

THE USE OF COGNITIVE GRAPHICS IN THE DIAGNOSIS OF COMPLEX VISION PATHOLOGIES

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Abstract: *Discusses the use of cognitive graphics tools for the diagnosis of complex vision pathologies. Research and development are carried out jointly by the Department of applied mathematics of the National Research University "Moscow Power Engineering Institute" ("MPEI") and the Department of clinical physiology of vision of the Moscow Helmholtz Research Institute of eye diseases. The obtained results are used in the development of an intelligent (expert) decision support system for the diagnosis of complex vision pathologies.*

Keywords: *Artificial Intelligence, Decision Support, Cognitive Graphic, Anomaly Detection, Vision pathology.*

Introduction

Methods of *cognitive graphics* (CG) are widely used, including in intelligent systems for various purposes for imaginative representation of the situation and a better perception of the processes [Pinker, 1984; Zenkin A.A., 1991]. It is known that the image (picture) is more convenient for human perception than text information, which is especially important in intelligent real-time systems. Typical representatives of such systems are intelligent decision support systems of real-time. At the Department of Applied mathematics of the National research University "Moscow power engineering Institute" together with the Department of clinical physiology of vision of the Moscow Helmholtz Research Institute of eye diseases conducted complex researches to creating an intelligent (expert) decision support system for the differential diagnosis of retinal diseases in complex clinical cases [Ereemeev et al., 2014; Ereemeev et

al., 2018]. For data analysis and diagnosis, an approach based on the integration of probabilistic methods, artificial intelligence methods (based on neural networks and fuzzy sets) and cognitive graphics tools for imaginative representation of the problem situation and the dynamics of its change is used. The main source of information for the diagnosis of complex visual pathologies such as diabetic retinopathy are the data obtained by *electroretinography* (ERG) - a method for assessing the functional state of the retina, based on the registration of biopotentials arising in it with light irritation [Shamshinova, 2009]. The use of means of CG can facilitate the process of perception of information and provide significant assistance to an ophthalmologist in the diagnosis, as well as be used to train novice specialists.

The structure of ERG

There are 3 main components in ERG: initial a-wave, b-wave and late c-wave (Figure 1). Depending on the type of ERG, the c-wave can be positive, negative or absent (in whole or in part).

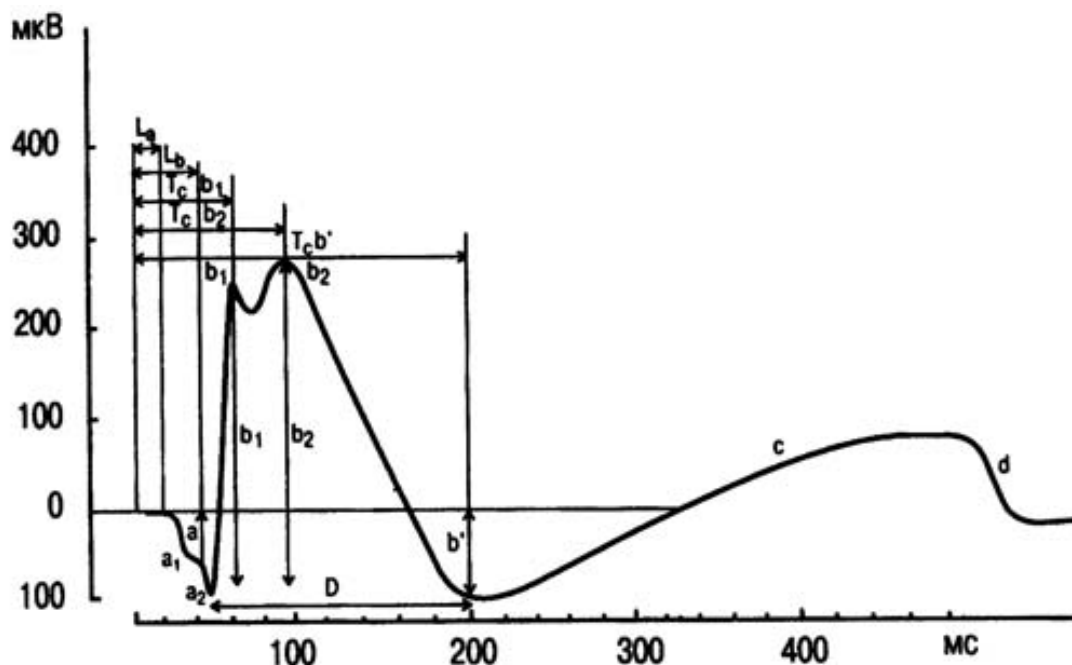


Figure 1. Schematic representation of maximum ERG: a1 and a2-amplitude of a-wave; b1 and b2 – amplitude of b-wave; D – duration of b-wave; L – latent

period; T_b – culmination time. On the ordinate axis-the amplitude of ERG waves, on the abscissa axis-the duration of ERG waves

Maximum ERG reflects the electrical activity of most cellular elements of the retina and the dependence on the number of healthy functioning cells. Different types of ERG reflect the diversity of retinal structure, and the evaluation of their components associated with different cellular elements of the retina, allows for early and differential diagnosis of retinal diseases. Figure 2 shows examples of ERG (Rod ERG, Rod-Cone ERG, Oscillatory ERG) used to diagnose retinal pathologies.

Negative *a*-wave ERG reflects the function of photoreceptors as the initial part of the late receptor potential. This wave has a dual origin, respectively, two types of photoreceptors: the earlier *a1*-wave is associated with the activity of the photopic system of the retina, *a2*-wave — with the scotopic system; *a*-wave passes into a positive *b*-wave, reflecting the electrical activity of bipolar and Muller cells with a possible contribution of horizontal and amacrine cells.

Wave *b* (on-effect) in the standard conditions of ERG registration reflects bioelectric activity depending on the adaptation conditions and the function of the photopic and scotopic retinal system, which are represented in the positive component by waves *b1* and *b2*. On the ascending part of the *b*-wave there are 5-7 waveforms, called oscillatory potentials, which reflect the interaction of cellular elements in the inner layers of the retina, as well as the activity of amacrine.

The knowledge of the nature of retinal biopotential generation allows us to assess the nature and localization of retinal changes. In Figure 3 shows an example of ERG with localization of retinal changes.

In order to be able to perform a comparative assessment of the results of electroretinographphy studies conducted in different clinics around the world, the international society of clinical electrophysiologists of vision (ISCEV) proposed standards for the registration of ERG, recommended for the study of visual functions in patients with various pathological changes in the retina [Types, 2016].

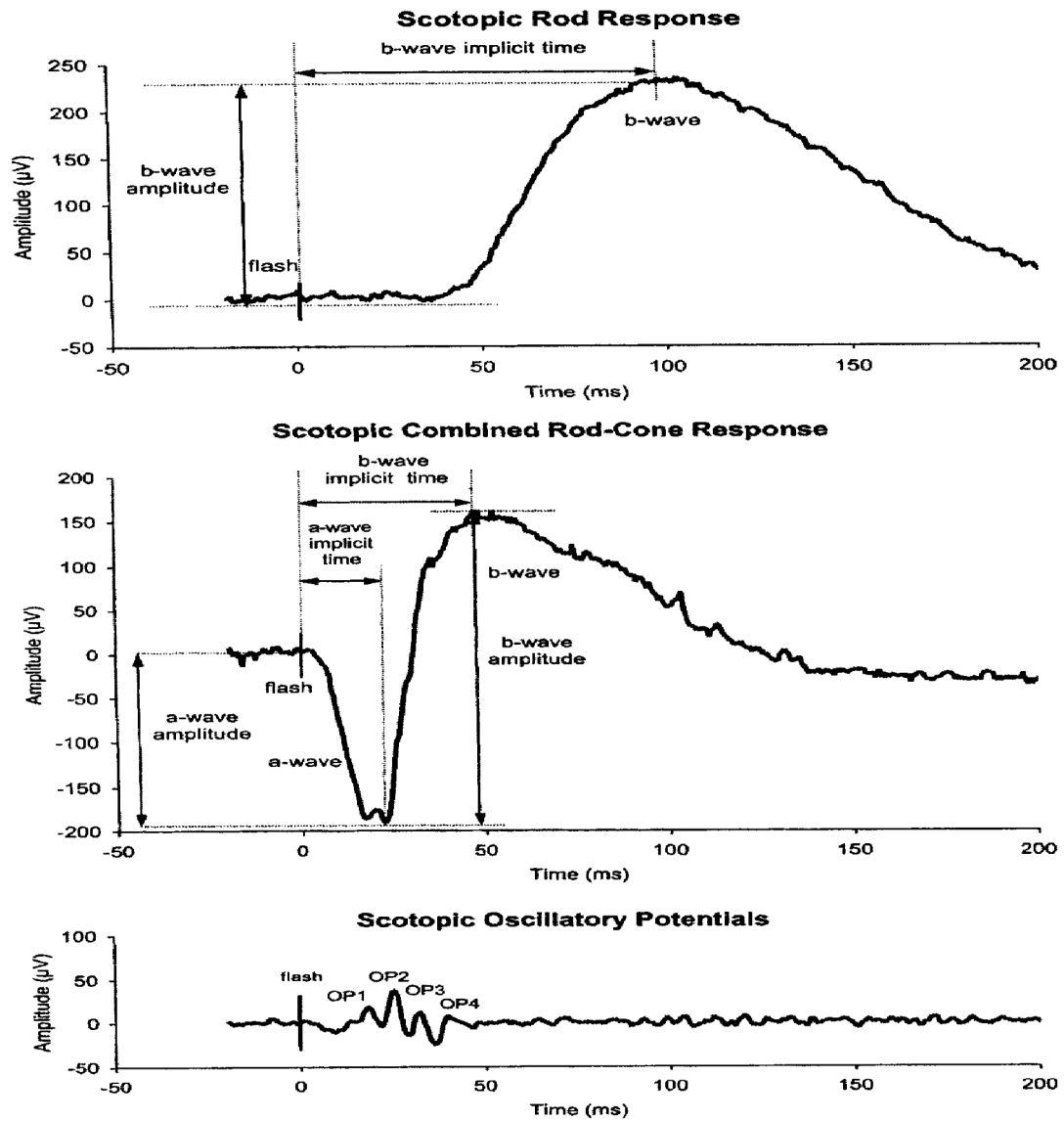


Figure 2. The examples of ERG used to diagnose retinal pathologies

The single flash Ganzfeld Electroretinogram

FIG. 2A

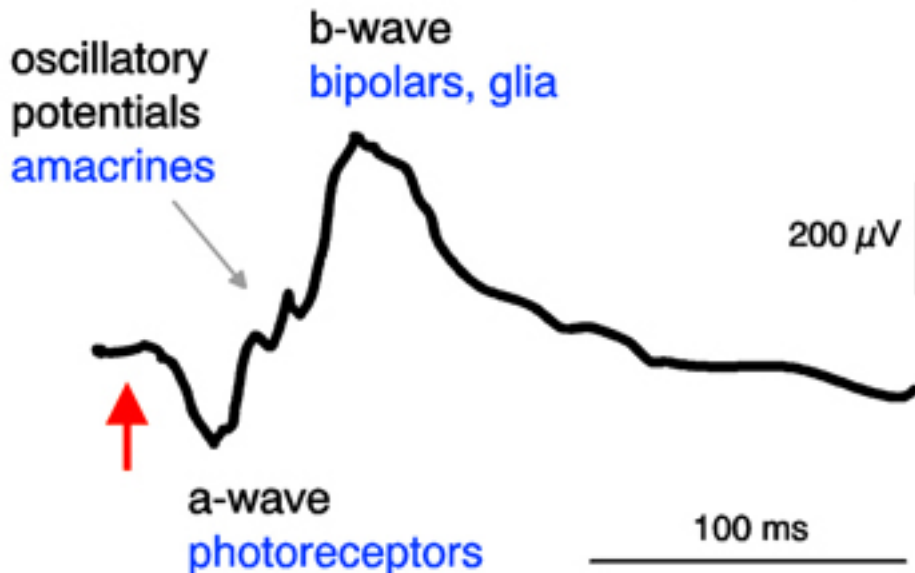


Figure 3. An example of ERG with localization of retinal changes

In clinical electroretinography using multiple ways of recording ERGS in order to distinguish the photopic, scotopic and mixed bioelectric responses of the retina. For this purpose, appropriate adaptation and stimulation conditions are used, in which the rod or cone system of the retina dominates (ERG registration for different flash intensity in special conditions of light and dark adaptation):

- maximum ERG under dark adaptation
- rod ERG in conditions of dark adaptation
- cone ERGS to single flash under light adaptation
- oscillatory potentials.

Additional information on retinal function can also be obtained using other electroretinographic techniques (which are not included in the "Standards"), such as: registration of chromatic ERG, macular ERG, multifocal ERG, ERG for long-term stimulus (on/off-response), early receptor potentials, registration of

scotopic response threshold, ERG for dual stimuli, S-cone ERG, determination of ERG dependence on the intensity of stimulating light (Naka-Rushton function). Visual representation

Visual representation of the retina

As known, in the retina there is a pre-processing of the entire flow of visual information. The conversion and transmission of signals in the retina in response to a light stimulus is a complex process that takes place in three stages [Zueva et al., 2002; Shamshinova, 2009]. The first stage involved the photoreceptors (rods and cones). Signals from photoreceptors come to bipolar cells (the second stage), and signals from bipolar cells — to ganglion cells (the third stage). Axons of ganglion cells form the optic nerve. The final output signal is the result of a complex integrative process occurring in the retina.

In the structure of the sensory retina are the following main layers, distinguishable under a microscope (Figure 4):

- (1) the layer of outer segments of photoreceptors;
- (2) the outer nuclear layer containing inner segments and nuclei of visual cells;
- (3) the outer plexiform layer with synaptic contacts between photoreceptors, bipolar and horizontal cells;
- (4) the inner nuclear layer containing nuclei of bipolar, amacrine and horizontal cells;
- (5) the inner plexiform layer with a variety of contacts between bipolar, amacrine and ganglion cells
- (6) the inner nuclear layer formed by the bodies of retinal ganglion cells;
- (7) the layer of nerve fibers formed by axons of ganglion cells forming the optic nerve.

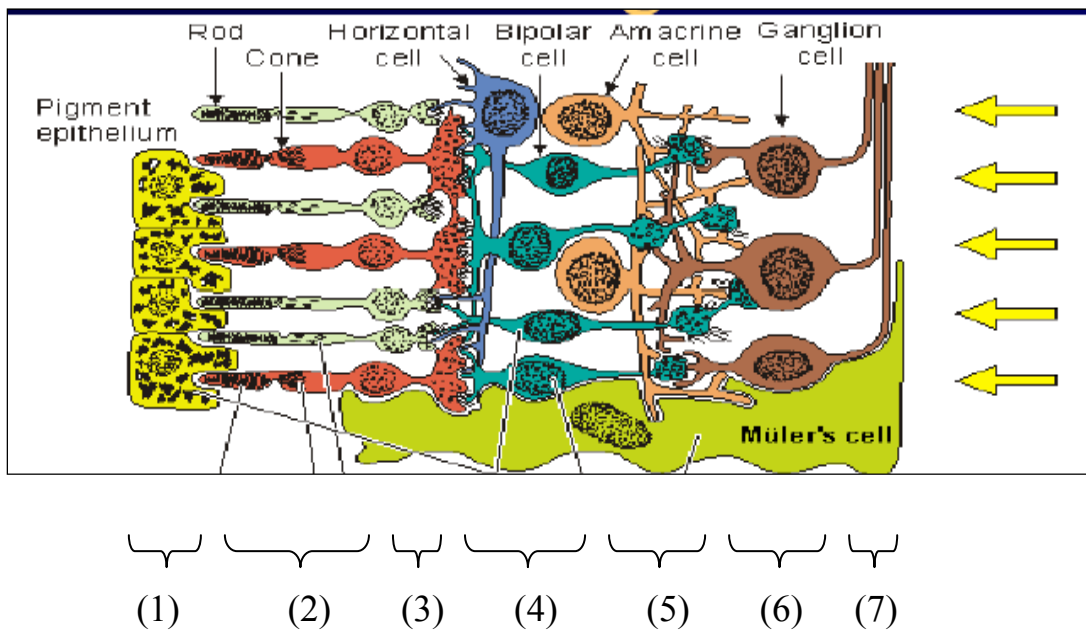


Figure 4. The main layers of the sensory retina [Webvision, 2016]

All the layers of the retina laced radial glial cells of Muller. The functions of these cells are extremely multifaceted. The intensive exchange of substances is realized trophic system of the capillary - glial cell - neuron. Muller glial cells are actively involved in the processes of repair of retinal damage, secrete various neuroactive substances. They can absorb the degenerating cells of the ganglion layer, as well as replace the nerve cells of the retina.

In retinal diseases, the normal functioning of the various layers of the retina is disturbed. Violations can go in two directions: increase or decrease the functional activity of cells. On the basis of what layers and divisions of the retina changes are observed and what character they are, it is possible to draw certain conclusions about what the pathogenesis of the disease is and correctly diagnose or clarify the diagnosis. In particular, in retinal detachment, the functioning of its layers is significantly reduced. The figurative representation of this pathology is given on Figure 5 (the result of a computed tomography of the retina obtained during examination of the patient).

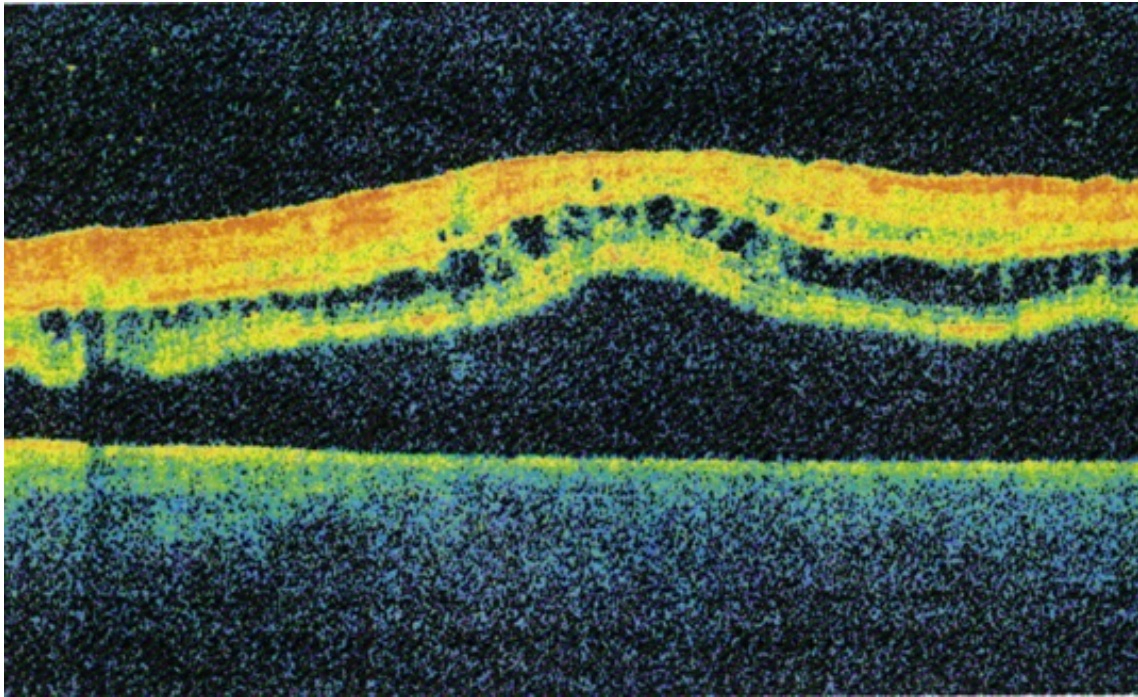


Figure 5. Retinal detachment

Formal model of the cognitive image of the retina

Formally, the model of cognitive image (CI-model) is defined by a triple: $K = (X, R, F)$, where $X = \{ C_i \mid i=1, 2, \dots, n \}$ – the non-empty set of concepts (objects of the subject area), $R = \{ R_j \mid j=1, 2, \dots, m \}$ – the family of relations on the set X , F – the set of interpretation functions (rules). Each concept C_i is a set: $C_i = (N_i, T_i, P_i, Ch_i, A_i)$, where N_i – the name of the concept C_i , $P_i = \{ C_i^k \mid k=1, 2, \dots, x \}$ – the set of ancestors of concept C_i , $Ch_i = \{ C_i^s \mid s=1, 2, \dots, y \}$ – the set of descendants of a concept C_i , $A_i = \{ A_i^u \mid u=1, 2, \dots, q \}$ – the list of attributes of concept C_i . Each attribute A_i^u of concept C_i is defined as follows: $A_i^u = (Na_i^u, Ta_i^u, Va_i^u)$, where Na_i^u – the name of attribute A_i^u , Ta_i^u – the type of attribute A_i^u , Va_i^u – the value of attribute A_i^u . T_i – the type of concept C_i is defined as follows: $T_i = (Nq_i, Aq_i, Mq_i, Pq_i)$, where Nq_i – the type name of concept C_i ; $Aq_i = \{ Aq_i^h \mid h=1, 2, \dots, r \}$ – the list of attributes of concept type C_i ; $Mq_i = \{ Mq_i^d \mid d=1, 2, \dots, f \}$ – the list of actions (methods) of concept type C_i ; Pq_i – the name of parent concept type C_i .

Then the alphabet in the CI-model of the retina is a set of geometric primitives (point, spline, ellipse, rectangle) $Aq_i = \{ Aq_i^h \mid h=1, 2, \dots, r \}$, and the formal image is one layer element consisting of a sequence of alphabet characters.

The axioms describe building elements (elementary CI) each:

- 1) the image "Stick" consists of two ellipses and is in the first layer;
- 2) the image of the "Cone" consists of three ellipses and is in the first layer;
- 3) the image "Bipolar" consists of a rectangle and an ellipse, occupying 0.3 parts of the entire element, and is in the second layer;
- 4) the image of the "Ganglion cell" consists of a rectangle and an ellipse, occupying 0.8 parts of the entire element, and is in the third layer;
- 5) the image of the "Horizontal cell" consists of an ellipse and a spline and is in the second layer;
- 6) the image of "Amacrine cell" consists of an ellipse and is located in the second layer;
- 7) the image of "Muller's Cell" consists of a rectangle and a set of ellipses of two types and is located on the side of all other layers.

Reasoning (output) rules define relationships between elements in different layers:

- 1) images of "Stick" and "Cone" can be associated with elements of "Bipolar" and "Horizontal cell»;
- 2) images of "Bipolar" and "Amacrine cell" may be associated with the element "Ganglion cell»;
- 3) the image of the "Ganglion cell" has a downward connection called "Axon".

The set of concepts is defined as follows:

$C1 = (Stick, 0, Bipolar(stick), A1);$

$C2 = (Cone, 0, Bipolar(cone), A2);$

$C3 = (Bipolar(rod), Wand, Ganglion cell, A3);$

$C4 = (Bipolar(cone), Cone, Ganglion cell, A4);$

$C5 = (\text{Ganglion cell, Bipolar (rod), Axon, } A5);$

$C6 = (\text{Ganglion cell, Bipolar (cone), Axon, } A6);$

$C7 = (\text{Axon, Ganglion cell, } 0, A7);$

$C8 = (\text{Horizontal cell, Stick, Bipolar(stick), } A8);$

$C9 = (\text{Horizontal cell, Cone, Bipolar(cone), } A9);$

$C10 = (\text{Amacrine cell, Bipolar, Horizontal cell, } A10).$

The list of three attributes is defined for each concept $A_i = \{ A_i^u \mid u=1,2,3 \}$:

$A_i^1 = (\text{Color, 3 digits, } 0-255);$

$A_i^2 = (\text{Width, number, } W_i);$

$A_i^3 = (\text{Height, number, } H_i).$

Similarly, multiple sets of indicators are introduced $P = \{ P_i^h \mid h=1, 2, \dots, r \}$:

$P_i^h = (\text{type of study, indicator, value });$

We give examples of indicators (the indicators are presented in full in the Appendix):

$P_i^1 = (\text{Maximum ERG, AA, } 70-220) - \text{ shows the change in photoreceptors (rods and cones);}$

$P_i^5 = (\text{Scotopic ERG, al, } 50-150) - \text{ shows changes in rod bipolar cells;}$

$P_i^8 = (\text{Photopic ERG, Ta, } 7-21) - \text{ shows the change in the bonds between the cones and their Bipolars;}$

$P_i^{11} = (\text{FERG 30 Hz, APIC-dead end, } 30-100) - \text{ shows change in cone bipolar without Mueller;}$

$P_i^{12} = (\text{Oscillatory potentials, O1, } 40-70) - \text{ shows the change in Amacrine and inverse coupling functions from ganglion cells to Amacrine;}$

$P_i^{18} = (\text{ERG pattern, N95, } 30-110) - \text{ shows changes in the ganglion cells and axons of cones (more in the macula).}$

Calculation of indicators is based on ISCEV recommendations [Types, 2016]:

- the amplitude of Ab is calculated from 0 to max negative;
- the amplitude of Ab is calculated from a to max positive;
- the climax time of Ta is calculated from the axis to max negative;
- the climax time of Tb is calculated from axis to max positive;
- the amplitude of A peak-to-peak is calculated from max negative to max positive;
- the amplitude of $P50$ is calculated from the first negative deflection to the max $P50$;
- the amplitude of $N95$ amplitude is calculated from the $N50$ (or contour) to the $N95$;
- the amplitudes $O1, O2, O3, O4$ are calculated from max negative to max positive;

The knowledge base is a set of production rules of the type "**If** (condition of the rule application), **then** (result of the rule application (conclusion of the rule))". The condition (the left part of the rule) is a set of indicators, the result-conclusion (the right part of the rule) is a set of concepts with attributes.

Examples of production rules:

If P^1 is (Maximum ERG, Aa, 60), then A_1^1 is (100.100.70) (color dim);

If P^1 is (Maximum ERG, Aa, 100), then A_1^1 is (150.79) (color moderate);

If P^{13} is (Photopic ERG, Aa, 15), then A_2^2 is (10) (width is small);

If P^{13} is (Photopic ERG, Aa, 30), then A_1^1 is 1(20) (width average);

If P^{14} is (Photopic ERG, Ab, 150), then A_3^1 is (200.220.130) (color bright).

If the condition of the rule is executed, then the result-conclusion of the rule is used to build the CI of the retina. Then, to assess the state of each type, a fragment of the retina, a combined visualization method can be used, which consists in changing the size of the image and its color depending on the selected parameters.

Software implementation

In the software system of visualization of complex pathologies of vision based on CI, the main users are the expert (electrophysiologist) and the user – the decision-maker personal (DMP), which is an ophthalmologist.

From the point of view of experts and DMP, the system should provide the following main functions:

- changes in indicators;
- getting display results;
- saving results;
- view help;
- program setting.

Diagram of use cases of the developed system is shown in the Figure 6.

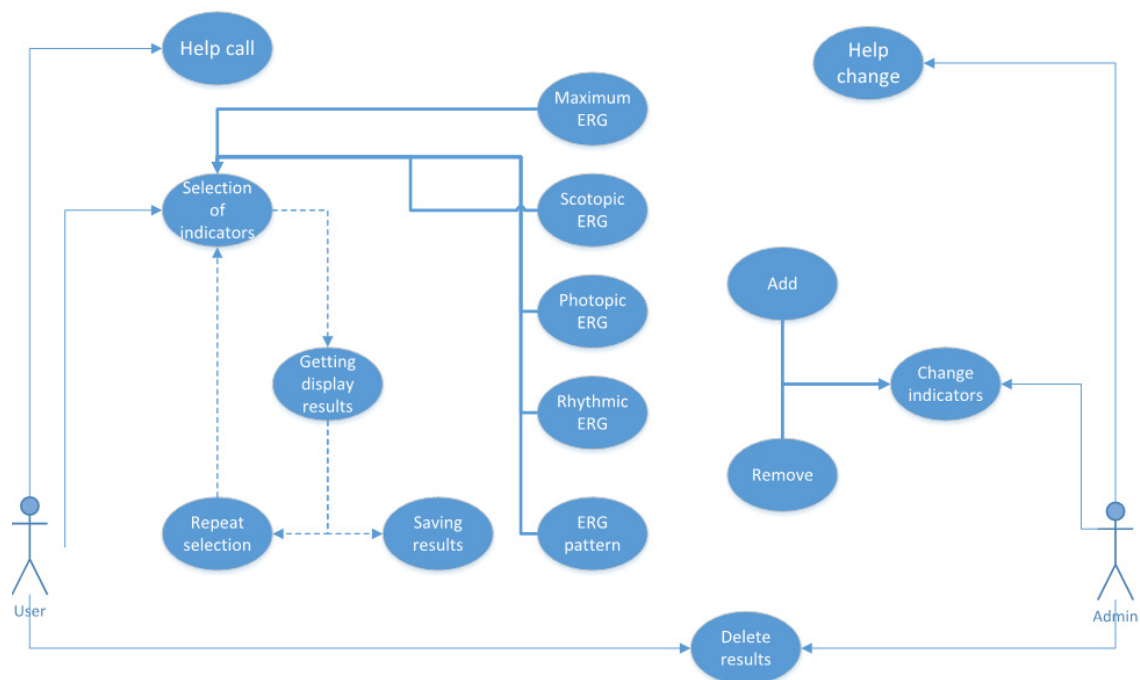


Figure 6. Diagram of use cases of the developed system

When working with the system, the user (expert, DMP or trainee) should be able to set values for all possible indicators. If the user has problems with the program, he can use the help by calling it in the "Menu". After determining all the indicators, the “Build” button is used to create a cognitive image.

Examples of cognitive images constructed by the system for the normal state and various pathologies of the retina are shown in Figure 7.

When developing the system, an object-oriented technology and C# implementation language were used, which allowed to present the main elements of the CI with the necessary expressiveness.

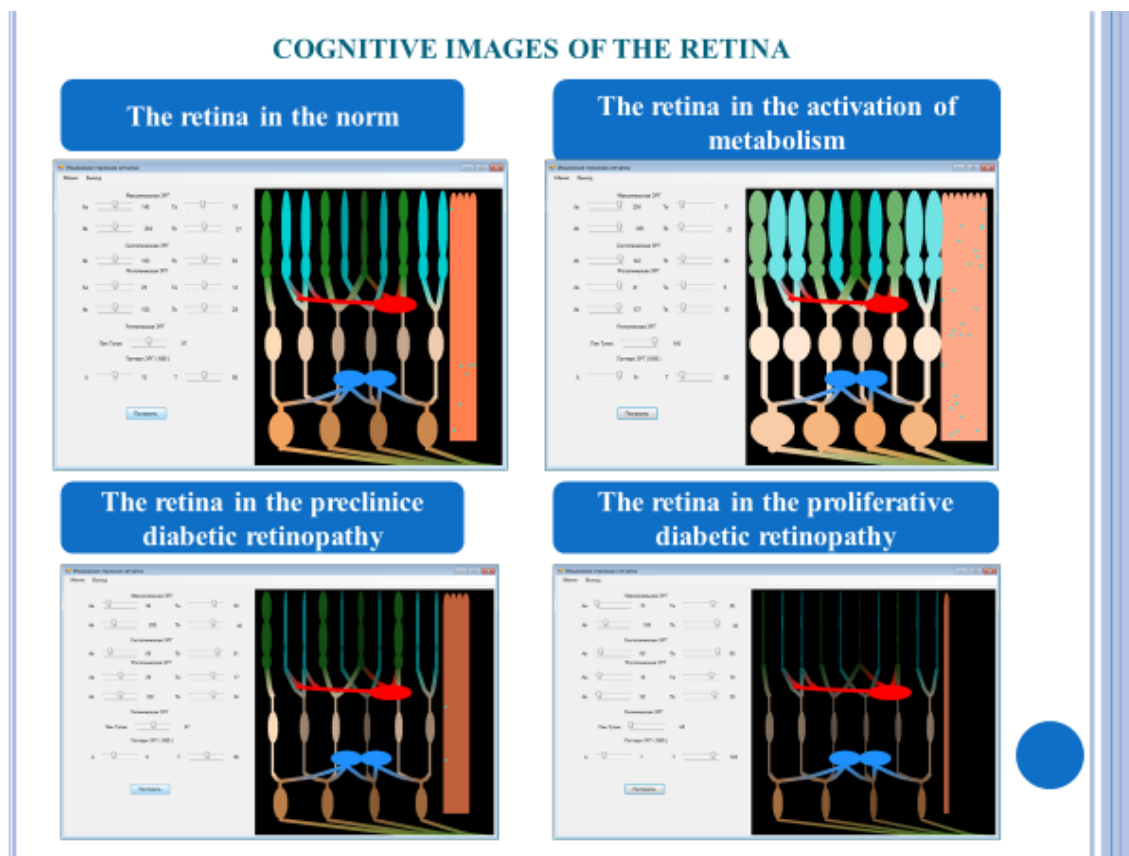


Figure 7. Examples of cognitive images

Result

The possibilities of using cognitive graphics (cognitive images) and the corresponding software system for the presentation of complex pathologies of vision according to the results of ERG are considered. A formal model of a cognitive image (CI-model) is proposed, including a set of basic elements for constructing CI and a set of production rules (reasoning rules) defining relations between elements of different levels of CI. Note that the results of the ERG can only be interpreted by physiologists. The developed means of cognitive graphics allow us to give a figurative representation of changes in the layers of the retina, which is also understandable to the ophthalmologist. The developed tools are intended to be included in the intelligent decision support system for diagnosing complex vision pathologies developed jointly by specialists from the National Research University “MPEI” and expert-physiologists from the Moscow Helmholtz Research Institute of eye diseases, a prototype system has been developed that can be used to train students and novice doctors.

Further work: An important factor is the further expansion of the library (database) of cognitive images to other pathologies of vision, as well as the implementation of the dynamics of changes in images, which will allow you to display the process of the disease in a given time mode (accelerated, normal or slow).

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Appendix

The set of indicators:

$P_i^1 = (\text{Maximum ERG, AA, 70-220})$ - shows the change in photoreceptors (rods and cones);

$P_i^2 = (\text{Maximum ERG, TA, 10-30})$ - shows the change in the connections between photoreceptors and their Bipolars;

P_i^3 = (Maximum ERG, Ab, 125-380) - shows change in sticks and their bipolar cells, also in Muller cell;

P_i^4 = (Maximum ERG, Tb, 18-56) - shows the change in the bonds between the sticks and their Bipolars;

P_i^5 = (Scotopic ERG, al, 50-150) - shows changes in rod bipolar cells;

P_i^6 = (Scotopic ERG, Tb, 30-90) - shows the change in the bonds between the sticks and their Bipolars;

P_i^7 = (Photopic ERG, Aa, 14-44) - shows the change in cones;

P_i^8 = (Photopic ERG, Ta, 7-21) - shows the change in the bonds between the cones and their Bipolars;

P_i^9 = (Photopic ERG, Ab , 50-150) shows change in cone Bipolars and Muller cells;

P_i^{10} = (Photopic ERG, Tb, 14-42) - shows the change in the bonds between the cones and their Bipolars;

P_i^{11} = (FERG 30 Hz, APIC-dead end, 30-100) - shows change in cone bipolar without Mueller;

P_i^{12} = (Oscillatory potentials, O1, 40-70) - shows the change in Amacrine and inverse coupling functions from ganglion cells to Amacrine;

P_i^{13} = (Oscillatory potentials, O2, 40-70) (basic index) -shows the change in Amacrine and inverse functions of the connection from ganglion cells to Amacrine;

P_i^{14} = (Oscillatory potentials, O3, 40-70) - shows the change in Amacrine and inverse coupling functions from ganglion cells to Amacrine;

P_i^{15} = (Oscillatory potentials, O4, 40-70) - shows the change in Amacrine and inverse coupling functions from ganglion cells to Amacrine;

P_i^{16} = (ERG steadystate pattern, APIC-deadlock , 50-120) - shows changes in ganglion cells and axon;

P_i^{17} = (ERG pattern, P50, 45-90) - shows change in photoreceptors and cone bipolars;

P_i^{18} = (ERG pattern, N95, 30-110) - shows changes in the ganglion cells and axons of cones (more in the macula).

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