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Graphical modeling of additive color mixing. Perception of objects with different color shades for different observers

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ABSTRACT

Aim: To research subjective perceptions in additive color mixing.

Materials and Methods: 79 individuals were surveyed, and they determined the colors they perceived in two photographs. The results of color mixing were determined using statistical analysis, graphical modeling, and Python program figures.

Results: A new color is obtained by additive mixing monochromatic colors. Interestingly, different individuals perceive observed images in different ways. Mixing neighboring colors on the spectrum and those in different produces various visual effects. Distinction was found in the physical mixing of beams with different colors. Visual perception in the presence of two is subjective and is determined by the viewer's greater to one of the colors. Due to additive color mixing, additional parts of objects may appear golden or orange when there is a yellow color in a picture with blue tones. When the background is violet, the sensitivity of the blue cones decreases.

Conclusions: An experiment involving the observation of color photographs established that individuals who perceive orange-violet snow do not perceive the blue color in the dress. The analysis revealed that yellow light activates the green and red cones. In contrast, blue light activates the blue cones in the retina, highlighting the importance of cone activation of color perception. The contrast between yellow and blue can create a visual effect where parts of objects appear more pronounced or have more intense color, demonstrating the brain's processing of contrasting colors. The experiment also indicated a reduction in blue cone sensitivity with a violet background, illustrating chromatic adaptation. Different individuals may perceive colors differently based on background and lighting conditions, underscoring the subjectivity of visual perception. Finally, there is a debate over the dress's color perception. These findings suggest that individuals working on media products can enhance image quality by considering additive color blending and background effects.

KEY WORDS: graphical modeling, colors, shades, additive mixing, optical effects

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INTRODUCTION

It is considered that human visual perception is the result of continuous evolution in animals. Color vision in animals is significant as it allows them to respond to visual signals in various situations. Animals use vision to find food and shelter, choose mates, and more [1,2]. The retina contains two morphologically distinct types of photoreceptors: rods and cones. Rods are responsible for vision in low light conditions, while cones function in higher light conditions. The highest concentration of cones is in the central area of the retina, where images of observed objects are formed, and it decreases significantly towards the periphery [3]. When light enters the eye, it stimulates the photoreceptors composed of photosensitive cells. Biochemical changes occur, leading to the generation of signals transmitted by various postsynaptic neurons in the retina. The information is then conveyed to bipolar and ganglion cells, whose axons form the optic nerve. The signal then travels through the optic nerve to the visual cortex, where visual perception is formed [3]. The visual spectrum ranges from 380 to 750 nm, with the following color ranges – violet (380–450 nm) (70 nm), blue (450–485 nm) (35 nm), cyan (485–500 nm) (15 nm), green (500–565 nm) (65 nm), yellow (565–590) (25 nm), orange (590–625 nm) (35 nm), and red (625–740 nm) (125 nm) [4]. Normal color perception is a function of the nervous system, resulting from the transmission of information to the visual cortex. The development and improvement of color vision are poorly understood but likely depend on the training of cone photoreceptor pathways. In humans, the ability to distinguish colors is mediated by specific mechanisms in the retina and the brain. The perception of all colors can be achieved through additive or subtractive mixing of the three primary colors [5].

Additive color mixing is an exciting phenomenon.

It involves creating a different color by mixing two or more visible light sources of different colors. This phenomenon is responsible for modern color television, where screen colors are generated by sources of the three primary colors – red, green, and blue. Multicolored images are produced from these colors. The additive combination of red and green produces yellow. Respectively, the combination of green and blue results in cyan, and the combination of red and blue results in magenta.

Subtractive colors are used in paints and color filters [6]. The color reflected from a painted surface or fabric depends on amounts of three subtractive primary colors: cyan, magenta, and yellow. Additive mixing can be achieved technically in various ways. For example, this is done on computer monitors and television screens by adding lights from three primary sources of different colors. The same result is achieved when light from different sources is projected onto a screen rapidly, with the mixing occurring due to the persistence of vision. In color printing, dots of different colors are printed closely on paper, making them indistinguishable individually, and due to the limited resolving power of the eye, a specific color is perceived. This approach is also applied to color television [7].

Designers in interior and exterior design increasingly use these and other possibilities, as well as the results of mixing subtractive and additive colors.

Controlled colored light sources are used, and the options for possible color effects are expanding. Color compositions combine subtractive and additive elements, which design solutions relying less on purely subtractive color on surfaces.

Using the same technology, there are already projects for programmable colored lighting with customer-controlled colors in commercial establishments, children's play areas, spa rooms, hotel rooms, etc. [2].

Determining colors in the complex also depends on an individual's reaction to the physical, physiological, and psychological aspects of color. However, color differences can be objectively measured using additive color systems under specific conditions: the observer, viewing angle, light source, and the observed field's extent. The International Commission on Illumination (CIE), established in 1931, regulates definitions and standards for measuring colors and color differences. The primaries it defines are not real but imaginary, used to determine all other colors. The quantities of each primary color in a given color are used to determine its hue and saturation using special coefficients and equations [6].

AIM

This study aims to research subjective perceptions of additive color mixing.

MATERIALS AND METHODS

COLOR PHOTOGRAPHS

The experiments were conducted using two color photographs. The first photograph (taken by one of the co-authors (Alexander I. Ignatov) depicts a winter sunset over Vitosha Mountain, Bulgaria. The second photograph displays a dress with two colors – blue and black (Fig. 1).

EXPERIMENTS

A survey was administered to 79 individuals of varying ages, who determined the colors they perceived in the two presented photographs. Graphical modeling is applied to determine the result of additive color mixing.

The statistical processing of the results was performed using the classic Student-Fisher t-test.

RESULTS

Table 1 presents the results from the experiments on additive color mixing. An interesting finding in these studies is that different observers perceive the colors of both photographs differently.

The first group comprised 45 people who observed the dress's blue-black colors. The second group is with 34 people who observe the dress with unreal colors. The number of the participants is 79. Statistical analysis of the data using Student's t-test revealed a strong positive linear correlation at $p<0.05$, with $r=-0.85$, indicating a significant relationship between the observers' surprise at the actual color of the dress.

ASSESSMENT OF SURPRISE BY GROUPS

The research was performed with 79 individuals, and from them, 27 women and 52 men.

Women (20) and men (18) see the real colors of the dress. Both groups show a relatively wide range of surprise ratings, with medians around 4-5. This suggests significant variation in how surprised participants in these groups are.

Men (7) who see the real colors in the dress. The ratings are more concentrated, with medians around 4-5.

Groups that see unreal colors of the dress (men and women (41). These groups present higher medians

Fig. 1. Photographs used in the study of additive color mixing: left - sunset over Vitosha Mountain, Bulgaria; right - a dress with two accurate colors – blue and black [9].

of surprise rating (around 8-10), suggesting that they were significantly more surprised by the unreal colors of the dress. These groups also show greater variation in ratings, possibly due to different color sensitivities.

Groups that see the dress's unreal colors have higher surprise ratings than those that see the real colors. Most groups have significant variation, possibly due to differences in individual color perception and interpretation. These results show that color perception is subjective and can vary significantly depending on individual differences and the context in which the colors are seen.

The experiment's results unequivocally demonstrate that visual perception in the presence of two colors is subjective and can be influenced by the observer's greater sensitivity to one of the colors [6].

When a yellow hue is present against a backdrop of blue, the yellow light activates the green and red light-sensitive cones in the retina, while the blue light activates the green and blue-sensitive cones. The contracting colors may create a visual effect where may create a visual effect where parts of objects appear enhanced. As a result, additional parts of objects may appear enhanced. As a result, additional parts of objects may appear to have a more intense or vibrant color due to the contrast between yellow and blue.

Experiments have shown that using a violet background can affect the perception of blue cones, a phenomenon explained in various studies. Consequently, individuals who perceive snow in orange-violet or pink-violet may not see the blue color in the dress.

This image sparked an internet debate over whether the dress is blue, black, white, or gold. However, the dress photograph was taken under specific conditions and is visible only on the screen, not in reality.

Therefore, the dispute over its actual colors cannot be conclusively resolved. Nevertheless, this is an example of the illusions that can be created through screens [8-11].

When an object's lighting changes in brightness or color, chromatic adaptation occurs, and the appearance of colored objects changes slightly as if the receptor mechanism's amplifications adapt to the surrounding light [3].

The phenomenon of simultaneous contrast, in which a surface changes its color depending on the background it is presented against, has been extensively studied.

When two colors are compared, they lose more or less of their shared color. For example, greenish-yellow appears more green on a yellow background and more yellow on a green background. The colors induced by the background are not precisely complementary, indicating the involvement of perceptional mechanisms beyond the receptors. Contrast situations are very complex, and the involved mechanisms are poorly understood. Unlike contrast, where the color and its surroundings are compared, this pertains to assimilation [3].

One type of cone is sensitive to short wavelengths near the blue end of the visible spectrum (S cones), while another type is sensitive to medium wavelengths, most responsive to green light (M cones).

Table 1. This results from observing snow at sunset and wearing a dress with multicolored stripes

Gender, Number	Snow at sunset	Dress	Assessment of surprise from the actual color of the dress
real colors of the dress			
women (20)	blue-red	blue-black	5, 6, 5, 4, 6, 5, 4, 3, 5, 4, 4, 3, 3, 5, 4, 3, 3, 4, 5, 5
men (18)	blue-red	blue-black	4, 6, 3, 7, 4, 3, 5, 4, 5, 5, 4, 4, 3, 3, 6, 4, 3, 5
men (7)	pink-red	blue-black	5, 4, 4, 4, 5, 3, 6
unreal colors of the dress			
men (8)	blue-orange	blue-gold	8, 7, 9, 9, 8, 5, 7, 8
men (5)	pink	blue-white	9, 9, 6, 9, 7
men (8)	orange-violet	yellow- white	10, 9, 10, 8, 7, 9, 9, 8
women (7)	orange-violet	golden-white	9, 9, 8, 10, 8, 10, 9
men (6)	orange	golden-white	10, 9, 9, 8, 8, 9

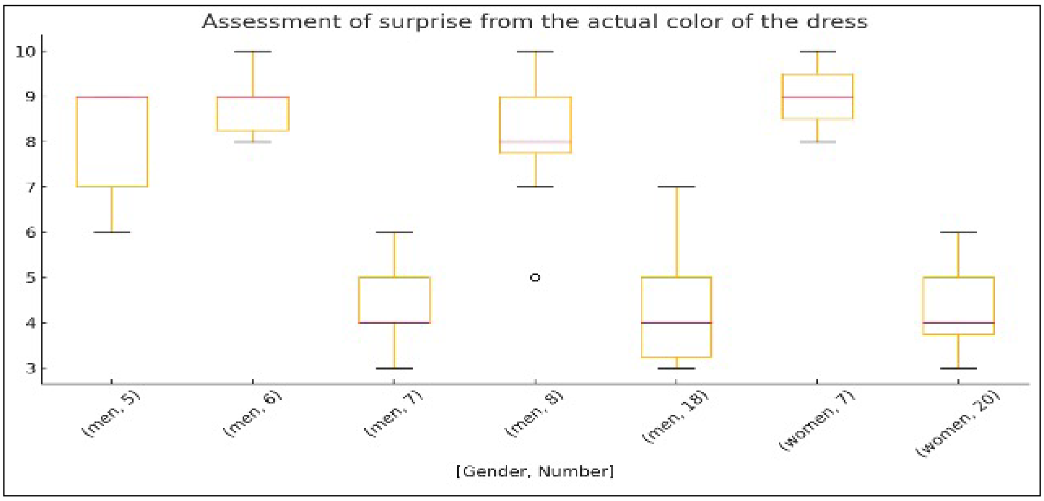

Fig. 2. Assessment of surprise from the actual color of a dress.

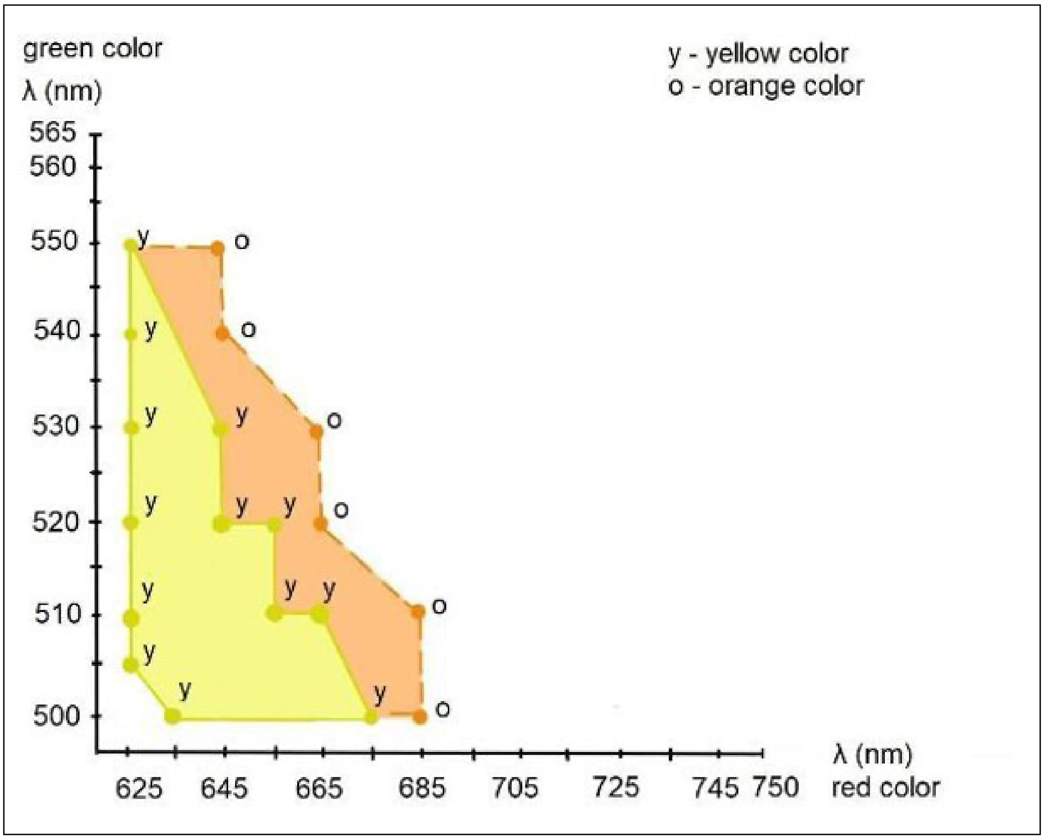

Fig. 3. Graphical modeling of additive mixing of green and red colors [13].

Humans are trichromats, as they have an additional type of cone, the L cone, which is sensitive to long wavelengths, falling in the red end of the visible spectrum [5]. The human retina has three types of cone cells – S, M, and L cells, each having different sensitivities to different parts of the visible spectrum. Since the sensitivity curves of cone cells overlap, monochromatic light cannot stimulate only one type of cone cell exclusively. The other types of cone cells react to a lesser degree.

Additive color mixing occurs when light of different wavelengths stimulates the cones, creating color axes between red-green, blue-red, and blue-green.

The additive mixing of red and green colors produces yellow and, under special conditions, orange. If the red light is significantly more intense than the green light, the brain may perceive the additive color as orange. The additive mixing of a red-green pair affects L and M cones.

The additive mixing of red and blue colors gives a magenta color, affecting the L and S cones. The results are perceived as mixed colors, a cyan color, affecting the M and S cones. The results are perceived as mixed colors within the visual spectrum range [8].

The vision analyzer forms images based on differences in light reflection from observed objects. The brightness of the background is differentiated from the central signal, emphasizing the object and achieving high sensitivity to light-dark contrast. Since the cone photoreceptors in the retina are sensitive to different wavelengths of light, there is a contract in reflected light and the separation of the color spectrum.

There are cases of blue cone monochromacy caused by deletion mutations, which result in the lack of expression of the normal protein encoded by the OPN1LW and OPN1MW genes. As a result, the red and green M cones lose their sensitivity. Color vision defects can result from genetic anomalies and eye diseases, such as glaucoma and cataracts. Defects in color vision are also connected with anomalies and impairments of the retina optic nerves and from some diseases like diabetes [5,12].

DISCUSSION

One of the co-authors, Ignat Ignatov, proposes a method for graphical modeling in which the physical blending of green and red colors can be visualized, resulting in combined colors that are yellow or orange [13]. This is illustrated in Fig. 3.

When the visual analyzer is exposed to green and red colors, the M and L cones in the retina are activated. The brain perceives the average color as yellow or orange, serving as an average solution [14].

The spectral sensitivity of green is higher than that of red, around λ=555 nm.

Let's consider two observers. One observes a monochromatic yellow color. The other perceives yellow as a result of additive mixing between red and green. Both observers cannot distinguish who sees a monochromatic yellow color and who perceives a mixture of red and green.

Blue-sensitive cones are maximally stimulated by blue and violet light, while green-sensitive cones are maximally stimulated by yellow and green light. The red and yellow range most stimulate red-sensitive cones. The photo pigments in cones absorb photons with different wavelengths. Various methods can be used to add primary colors to achieve color mixing. In each method, photons with different wavelengths enter the eye from the same part of the visual field. They integrate into photoreceptors located in the outer segments of the cone cells. Individual molecules of photo pigments [15] absorb photons with different wavelengths.

Adding primary colors to achieve additive color mixing can occur through four primary methods. Still, in each of them, photons with different wavelengths enter the eye from the same part of the visual field. Their integration occurs in the photoreceptors located in the outer segments of the cone cells. Like a given photoreceptor, individual molecules of photo pigments [15] absorb photons with different wavelengths. On the other hand, in subtractive color mixing, the spectral light distributions are modified outside the eye through absorbing dyes.

Color vision is vital in human interactions with the surrounding environment, including professional and household activities, driving, etc. The loss of functional color vision leads to difficulties and disruptions in these activities and worsens the quality of life, including job performance. Diseases affecting the cone-rich macula, such as age-related macular degeneration, can cause early color distinguishing loss. Ocular hypertension and glaucoma can impair the optic nerve function and, thus, cause color vision defects. Retinal tears and detachments, diabetic retinopathy, and disorders affecting the optic nerve can also lead to color vision loss. Many drugs, as well as environmental factors such as exposure to ultraviolet rays, chemicals, and more, hurt this aspect [5].

In subtractive color mixing, the spectral light distribution is modified outside the eye through absorbing dyes. Dyes or pigments are mixed, not light. For example, in some color photography processes, layers of non-dispersing, selective filters are used. Combining the subtractive primary colors magenta and yellow produces red. The transmittance function of the resulting red is simply the product of the wavelengths on the transmittance function of the input colors. Black is obtained from all three subtractive primary colors (cyan, magenta, and yellow) are used, as very little light can pass through such a combination. If the filters are replaced with dyes in an ideally non-dispersing solution, the transmittance functions of the primary colors can be quantitatively altered depending on their concentrations, and a wide range of colors can be obtained. Dichromatic filters, like those used in color television cameras, do not absorb but reflect the component of light that is not transmitted, so the two components complement each other in color. The result is similar to applying pigments to the surface. Predicting color matches, including pigment mixture in a scattering medium, is not easy [15].

The most commonly used method for diagnosing color vision defects is "pseudochromatic" plate tests. However, they often fail to distinguish between different types of dyschromatopsia. Tests requiring patients to sort different discs based on color progression are more sensitive in detecting anomalies in color vision. Additional tests for color matching, which can be conducted and evaluated by a computer, as well as electrophysiological, genetic tests, and examination of retinal morphology, are applied in diagnosing and characterizing color vision defects [5]. The conditions and experiments presented offer insights for professionals working in media products to improve image quality conditions based on additional color mixing and background.

CONCLUSIONS

An experiment involving the observation of color photographs established that individuals who perceive orange-violet snow do not perceive the blue color in the dress. The analysis revealed that yellow light activates the red and green cones. In contrast, blue light activates the blue cones in the retina, highlighting the importance of cone activation in color perception.

The contrast between blue and blue can create a visual effect where parts of objects appear more pronounced or have more intense color, demonstrating the brain's processing of contrasting colors. The experiment also indicated a reduction in blue cone sensitivity with a violet background, illustrating chromatic adaptation. Different individuals may perceive color differently based on background and lighting conditions, underscoring the subjectivity of visual perception. Finally, the debate over the dress's color emphasizes the role of specific lighting conditions in color perception. These findings suggest that individuals working on media products can enhance image quality by considering additive color blending and background effects.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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