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GRAPHICAL MODELING OF ADDITIVE COLOR MIXING. ANALYSES OF ELECTROMAGNETIC EFFECTS AS COLORS OF THE VISION ANALYZER

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Key words: *colors, shades, additive mixing, electromagnetic waves, vision analyzer*
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Abstract. Graphical modeling of additive color mixing. Analyses of electromagnetic effects as colors of the vision analyzer. Ignatov I., Popova T.P. *The human visual analyzer is a high form of evolution. Some jellyfish can distinguish light and dark objects with sensitive cells. Squids, octopuses, and nautiluses from Cephalopods family have eyes with which they can see objects. Visual information is processed in the brain. In fishes, the visual analyzer evolved. Fishes living below 100 m depth inhabit a world with blue light. The authors consider the evolution of vision in these fishes due to the lowest absorption of blue and violet colors of electromagnetic waves from the optical spectrum. Subsequently, on land, in humans vision evolved towards the green color. Green is the most prevalent color on the land. In humans, three light-sensitive cones evolved – S, M, and L. S cones are most sensitive to blue, M – to green, and L – to red color in the spectrum. Some humans retain sensitivity of S to genetic changes and disorders. Additive color mixing is a high form of color perception in humans. The additive mixing of different colors achieves a new color in the human visual analyzer. Remarkably, different individuals perceive observed images in varying manners. Mixing neighboring colors on the spectrum gives one, two, or three colors. This process is estimated using graphical modeling. The graphical modeling with two colors allows for the creation of additive colors. One, two, or three additive colors can be obtained. The production of colors results from the light sensitivity of S, M, and L cones. An analysis that physically demonstrates the mixing of green and red colors, resulting in the colors yellow or orange. When blue and red are mixed, the resulting colors are green, yellow, and orange is proposed. The additive mixing of blue and yellow gives green. The subjective nature of visual perception, influenced by the viewer's heightened sensitivity to one of the colors, becomes evident in the presence of two colors. Notably, when the background is violet, the sensitivity of the blue cones diminishes.*

Реферат. Графічне моделювання адитивного змішування кольорів. Аналіз електромагнітних ефектів за кольорами аналізатора зору. Ігнатов І., Попова Т.П. *Зоровий аналізатор людини є найвищою формою еволюції. За допомогою чутливих клітин деякі медузи можуть розрізняти світлі й темні предмети. У кальмарів, восьминогів і головоногих наутилусів з'явились очі, за допомогою яких вони можуть бачити предмети, і візуальна інформація обробляється в мозку. У риб сформувався зоровий аналізатор. Риби, що живуть на глибині нижче 100 м, населяють світ із синім світлом. Автори описують еволюцію зору в цих риб за рахунок найменшого поглинання електромагнітних хвиль синього і фіолетового кольорів з оптичного спектра. Згодом на суші зір еволюціонував до зеленого кольору в людей. Зелений — найпоширеніший колір на Землі. У людини сформувались три світлочутливі колбочки – S, M і L. S-колбочки найбільш чутливі до синього, M – до зеленого, а L – до червоного кольорів спектра. Деякі люди мають чутливість S до генетичних змін і розладів. Адитивне змішування кольорів є високою формою сприйняття кольорів у людей. Додаткове змішування різних кольорів створює новий колір у зоровому аналізаторі людини. Важливо, що різні люди сприймають спостережувані зображення по-різному. Змішування сусідніх кольорів у спектрі дає один, два або три кольори. Цей процес оцінюється за допомогою графічного моделювання. Графічне моделювання* *двома кольорами дозволяє створювати додаткові кольори. Можна отримати один, два або три додаткові кольори. Створення кольорів є результатом світлочутливості колбочок S, M і L. Пропонується аналіз, який фізично демонструє змішування зеленого та червоного кольорів, що призводить до отримання жовтого або оранжевого кольорів. При змішуванні синього й червоного утворюються зелений, жовтий і оранжевий кольори. Адитивне змішування синього і жовтого дає зелений. Суб'єктивний характер зорового сприйняття, зумовлений підвищеною чутливістю людини до одного з кольорів, проявляється в наявності двох кольорів. Важливо, що коли фон фіолетовий, чутливість синіх колбочок знижується.*

Human visual perception has been evolving continuously in animals to facilitate orientation in the environment [1, 2]. The retina registers light information as light quanta. Subsequently, the signals from the retina are transmitted to the optical nerves and visual center. The retina comprises two morphologically distinct types of photoreceptors: cones and rods.

Cones are responsible for the vision in higher light conditions. The rods function in low light conditions.

Physically, the retina analyzes electromagnetic waves, and through biochemical processes, the brain interprets them as colors [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 nm) (25 nm), orange (590-625 nm) (35 nm), and red (625-740 nm) (125 nm) [4]. The photoreceptor cones and rods are composed of photosensitive cells. In the retina, there are S, M, and L cells. One type is sensitive to short wavelengths near the blue end of the visible spectrum (S cones), while the other is sensitive to medium wavelengths, most responsive to green light (M cones).

All colors can be perceived through additive or subtractive mixing of the three primary colors – red, green, and blue [5].

Any three colors from the spectrum can serve as primaries, provided they are independent. Mixing any two will not produce the third primary color. Combining two additive primary colors forms a subtractive primary color, achieved by removing light from different parts of the visible spectrum. Subtractive colors find applications in paints and color filters [6]. The result of mixing depends on the observer and the quantity of the three primary color lights produced by the standard source. The color reflected from a painted surface or fabric relies on the amounts of the three subtractive primary colors.

Additive mixing can be achieved through various technical methods [7]. For instance, in computer monitors, television screens, and more, this is accomplished by adding light of different colors from three primary sources. The same result is attained on a screen, with the mixing occurring due to the persistence of vision.

In color printing, dots of different colors are closely printed on paper, making them indistinguishable individually. Due to the limited resolving power of the eye, a specific color is perceived. This approach is also employed in color television [7].

One of the goals of the study is to demonstrate that evolutionary the visual analyzer is most sensitive to wavelength with smallest absorption coefficient. There are the waves in the optic spectrum of electromagnetic waves. Additive color mixing is shown with three types of cones – S, M and L.

The aim of the study is to demonstarate with graphical modeling which color is obtained in additive color mixing.

MATERIALS AND METHODS OF RESEARCH

Figures for the sensitivity of S, M, and L cones

On the X-axis is the wavelength in nanometers (nm). On the Y-axis with reliable values is the spectral susceptibility of each color (Fig. 1) [8].

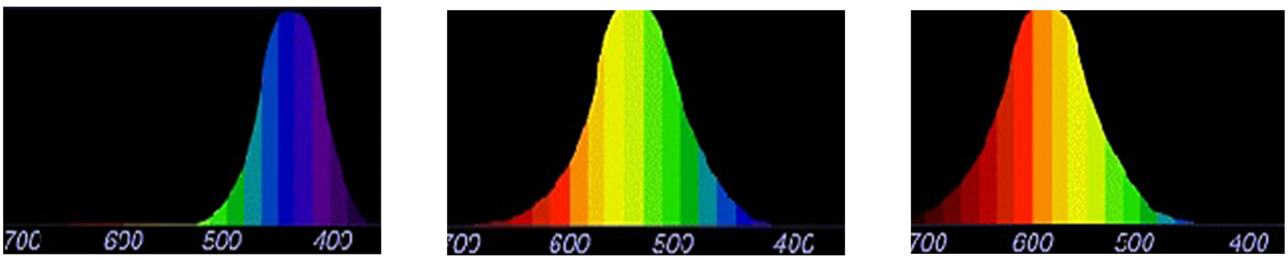

Fig. 1. Colors of sensitive cones in the retina – S, M, and L cone cells

Graphical modeling

With the method of graphical modeling, it is performed average result from X and Y-axis in nm. The average result illustrates in nm the average color for additive color mixing.

There is no ethical issue because the investigations are not connected with participation of patients and personal data of people.

RESULTS AND DISCUSSION

The light for fish over 100 m is dim and blue [9, 10]. The author's conception is that the absorption of electromagnetic waves has the smallest absorption coefficient for violet and blue colors [11]. The properties of water determine the vision of marine inhabitants. On land, the visual analyzer has evolved. In humans, the highest sensitivity is toward the green color.

The experiments' results unequivocally demonstrate that visual perception in the presence of two colors is subjective and can be influenced by the observer's heightened sensitivity to one of the colors [12, 13].

The image of the dress is debated over whether the dress is blue, black, white, or gold. However, the photograph of the dress was taken under specific lighting conditions and is only visible on a 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 [14].

The analyses were made with dress [14, 15]. When a yellow hue is present against a blue backdrop, the orange and red hues in the green and red light-sensitive cones in the retina are activated, resulting in an additive mixing of yellow with blue. Consequently, additional parts of objects exhibit a golden or orange appearance in the case of the dress.

Furthermore, experiments also showed that using a violet background significantly reduces the sensitivity of the blue cones, a phenomenon is explained [13, 14, 15].

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 mechanisms' amplification adapts 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. By comparing two colors, they lose more or less of the color they share; 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 perceptual mechanisms beyond the receptors. Contrast situations are very complex, and the involved mechanisms are poorly understood. Unlike contrast, where the color of a surface tends to take on the color of its surroundings, this pertains to assimilation [3].

Humans are trichromats, and they have L cones [5]. The human retina has three types of cone cells – S, M, and L cells. They have different sensitivities to the different electromagnetic waves from the visible spectrum (Fig. 2). The monochromatic light can not activate only one type of cone cell. The reaction of the others is to a lesser degree.

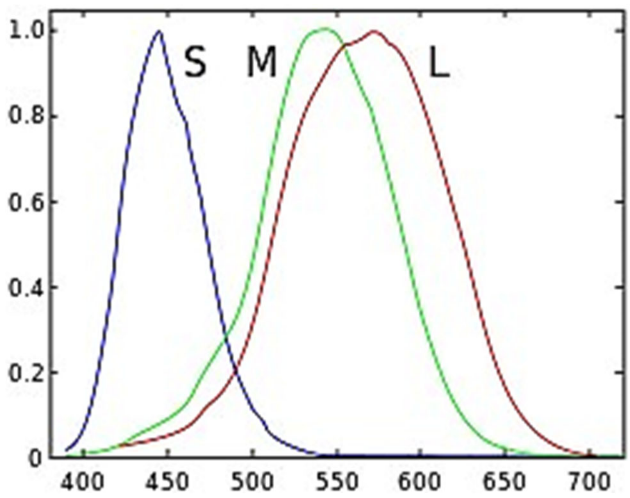

Fig. 2. Spectral sensitivity of the different types of receptor cells (cones) in the retina

When stimulating the cones with light of different wavelengths, color axes are created between red-green and blue-yellow. This results in perceived mixed colors within the visual spectrum range [14]. The blue-yellow color distinguishes blue from green and yellow from red. The eye 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 contrast in refracted light and a separation of the color spectrum.

There are cases of monochromacy of the blue cone caused by the lack of expression of normal proteins encoded by the OPN1LW and OPN1MW genes due to deletion mutations. As a result, the red and green cones lose their sensitivity. Color vision defects can result not only from genetic anomalies but also from various eye diseases such as glaucoma and cataract, anomalies and impairments of the retina, optic nerve, visual tract, and visual cortex, as well as from some systemic conditions like diabetes. Understanding the physiology of color vision is paramount in detecting anomalies and developing treatment [5, 16].

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. This is illustrated in Figure 3.

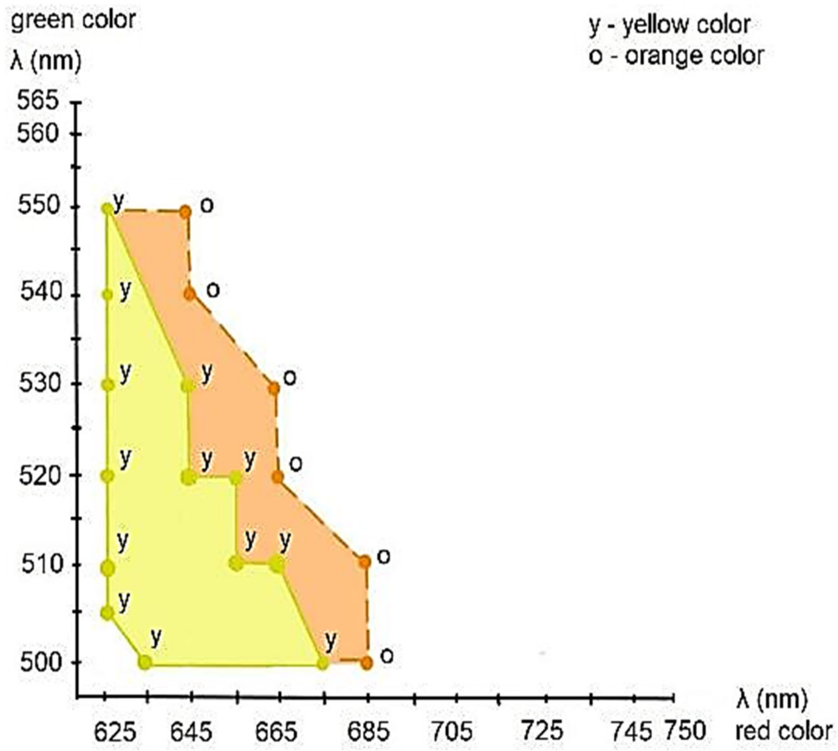

Fig. 3. Graphical modeling of additive mixing of green and red color

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 [15, 17].

Yellow is obtained when green and red colors are additively mixed with closely located wavelengths. As the wavelength increases, the additive mixing transitions into an orange color. Clearer yellow and weaker orange colors are observed in more activated M cones, and clearer orange and weaker yellow colors are observed in more activated L cones.

When the visual analyzer is exposed to blue and red color, the M cones in the retina are activated. The brain perceives the average color as yellow or orange, serving as an average solution [15, 17].

A green color is obtained when blue and red colors are additively mixed with closely located wavelengths. As the wavelength increases, the additive mixing transitions into a yellow color. As the wavelength increases, the additive mixing transitions into an orange color. Clearer yellow and weaker green and orange colors are observed in more activated M cones. Clearer orange and weaker yellow and green colors are celebrated in more activated L cones.

The physical blending of blue and yellow colors can be visualized, resulting in a combined green color. This is illustrated in Figure 4.

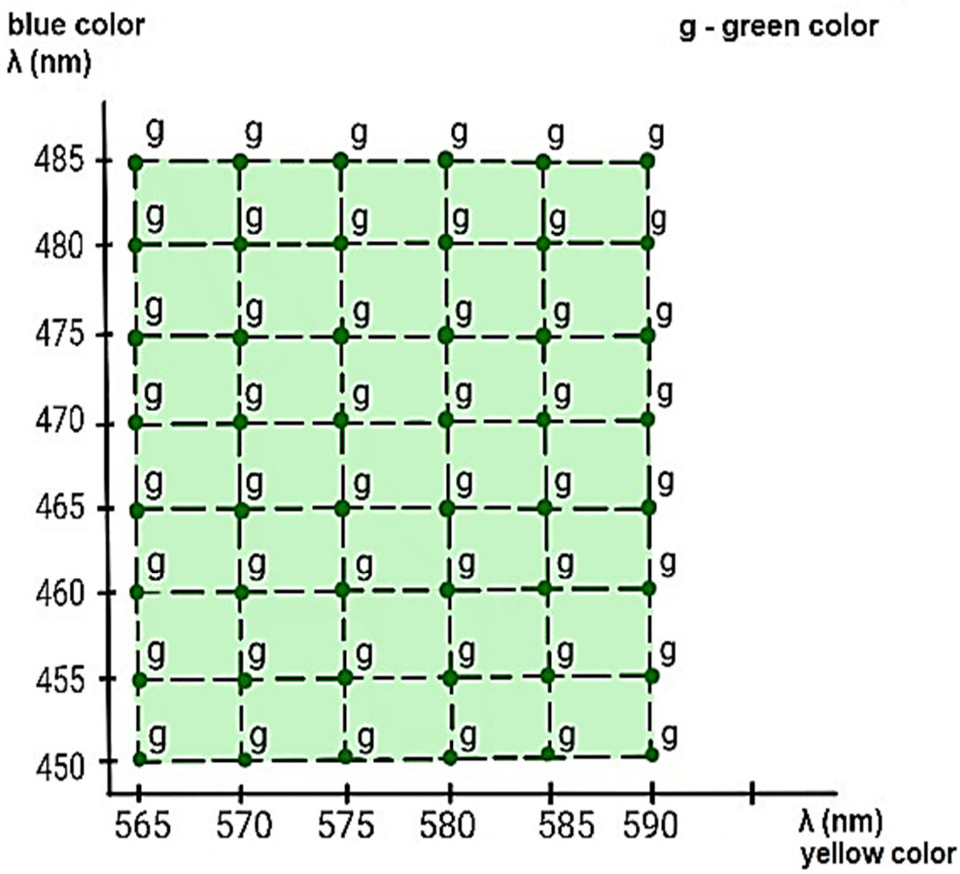

Fig. 4. Graphical modeling of subtractive mixing of blue and yellow color

When the visual analyzer is exposed to blue and yellow pigments, green light activates the M cones in the retina.

The green light result is from subtractive mixing. The brain perceives the color as green due to the reflection of green wavelengths. Green is obtained when blue and yellow pigments are mixed because they absorb other wavelengths and reflect green.

Green is more apparent when the M cones are more activated.

The blending of monochromatic radiations is illustrated in Figure 4.

Figure 5 illustrates that the spectral sensitivity for the green color is higher than that for red. The peak sensitivity occurs at λ=555 nm.

Monochromatic color possesses several characteristics: hue, saturation or chroma, lightness or brightness. The hues form the color wheel, where four elementary hues hold a special status and oppose each other in pairs: red and green, blue and yellow [3].

Blue-sensitive cones are maximally stimulated by blue and violet light. Green-sensitive cones are maximally stimulated by yellow and green light. The red and yellow range most stimulate red-sensitive cones. 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 [18] 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. Dyes or pigments are mixed, not lit. For example, in some color photography processes, layers of non-dispersing, selectively absorbing filters are used. Combining the subtractive primary colors, yellow and blue produces green. The transmittance function for the resulting green is simply the product of the wavelengths on the transmittance functions of the input colors. Studied have been conducted on macaques. The results show there are no synaptic contacts between S, M and L cones [19]. Such signal transfers exist in humans.

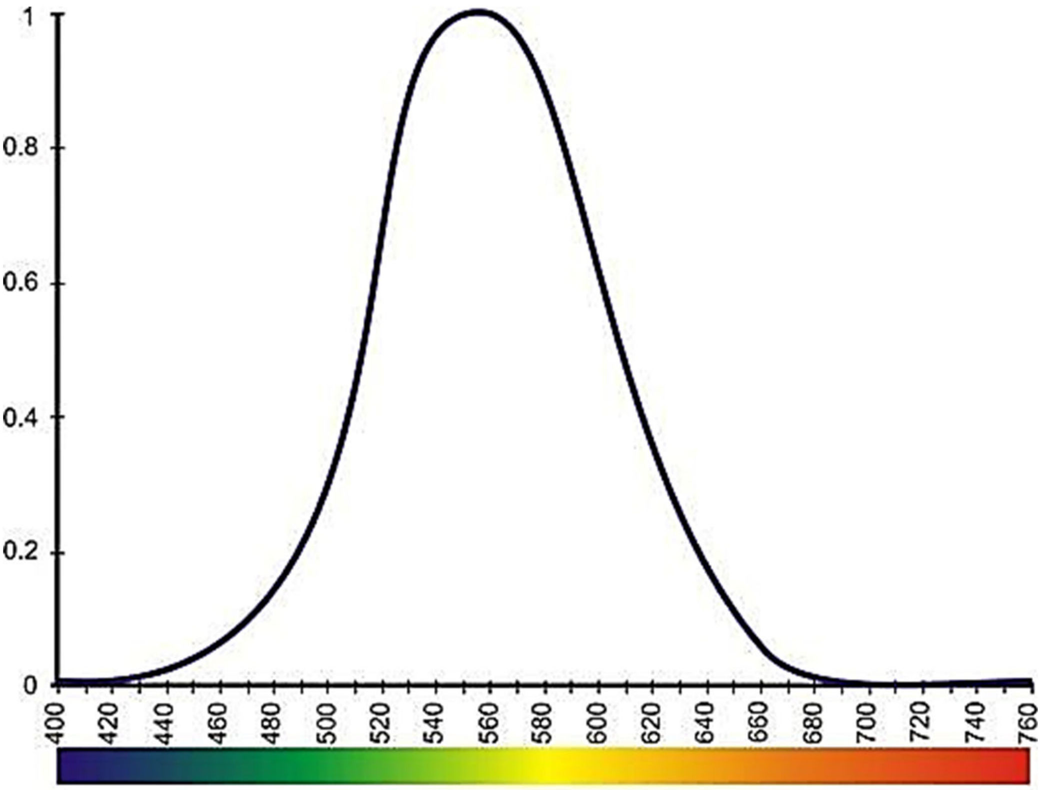

Fig. 5. Spectral sensitivity of the visual analyzer

CONCLUSIONS

1. Analysis with graphical modeling of color mixing has been conducted. The pairs red-green, red-blue, and yellow-blue have been analyzed. The main conclusion is that, with increasing differences in wavelength, the dependences of additive colors are observed:

- when the yellow color starts at λ=565 nm and the blue at λ=450 nm, the subtractive color is one, and it is green. The difference between initial values is 115 nm.
- when the red color starts at λ=625 nm, and green at 500 nm, the additive colors are two, and they are yellow and orange. The difference between the initial values is 125 nm.
- when the red color starts at λ=625 nm, and the blue at λ=450 nm, the additive colors are three, and they are green, yellow, and orange. The difference between the initial values is 175 nm.

2. The observed results are for M and L cones. For S cones, mixing blue and green colors is one of the results of cyan. The cyan color has a smaller spectral range of 15 nm.
3. The presented analysis shows that the choice of the background can be crucial for color perception in additive color mixing. When and blue colors are mixed, the presence of a green background will hinder observation when red and green colors are mixed.
4. The most challenging situation is when red and blue colors are mixed. A green, yellow, and blue background may also present difficulties.
5. The change in brightness affects color perception in additive color mixing. The blue color is best seen in low light conditions because the S cones have the highest sensitivity to the blue color.

Contributors:

Ignatov I. – physical analyses, graphical modeling, and references;

Popova T. P. – analyses with animal vision, original draft, and format analyses.

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