*** | *55* | *-18* | -31 |
| ***X5*** | ***Panteone P 113-14C*** | *51* | *-20* | -34 |

The test samples were made in the computer tool for graphic design Adobe Photoshop. The colors that were used to display the colored areas within the test samples are cyan colors from the Pantone catalog and they are Pantone P 113 - 10 C (x1), Pantone P 113 - 11 C (x2), Pantone P 113 - 12 C (x3). Pantone P 113 – 13 C (x4), Pantone P 113 – 14 C (x5). For the background colors on the samples, the following were taken: black, yellow, red, and magenta.

### 3.2. A psychophysical visual experiment

The differences in the perception of the shades of cyan colors of the letter T on the left and right samples concerning the shades of cyan colors on the reference atlas were measured using a psychophysical visual experiment using the simultaneous binocular matching technique. The strength of the effect was measured using colorimetric differences in lightness $\Delta L_{2000}$ and color differences $\Delta E_{2000}$ in the CIE $\Delta E_{2000}$ system. In the experiment, 30 subjects of a younger age, of different sexes, who passed the Isihara color test, participated, so only those subjects who did not have vision problems took part in the experiment. The obtained results represent the intensity of the Von Bezold effect as experienced by the subjects. Specifically, the subjects were given two samples each with A and B parts (Figure 3 and Figure 4) on which the Von Bezold effect is manifested. The samples were displayed on a calibrated electronic computer screen. Respondents had the option of choosing 5 shades of color (x1,x2,x3,x4,x5) on the reference color atlas, of which only the color marked x3 is identical to the color used to color the letters in both samples (A and B). They had to choose the shade that they think is the most similar to the shade used to color the letter T. The conducted experiment aimed to answer the question of whether the subjects would choose the shade of cyan that is identical to its physical value. In other words, the experiment examined whether the perception of the cyan color of the letters T on the left and right sides of the sample differs from its physical value. In this way, the strength of the Von Bezold effect on letters was experimentally measured. Differences in color and differences in lightness between the colors on the reference color atlas and the color used to color the areas of the letter T (x3) calculated in the CIE $\Delta E_{2000}$ system are given in the following Table 2.

Table *2 Colorimetric differences between colors in the CIE $\Delta E_{2000}$ system*

| ***Colorimetric differences between colors*** | $\Delta L_{00}$ | $\Delta E_{00}$ |
|---|---|---|
| ***X1-X3*** | *11,00* | *9,68* |

| | | |
|---|---|---|
| ***X2-X3*** | *6,00* | *5,36* |
| ***X4-X3*** | *-6,00* | *5,68* |
| ***X5-X3*** | *-10,00* | *9,78* |

To assess the strength of the Von Bezold effect measured by color differences $\Delta E_{00}$, the classification given in the following Table 3 is used in the paper.

***Table 3.*** *Classification of colorimetric differences [28]*

| | |
|---|---|
| $\Delta E < 0,2$ | ***The difference is not visible*** |
| $0,2 < \Delta E < 1$ | ***The difference is noticeable*** |
| $1 < \Delta E < 3$ | ***The difference is visible*** |
| $3 < \Delta E < 6$ | ***The difference is clearly visible*** |
| $6 < \Delta E$ | ***An obvious deviation*** |

Therefore, the color differences between the colors of the letters on the reference atlas and the color with which the surfaces of the letter T are painted are clearly visible and clearly deviate (Table 2 and Table 3).

## 4. Results and discussion

### 4.1 Descriptive statistical analysis

A descriptive statistical analysis of the results of colorimetric differences was made, namely the difference in lightness $\Delta L_{00}$ and the difference in color $\Delta E_{00}$. The statistical package STATISTICA 12 (StatSoft, Tulsa, USA) was used. The analysis includes arithmetic mean, median, mode, mode frequency, minimum, maximum, variance and standard deviation calculations. Also, the data is presented graphically using Box & Whisker charts.

***Table 4*** *Results of descriptive statistics of differences in lightness $\Delta L_{00}$ samples*

| ***Variable*** | ***Descriptive statistics*** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***N*** | ***Arithmetic mean*** | ***Median*** | ***Mode*** | ***Fr.moda*** | ***Min*** | ***Max*** | ***Var*** | ***Std.Dev.*** |
| ***Sample A1 black background*** | *30* | *7,60* | *6,00* | *6,00* | *16* | *0,00* | *11,00* | *10,18* | *3,19* |
| ***Sample B1 magenta background*** | *30* | *-5,33* | *-6,00* | *-6,00* | *15* | *-10,00* | *0,00* | *13,33* | *3,65* |
| ***Sample A2 red background*** | *30* | *7,10* | *6,00* | *6,00* | *19* | *0,00* | *11,00* | *8,99* | *3,00* |
| ***Sample B2 yellow background*** | *30* | *-8,00* | *-8,00* | *multiple* | *15* | *-10,00* | *-6,00* | *4,14* | *2,03* |

***Legend:*** *The table contains the number of observations N, arithmetic mean, median, mode, mode frequency, minimum, maximum, variance and standard deviation*

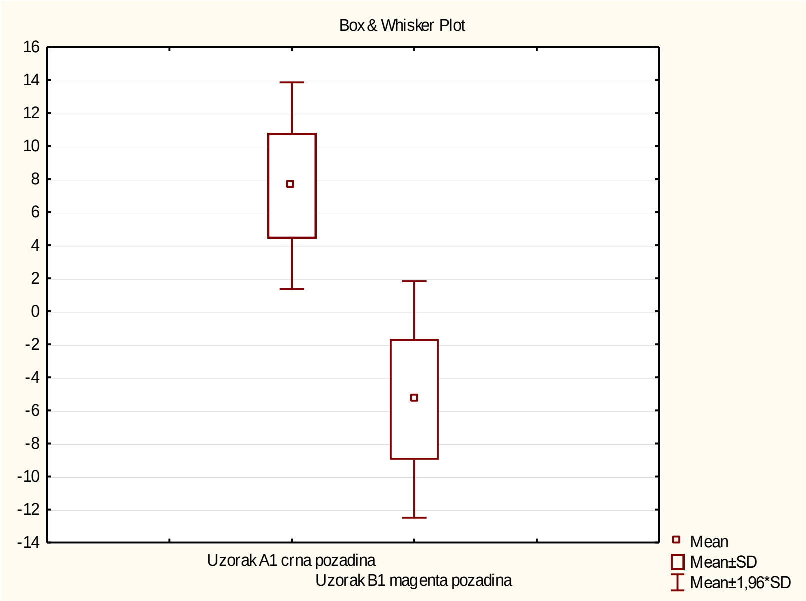


***Figure 5*** *Box and Whisker graphic representation of the Von Bezold manifestation of this effect on the first sample*

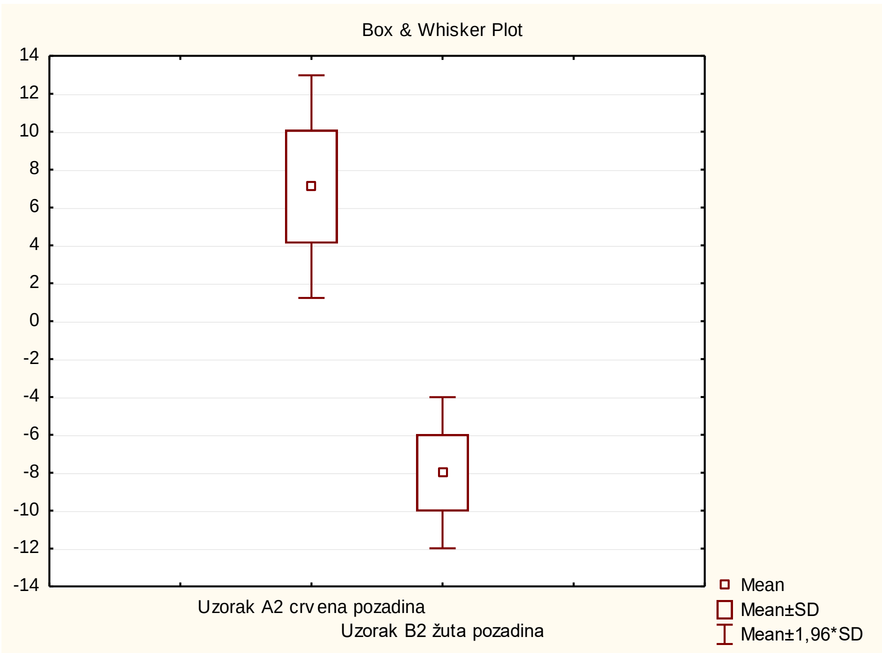


***Figure 6*** *Box & Whisker graphic representation of the manifestation of the Von Bezold effect on the second sample*

The difference in brightness on the first sample 1A with a black background and letters crossed by thin magenta lines is positive, which means that under the influence of the Von Bezold effect the stimulus is perceived as brighter than its physical value (Table 4 and Figure 5). The arithmetic mean of the effect strength is equal to $\mu_{1A}$=7.60 with the median value $med_{1A}$=6.00, which proves the extremely strong influence of the Von Bezold effect. In this sample, the mode is $Mode_{1A}$=6.00 with frequency $fr_{1A}$=16 out of 30 respondents. In the complementary design 1B with a magenta background on which the letters T are crossed by thin black lines, the stimuli are perceived as darker than their physical value. In this sample, the arithmetic mean of the brightness deviation is $\mu_{1B}$=-5.33 with a median $med_{1B}$=-6.00 and a mode of identical value $Mode_{1B}$=-6.00 with a frequency $fr_{1B}$=15.

The difference in brightness that occurs due to the Von Bezold effect in the second sample 2A with a red background and yellow lines crossing the letters T is slightly smaller than in the analogous sample 1A (Table 4 and Figure 6). The value of the difference in brightness is positive, which means that the shift in the appearance of brightness is in a positive direction. The arithmetic mean of the manifestation of the effect is $\mu_{2A}$=7.10 with the median amount $med_{1A}$=6.00. Mode 2A sample is $Mode_{2A}$=6.00 with frequency $fr_{2A}$=19. On the complementary 2B pattern with letters intersected by thin red lines on a yellow background, the effect is very strong with the arithmetic mean of the brightness deviation of the amount $\mu_{2B}$=-8.00 and the median $Med_{2B}$=-8.00. Since the brightness deviation is negative, the sample is perceived much darker than its physical value. In this sample, the mode is multiple.

The variances and standard deviations are of very high values, which is usual for such experiments in which the subjective experience of color plays an important role. For the same reasons, large ranges between minimum and maximum were determined (Table 4).

Differences in color $\Delta E_{00}$ as seen by observers concerning the physical color value were also determined, and the results of deviations are shown in the following table 5. Color deviations are caused by deviations in brightness, so the corresponding results are consistent with the deviation results in brightness (Table 4).

***Table 5*** *Results of descriptive statistics of color differences* $\Delta E_{00}$ *samples*

| Variable | Descriptive statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **N** | **Mean** | **Median** | **Mode** | **Fr.moda** | **Min** | **Max** | **Var** | **Std.Dev.** |
| **Sample A1 black background** | 30 | 6,48 | 5,39 | 5,39 | 16 | 0,00 | 9,01 | 6,20 | 2,49 |
| **Sample B1 magenta background** | 30 | 4,78 | 5,20 | 5,20 | 15 | 0,00 | 9,34 | 11,40 | 3,38 |
| **Sample A2 red background** | 30 | 6,12 | 5,39 | 5,39 | 19 | 0,00 | 9,01 | 5,53 | 2,35 |
| **Sample B2 yellow background** | 30 | 7,13 | 5,20 | 5,20 | 16 | 5,20 | 9,34 | 4,41 | 2,10 |

***Legend:*** *The table contains the number of observations N, arithmetic mean, median, mode, mode frequency, minimum, maximum, variance and standard deviation*

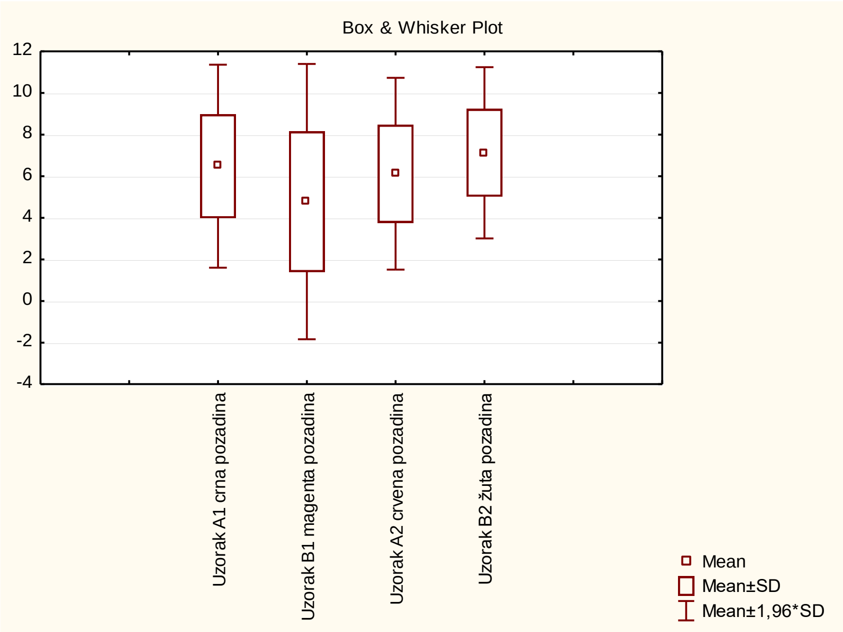


***Figure 7*** *Box & Whisker graph*

Color differences $\Delta E_{00}$ are a measure of the absolute value of the strength of the Von Bezold effect, regardless of whether it is a perception shift when the stimulus is perceived brighter than its physical value or a shift when it is perceived darker. All color differences are quite large, such that according to the accepted classification they are clearly visible and clearly diverge (Table 3, Table 5 and Figure 7). In three samples (1A, 1B, 2A) the ranges between minimum and maximum are between 0 and 9.5, while in the case of sample 2B the range is between 5.20 and 9.5 (Table 5). The variances and standard deviations are quite large, which is common for psychophysical visual effects (Table 5).

From the results of the experiment, it can be seen that the effect of the strongest power is on sample 2B with letters that are on a yellow background and are crossed by thin red lines (Table 5). As the Von Bezold effect is primarily a brightness effect, it is clearly seen from the results of the experiment that the color appearance shift is most strongly influenced by the brightness appearance shift factor (Table 4 and Table 5). In sample 2B, the arithmetic mean of the color shift is $\mu_{2B}$=7.13 with a median value of $Med_{2B}$=5.20 (Table 5). Mode has a frequency of $fr_{2B}$=16 respondents out of 30 and is $Mod_{2B}$=5.20, which coincides with the median value. On sample 1A with a black background and letters crossed by thin magenta lines, the arithmetic mean of the color difference is $\mu_{1A}$=6.48 with a median value of $Med_{1A}$=5.39 (Table 5). On the mentioned sample, the Von Bezold effect is somewhat weaker than on sample 2B and is in the opposite direction, i.e. the color of the letters is perceived as brighter than its physical value (Table 5). The mode is $Mod_{1A}$=5.39 with a frequency of $fr_{1A}$=16 respondents. On sample 2A with a red background, when the letters are crossed by thin yellow lines, the strength of the Von Bezold effect is in third place with the arithmetic mean of the color difference $\mu_{2A}$=6.12. In this sample, the shift in the appearance of brightness is in the direction of greater brightness. The median value is $Med_{2A}$=5.39, which is a higher value than the median of sample 2B, where the effect is strongest. The mode is $Mod_{2A}$=5.39 with a frequency of as many as 19 respondents $fr_{2A}$=19. The effect is weakest on sample 1B with arithmetic mean $\mu_{1B}$=4.78 and the brightness shift is negative, that is, the stimulus is perceived as darker than its physical value. Median and mode have identical values $Med_{1B}=Mod_{1B}=5.20$ with mode frequency $fr_{1B}=15$.

### 4.2. Friedmannova ANOVA

Below are the results of the non-parametric Friedmann ANOVA, which determined the existence of statistically significant differences in the manifestation of the Von Bezold effect on the observed samples. A non-parametric test was chosen because none of the samples conformed to the law of normal distribution, which was proven by the Kolmogorov-Smirnov test (Table 6). A significance level of α=0.05 was determined, which is common for psychophysical visual experiments.

***Table 6*** *Results of the Kolmogorov-Smirnov color difference test*

| Variable | Normality test | | |
|---|---|---|---|
| | N | max D | K-S p |
| Sample A1 black background | 30 | 0,269045 | p < 0,05 |
| Sample B1 magenta background | 30 | 0,282796 | p <0,05 |
| Sample A2 red background | 30 | 0,321425 | p < 0,01 |
| Sample B2 yellow background | 30 | 0,354466 | p < 0,01 |

***Legend:*** *The table contains the number of observations N, the test statistic Max D and the Kolmogorov-Smirnov empirical p*

According to the results of the Kolmogorov-Smirnov test, not a single sample conforms to the normal distribution (Table 6, $p<0.05$). Therefore, the non-parametric Friedmann ANOVA was chosen, the results of which are shown in the following table 7

***Tablica 7*** *Results of Friedmann's ANOVA of color differences*

| Variable | Friedman ANOVA: ANOVA Chi Sqr. (N = 30, df = 3) = 11,12 p =0 ,01110 |
|---|---|
| | Sum of ranks |
| Sample A1 black background | 83,00 |
| Sample B1 magenta background | 55,50 |
| Sample A2 red background | 80,00 |
| Sample B2 yellow background | 81,50 |

*Legend: The table contains the Friedmann chi-square values, the number of observations N, the number of degrees of freedom, the empirical p-value and the sum of the ranks.*

The results of Friedmann's ANOVA clearly show that there are statistically significant differences in the intensity of the Von Bezold effect on different samples (Table 7).

***Table 8.*** *Wilcoxon test results*

| Sample | | A1 bleck background | 1B magenta background | 2A red background |
|---|---|---|---|---|
| 1B magenta background | T | 136,00 | - | |
| | p | 0,078021 | - | |
| 2A red background | T | 66,00 | 131,00 | - |
| | p | 0,619154 | 0,061428 | - |
| 2B yellow background | T | 156,00 | 35,00 | 123,0000 |
| | p | 0,115609 | 0,005142 | 0,024308 |

***Legend:*** *Table contains test T statistic and empirical p-value*

Namely, the empirical p-value of the test is $p=0.01110<0.05$.(Table 7). Friedmann's chi-square is $\chi^2=11.12$ with df=3 degrees of freedom. Therefore, post-hoc tests were performed to find pairs for which there were statistically significant differences. Non-parametric Wilcoxon tests were chosen to identify those pairs for which there are statistically significant differences in the strength of the Von Bezold effect. The results of Wilcoxon tests are given in the following Table 8.
The results of Wilcoxon tests show that the intensity of the Von Bezold effect on test sample 2B is statistically significantly different from the intensity on samples 1B ($p=0.005142<0.05$) and 2A ($p=0.024308$) (Table 8). It is important to point out that 2A and 2B are complementary samples, and that on sample 2A the effect is in the direction of greater lightness, and that on its complementary sample 2B the effect is in the direction of less lightness, i.e. it is perceived as darker than its physical value (Table 4.) . Therefore, on sample 2B with a yellow background and red lines, the effect is stronger in absolute value than the effect manifested on sample 2A on a red background with yellow lines ($p=0.024308<0.05$). The effect occurring on sample 2B on a yellow background with red lines is stronger than the effect on sample 1B on a magenta background with black lines ($p=0.005142<0.05$). On samples 1A and 2B, the effect is strongest but in opposite directions (Table 4 and Table 5). No statistically significant differences were found in the intensity of the Von Bezold effect measured by the color difference on the previously mentioned samples 1A with a black background and magenta lines and 2B with a yellow background and red lines ($p=0.115609>0.05$).
Based on Wilcoxon tests, it can be concluded that the Von Bezold effect is strongest on samples 2B on a yellow background with red lines and 1A on a magenta background with black lines, but the effects are in the opposite direction. On sample 2A on a red background with yellow lines, the effect is somewhat weaker in the direction of greater lightness. The von Bezold effect is the weakest in sample 1B with a magenta background with black lines.

## 5. Conclusion

The von Bezold effect occurs very often in graphic communication, including typography. The paper presents the quantitative results of testing the Von Bezold effect on four different samples. It was determined that the effect is primarily an effect of a shift in lightness perception. On samples 1A and 1B with the letters T painted in cyan on a black background with magenta stripes and a magenta background with black stripes, a very strong effect occurs that works in opposite directions. The situation is similar with patterns 2A and 2B with the letters T on a red background with yellow stripes and a yellow background with red stripes. Namely, even for this pair of samples, the Von Bezold effect manifests itself in opposite directions. The absolute value of the manifestation of the effect was measured using colorimetric color differences. Statistical analysis that included descriptive statistics, Friedmann's ANOVA with post-hoc Wilcoxon tests determined that the effect was most strongly manifested on samples 2B with the letters T on a yellow background with red lines and 1A with the letters T on a magenta background with black lines, with arithmetic means $\mu_{2B}=7.13$ and $\mu_{1A}=6.48$. No statistically significant differences were found between the previous samples ($p=0.115609>0.05$). A slightly weaker effect was found on sample 2A on a red background with yellow lines with the arithmetic mean of the color difference of the amount $\mu_{2A}=6.12$. The effect is weakest on sample 1B with a magenta background with black lines with an arithmetic mean $\mu_{1B}=4.78$.

It can be concluded that the results on the Von Bezold effect presented in the paper can be extended so that the experimental method used in the paper is applied to a wider range of samples of letter characters, where different letters can be used. Letter characters can be painted in different colors and can be placed on different colored backgrounds. Letter characters should be crossed with thin stripes of different colors. In this way, the effect of simultaneous contrast and the Von Bezold effect would be obtained. To investigate the effects in detail, it is necessary to use different methods of statistical analysis, especially the ANOVA method of variance analysis, which is also shown in this paper, and it is possible to apply different regression models. Also, the widespread use of various artificial intelligence applications with mathematical algorithms such as machine learning is ubiquitous today. The authors propose the use of machine learning as an important segment of the application of artificial intelligence to various visual effects, which would enable the application of mathematical computer applications to visual effects problems. This would enable efficient and quick observation of visual effects that appear on different colored elements of graphic design.

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