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Study of The Peculiarities of Color Vision in The Course of "Biophysics" in A Pedagogical University

Elena Borisovna Petrova[a], and Fairuza Musovna Sabirova[b]

[a]Moscow State Pedagogical University, Moscow, RUSSIA;
[b]Kazan (Volga region) Federal University, Elabuga institute, Elabuga, TATARSTAN

ABSTRACT

The article substantiates the necessity of studying the peculiarities of color vision of human in the course "Biophysics" that have been integrated into many types of higher education institutions. It describes the experience of teaching this discipline in a pedagogical higher education institution. The article presents a brief review of the most compelling existing color vision hypotheses, according to the authors mind: G. Allen, P. Lucas and N. Domini, which are mainly associated with the appearance of color perception with dietary habits of human ancestors, and a fundamentally different assumptions of M. Changizi, whereby the color perception was necessary for a human for a good communication with their own kind for the evaluation of skin tones. In this article is observed the system of the educational experiment research of the functioning of the color perception system of the human eye, as a natural addition to the proposed hypotheses. An experimental study model of a fragment of the retina is proposed, and a laboratory work on the study of a system of a colour human perception, the study of a photobiological paradox of vision by the example of a study model of the opaque lens (cataract). The subject results of its use in a pedagogical university are debated. All this allows us to focus on a caring attitude for human biotic sensory systems in aggressive abiotic influences. It is especially important in teachers training, aimed at training and raising a healthy younger generation. The authors also consider it necessary to acquaint future teachers with the authors of the various theories of color vision and the curricula vitae of the authors of the various discoveries, because this allows enhancing an interest in the study course.

KEYWORDS
Teaching, biophysics, human vision, color vision, educational experiment, photobiological paradox, biographical information

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CORRESPONDENCE Elena Borisovna Petrova 1960_15@list.ru

Introduction

Currently, the course "Biophysics" is read in some classical universities and pedagogical universities, in educational institutions, where there is no training in the medical specialty or professionals directly in the field of Biophysics. In many universities while preparing of bachelors in a course of "Biology" or "Pedagogical education" (profile "Biology") it is taught as the discipline of choice. Overall, this course is more of a secondary character; he is designed to get acquainted with the basic terms and problems of the scientific field "Biophysics". So it is natural that there are no strict requirements to its content, and each teacher has the right to adjust the course content at its discretion. Basically, it depends upon the basic training he received: the biological, physical or physical and mathematical.

The authors of the article discussed one of the issues which should be given a serious attention on the Biophysics course - the color human vision. This question, as showed the experience of teaching, is interesting and important for students for several reasons.

1. In general, the visual system is the source of more than 80% of the information received by the person. This information is necessary for a full quality of life, for the intellectual development, for getting positive emotions from the contemplation of nature, art and etc (Tkachenko 2005).

2. In the course of physics and biology are usually reviewed in detail the optical system of the eye, as a complex of lenses, the optical power of this system is evaluated, the ways of its correction necessary for myopia, hyperopia or astigmatism are learned (Values 1963; Landsberg 2003).

But there is also a system of color perception, and practically it has not been given any sufficient attention for its studying, mainly in the specialized literature (e.g. Padham and Saunders 1978), though it is quite accessible even with minimal funds and has attracted the interest of the learners.

3. The idea of the transformations of the visual pigment in the color perception, the understanding of related processes are not only important from the point of view of education, but also for the health of the person. In particular, this is due to the trend of replacing household light sources (filament lamps) for energy saving, due to the active use of the on-screen tools: computers, tablets, modern phones. By the way, once there was a change of light sources in the history of mankind, for example, from the direct exposure of sunlight or flames to the filament (glower). All this lead to the changes in the human visual system. The importance of the discussed issue is highlighted in the writings of specialists in the field of ophthalmology (Vladimirov and Potapenko 2006; Rubin 2013), where it is shown how much a person dismissive of his vision undergoing a very strong hostile external influence due to the development of on-screen tools.

4. The photobiological paradox of vision that was described in the literature is of a great interest (Zack at al. 2005; Ostrovsky, Sakina, Dontsov 1987), which can also be simulated in a laboratory (Petrova 2015). The paradox of vision is that light, as a carrier of visual information, at the same time acts as a risk factor. That is why during the evolution of the visual organs has formed a fairly reliable system of protection against the risk of a light damage (Ostrovsky, Sakina, Dontsov 1987; Ostrovsky *et al.* 2002). This system includes not only the constantly updating light-sensitive outer segments of the visual cells but also - the optic

media of the eye, which are a kind of light filters, and a key role in this system plays the lens.

5. The problem of perception of color is associated with some other important issues dealt with in natural science: the photoelectric effect and the photosynthesis. Quite often teachers don't pay much attention for the generality of these phenomena – the processes of photosynthesis and the photoelectric effect are triggered by the light quanta. Discipline "Biophysics", as well as any other scientific subject, is primarily aimed at a forming of a complete picture of the world.

6. Academic discipline "Biophysics" as a rule, rarely accompanied by demonstration experiments (there are not much experiments specially created for her).

The article describes the experiments and the devices that can be used to solve several educational tasks: the development and the study of the real physical models. Functionally they can be used both for demonstration purposes and laboratory works.

The authors believe that one of the tools of the studied discipline that is able motivating future teachers is the study of biographical information about scientists who are the authors of certain hypotheses or theories of color vision (Sabirov 2015; Sabirova 2013).

The Color Perception of the Human Eye

Integrating Let's discuss the features of the perception of the human eye color, because surprisingly, not all of the inhabitants of the planet can distinguish colors, possessing only the ability to distinguish between light and dark. Their vision is based on the light-sensitive cells. Many mammals do not distinguish red from green. This can be explained by the fact that their ancestors were nocturnal, and the color production had no special value for them. One of the significant differences between primates (including humans) from the other mammals is the existence of a color vision among them, which is the subject to the availability of pigments in cones. Only primates have three types of pigments, the other mammals have only two (e.g., dogs) – longwave and shortwave.

The question arises, what`s the need in three pigments for a color vision of a person? Scientists are looking for the answer of this question for about a hundred years. As a result, there were several hypotheses trying to explain the need for a color vision, especially in three colors.

The very first was proposed in the XIX century by an English philosopher Grant Allen (Vorobyev 2004).

She was quite convincing and told us the following: about 40 million years ago, there was a need for assessing the ripeness of tropical fruits, which were needed for the expansion of the diet. This led to the emergence of the green pigment of the cones, located between the existing long-wavelength red and short-wave blue.

More recently, scientists from Hong Kong University Peter Lucas and Nathaniel Dominy put forward the another hypothesis (see, for example, Nikonov; Wakakuwa *at al.* 2010; Melin *at al.* 2013). Observing the behaviour of chimpanzees in the African forests, they noticed that chimps were usually collected gentle and nutritious young leaves in food, which usually have a reddish tint. They suggested that perhaps because of the menu primates became to distinguish red colour from green.

The most interesting and well founded, in our opinion, is the last, the third hypothesis by Mark Changizi (Changizi 2009). He suggested that color vision is necessary for a human for carrying out a full communication with each other, which can happen without any words, by the assessing of skin tones. The skin tones are the main sources of information about the health of a person and his emotions, as he often blushes or turns pale in addition to his desire. Life in society causes people to be attentive to the physical and emotional state of each other, it is important in selecting the type of communication. The researcher believes that the human skin comes in many shades, which is determined by the changes associated with blood supply (Changizi and Rio 2009). Figure 1 shows curves which illustrate this. On the chart you will notice the coincidence of green and red maxima with the maximum and minimum of its W-shaped plot.

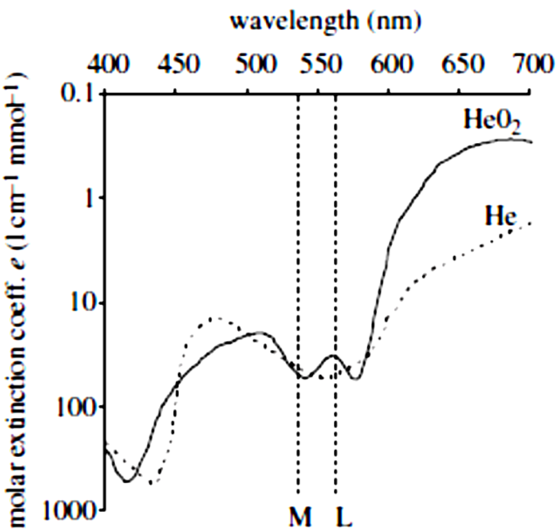

Figure 1. The dependence of the reflection coefficient of the skin of wavelength (reproduced from Changizi, Zhang and Shimojo 2006).

As the another proof of his hypothesis, M. Changizi considers the presence of a number of animals plots uncovered or covered with feathers and hair, in other words, the lack of the exposed skin, which could change the colors. In these animals, insects and birds' sensitive cells respond to wavelengths that are distributed in the visible range more or less uniformly (for example, for birds is 370 nm, 445 nm, 506 nm, 565 nm). For example, four types of pigmentation the cones of birds are expanding their range of color vision to the field of ultraviolet (370 nm) (Hart *at al.* 2000). For comparison, in humans there are three types of pigmentation of cones corresponding to 420 nm, 534 nm and 564 nm (figure 1, the last two types of pigment marked, respectively, M and L).

Photobiological paradox of vision

Teaching During the study of a colour perceptive system of a human eye in a course of Biophysics a consideration of photobiological paradox of vision is of a great interest for the future teachers. The photobiological paradox of vision (this term was proposed by academician M. A. Ostrovsky) is closely connected with two wondering factors: the light is both a source of visual information, and a factor leading to the destructive processes in the organs of vision.

The combination of light and oxygen is a necessary condition for normal photoreceptor process, but at the same time it is a necessary and a sufficient condition for the development of destructive photochemical reactions in the eye structures. A detailed description of the processes and photochemical reactions is not the subject of this article, so we do not reproduce them.

The photochemical damage of vision organs occurs under the influence of the very large doses of ultraviolet radiation that cause turbidity in particular of the lens (cataract occurs). The cornea and the lens are exposed to excessive exposure for the first in this case. They are a kind of filters that are able to delay the most dangerous part of the spectrum for the internal structures of the eye. It is known that among elder people when the eye is most vulnerable to the effects of ultraviolet radiation, the lens change its color. It turns yellow and this is the reason that the most dangerous part of the UV spectrum is not permitted.

Cataract is usually called a physiological state of the eye, associated with clouding of the lens of the eye and causes varying degrees of vision disorders. These disorders are related to changes in the accuracy of transmission of color sense that is associated with the change of the spectral composition of light entering color perception patterns. The second disorder is due to the fact that the light passes worse through a turbid medium and doesn`t reach the retina. Depending on the degree of attenuation of the radiation flux reaching the retina, the eye sees worse or does not see at all.

Experiments accompanying the topic "The colour vision of man"

Model of a fragment of the retina

Science On a general view of a device shown in figure 2 we should pay attention on the marked fragment of a prototype of the retina contains three different cones types on the model (white circle). The three LEDs (light-emitting diodes) of red, green and blue colors are imitating the function of the cones. Note that they are placed on the model just in the same way as on the retina. The cones on the plane in the best zones of vision (in the macula) were built in a very regular triangular grid with a distance between the centers of 2.5-3 µm (Smith 2008). The demonstration helps to illustrate the principle of color vision. Each of the LEDs included in the circuit with its own galvanometer.

When the model is illuminated with the wavelength coinciding with the frequency of one of the LEDs, you may notice that the current (or voltage) appear only on the device that is connected to this led. You can check for other LEDs.

Now let`s take a standard illuminator with a set of color filters, and will illuminate the model with a light of arbitrary frequency (as determined by the color filter). Since the filters have a wide frequency response, so the light received from them can be decomposed into the simple colors in appropriate proportion. This is done with the help of the model. In fact, it is a simple spectrum analyzer.

The above mentioned model in cooperation with a low-frequency generator could be used for the performance of laboratory works aimed for a research of a colour perception system of the eye.

Laboratory work on the study of a system of colour perception of a person

Let`s describe the device for our study (Fig. 2). Its base, as mentioned above, is the three LEDs of primary colors (blue, green and red) with about the same power. The diodes are mounted in plastic. There is also a possibility for the external connection of a low-frequency generator. The low-frequency generator must meet the following criteria: to have the ability of changing the frequency in the range from 1 to 30 Hz and a voltage from 0 to 3 V. The experiment should preferably be carried out in a darkened room or with use of a special protective shield.

Figure 2. The appearance of the device. The diodes of three colors are marked with a white circle (model groups of three cones).

The aim of a laboratory work is to study the dependence of the spectral sensitivity of cones of different colors.

The experimental part of the work is as follows: at a fixed frequency of flashing of one of the LEDs, starting from the minimum (1 Hz), is determined by the led voltage, at which the researcher begins to see the illumination of the diode (starting with the lowest). Then we repeat the experiment for each successive frequency.

All the changes happening with the diode are committed by a researcher (one eye is closed). The main objective of the test is to determine the frequency of the led when the eye ceases to distinguish the blink. On the basis of the obtained dependences a speed of recovery of the visual pigment would be calculated.

Here is an example of the dependences obtained for three researchers. The first thing we found from the obtained dependencies was that a blue colour would always be much higher (to an average eye without distinct pathologies) comparing to the green and red colours (Fig. 3).

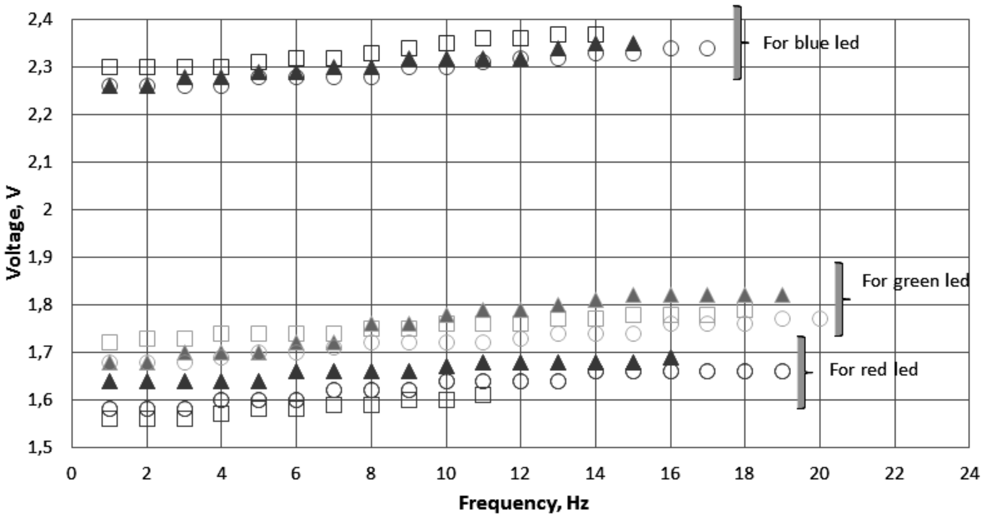

Figure 3. The experimental dependence of the spectral sensitivity of cones of different colours (for each of the subjects is shown according to their marker).

This result is quite explainable theoretically. As mentioned earlier, the photoreceptors of the human eye are less sensitive to the blue colour comparing to red and green. Then it is clear that the position of the rightmost point differs from the different subjects. This illustrates the different recovery time of "health" of cones. Now let's calculate the recovery time. For this purpose we use the correlation between the frequency and time:

$$t \approx 1/\nu$$

So for the test, marked with squares, the recovery time for the red colour is approximately of 0.09 s, and the subject indicated by the circles, is recovered about twice as fast (0.05 s). But as we have said, it's all very individual.

Let`s pay attention to the results presented in figure 4, obtained for people of different ages (14 years and 50 years). Obviously, the older a person becomes, the slower regenerate the visual pigments. The calculation for the presented curves shows that this time had increased from 0.05 to 0.09 s. The relative sensitivity remains the same as in figure 3. In our opinion, a comparing of the differences in sensitivity for people of different ages does not make sense, since we do not know what results in a test a 50 year old person had previously.

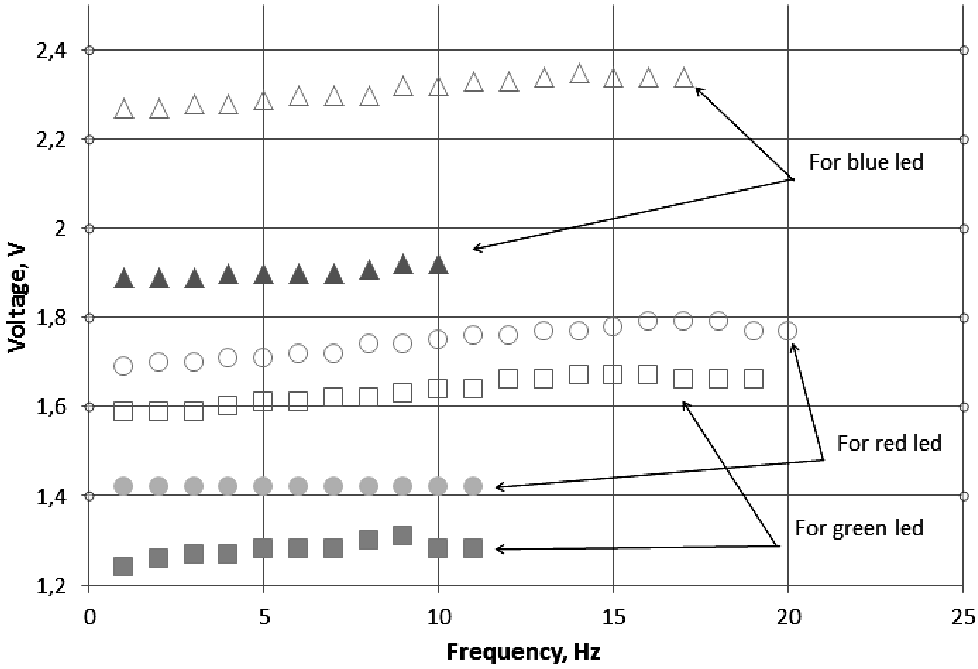

Figure 4. Experimental dependence of the spectral sensitivity of cones of different colours (hollow markers for the age of 14 years, solid markers for 50 years)

The photobiological paradox of vision: a study of the model of lens opacity (cataract) (Petrova 2008)

As a model of the damaged lens we will use the cell with the fluid whose properties vary in the course of the experiment.

1. We will explore a clear liquid to establish its influence on the intensity and a spectral composition passing through her radiation.

2. We will examine the liquid of different degree of yellowing. For this purpose, we will use the solution of tea in different concentrations simulating the yellowing of lens.

3. We will examine the liquid of different degree of turbidity, using a suspension of milk of various concentrations. Simulating the cataract of lens.

For this study fit almost any spectral instrument, but it is preferable to allow not only qualitative observations but also quantitative assessment of the past radiation. We used the spectrometer with a reflective diffraction grating.

It is known that the human eye perceives only a narrow part of the spectrum in the interval from 400 to 700 nm, as it has vital information for humans. The bordering radiation (infrared (IR) and ultraviolet (UV) light) is harmful, and the eye has mechanisms of protection against it.

Let's see what`s the percentage of these IR and UV in the investigated spectrum. To do this, let`s insert the cuvette with water (clear liquid) in the light path from the emitter to the detector and see how this will change the look of the resulting spectrum. As the radiation unit was used a led, whose spectrum is shown in figure 5 (upper curve). While passing through a transparent liquid, the intensity of the transmitted radiation decreases slightly, but the shape of the curve it retained and its spectral composition does not change.

Next we will investigate the liquid of different degree of yellowing. The experiment shows that in this case not only the intensity changes but also the spectral composition, and in the blue part of the spectrum of the radiation intensity varies much stronger than in the red. In addition, there has been a change in the spectral composition. In the blue part of the spectrum is cut off a radiation in the range of up to around 410-415 nm (Fig. 5, bottom curves). If you increase the "turbidity" this boundary is shifting in the direction of increasing wavelength.

Let's assume eyes with pathology. Let the patient suffers from cataract. Thus there is a clouding of the lens. Let`s put a fluid tinted in a yellowish color in the way of light. Will get the dependence I=f(λ). The graph of the dependence shows as in the previous case, not only the intensity of radiation has changed but also its spectral composition (Fig. 5, bottom curves; the upper curve is given for comparison, the spectrum of radiation transmitted through the transparent liquid).

Clouding of the environment has led not only to the changes in intensity and spectral composition of the transmitted radiation. Turbid liquid absorbed radiation in the range of up to 415 nm. And this value changes with increasing turbidity of the medium.

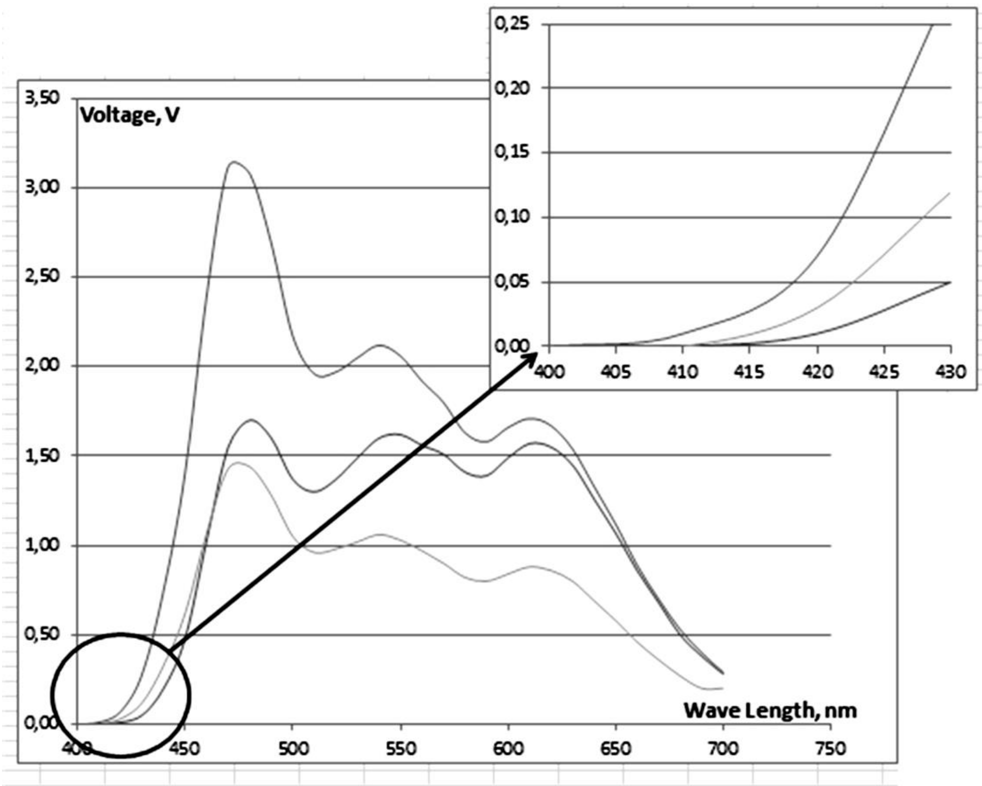

Figure 5. Comparison of the emission spectrum of the led (upper curve) and absorption spectrum of liquid turbid liquid (of different concentrations)

So, we can conclude that people with this disorder of the eye perceives visual information with a large distortion. The eye ceases to perceive the blue part of the spectrum. This leads to the fact that the perceived image will become reddish-brown tint.

In order to help students to see the real result of such changes in the structure of the eye it is necessary to resort to another kind of modelling, to a computer simulation. This requires the use of a graphical editor with the ability to change the ratio of red, green and blue colors (RGB settings).

To conduct this experiment, we must choose a multi-color image (it is desirable that it was mainly dominated by green, yellow and blue). Then it is recommended consistently changing sliders positions. In accordance with the results of the above mentioned experiment the change in blue colour is approximately in 6 times, green colour in 4 times, red colour in 3 times. The image on the monitor gradually changes, and acquires the color range that can see a person suffering from cataracts.

Overall, the experiment well illustrates the internal processes and the result (the human perception of color) the change of lens transparency.

Note the similarity in the results obtained for yellow and turbid liquids. The yellowing of the crystalline lens is a protective mechanism of the eye, which seeks to protect its internal structure from too much UV radiation. The intensity of the transmitted radiation changes, perception also, but these changes are not as fatal as when the clouding of the lens. The clouding of the lens is a disease that should be treated. Currently it is successfully implemented with the replacement of the crystalline lens. Note that in this case the yellow lens is implanted.

Results and Discussion

A review of the main hypotheses of occurrence of color vision of a human and an experience of teaching in pedagogical higher educational institution allowed the authors to show that:

1) it`s possible to make a new addition to the system of the educational experiment aimed for the research of a colour-perception system of the eye, and the same time the authors make no claims of high accuracy measurements, but only offer a qualitative illustration of the patterns. However, according to the obtained results we can judge about the speed of proceeding of the physical and the chemical processes;

2) the proposed experimental training studies reflect the current trends of a research in the field of ophthalmology and physiology;

3) the conducted pedagogical research has shown that such learning experiments significantly increase the motivation of students – future teachers – to the study of natural-science disciplines, including Biophysics;

4) in the case of teacher training, such studies demonstrate the capabilities of the educational experiment for the communication of basic training in the discipline with its applied aspects.

So, taking into the consideration the load and the external influences for the eyes of a modern man, we believe that every man must understand the principles of its functioning, to assess the real danger and to follow the certain rules of hygiene.

Unfortunately, the authors have experienced some difficulties while conducting their research that were associated with the specifics of their activities: it was difficult to find a sufficient number of suitable subjects for the test (e.g., humans, suffering from various forms of color blindness, or a sufficient number of uneven-aged elderly people).

Conclusion

Study of the peculiarities of color vision is of a great importance not only for the increasing of general awareness of biological and physical processes in the human body, but also it allows us to extend the capabilities of the experimental simulation of processes.

The important achievement of the described work is the ability to use available and visible experiment for students while teaching the discipline of "Biophysics".

The authors are planning to continue their work on the development and improvement of models of color vision, and the subject of this study will become the visual system of people suffering from various forms of color blindness; visual system of animals, birds and insects.

A comparative analysis of the visual system of the animals leading the diurnal and nocturnal lifestyle is of a great interest for the authors.

We are also intended to examine more carefully and to compare the features of the visual system of people of all ages. In our opinion, the study of the change in the speed of recovery of the pigment for people spending a lot of time in front of the computer is of a great interest also.

In addition, a teaching experience has shown that along with the main hypotheses and theories of the emergence of color vision, among the future teachers a fairly wide interest causes information about scientists who made discoveries in the field of Biophysics, a large proportion of whom are Nobel prize winners. In this regard, we believe that in order to improve interest in any studied subject, including "Biophysics", during the learning course some attention should be paid to the biographical information of scientists.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Elena Borisovna Petrova holds a PhD in science education and now is professor at Moscow State Pedagogical University, Moscow, Russia.

Fairuza Musovna Sabirova holds a PhD in science education and now is associate professor at Kazan (Volga region) Federal University, Elabuga institute, Elabuga, Tatarstan.

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