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Physiological aspects of visual information perception of the oculomotor apparatus

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Abstract: The individual characteristics of the human visual apparatus are associated with the anatomical and psychophysiological parameters of his body. Based on the EyeTracking technology, the physiological aspects of the perception of visual information by the oculomotor apparatus, which are not associated with active cognitive activity, have been investigated. The individual features in the size of fixation when reading text and examining halftone graphic objects in various people have been investigated. The time durations of fixations in different people, associated with the process of accommodation, as well as the internal structure of fixations, were investigated. It is shown that the trajectory of the gaze shift in fixation has an internal heterogeneous structure. The total trajectory of eye movement in the fixation area is determined by a set of successive clusters. This fixation structure is apparently associated with the processes of restoration of the photosensitivity of rhodopsin in the photoreceptors of the retina. All the above studies of the fixations of various subjects on the basis of various images showed that the oculomotor system, taking into account the physiological characteristics of the visual apparatus, is equally controlled by the "video processor" of the brain when the eye is accommodated to the image elements. And the only objective individual feature of human vision, which uniquely characterizes the perception of graphic information, is the value of the average displacement in fixation. It is she who is the "visiting card" of the subject and remains practically unchanged both when reading and when examining halftone images and in test validation with forced fixation of the gaze.

Keywords: oculomotor reactions (oculomotorics), technology of eye-tracking, fixation, saccades, reading text, perception of graphics, individual characteristics of the visual apparatus

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CONTENTS

1. INTRODUCTION (390)

2. EYE TRACKING TECHNOLOGY (394)

3. INDIVIDUAL FEATURES OF FIXATIONS IN THE PERCEPTION OF GRAPHIC IMAGES (395)

3.1. FIXATION GEOMETRIC PARAMETERS (395)

3.2. DURATION OF FIXATION (397)

3.2. DYNAMIC FEATURES OF THE PERCEPTION OF GRAPHIC INFORMATION (399)

3.4. INTERNAL STRUCTURE OF FIXATIONS (400)

4. CONCLUSION (401)

REFERENCES (402)

1. INTRODUCTION

In the perception of the external world, the leading place belongs to the organ of vision. It takes light to see. The human organ of vision is able to perceive light of different wavelengths, its different brightness, shape and size of objects, to orient itself in space, can estimate the distance between objects, their volume.

It has now been proven that we see not with our eyes, but with our brain. Those. object recognition takes place in the brain, which receives only "raw" information about the distribution of light spots in space from the retina. A large number of brain structures are involved in the processing of visual signals, the interconnections of which are numerous and not fully understood.

The combined function of the oculomotor apparatus is to provide a focused, clear image of the outside world on the two retinas. For both eyes, the task of tracking an object must be performed with an accuracy of several arc minutes - otherwise, the visible image will be doubled.

All oculomotor reactions are designed to provide the main task of the visual apparatus - the maximum human perception of visual information. The physiology of vision is provided by various systems that make up the visual apparatus. The optical system of the eyeball focuses images on the retina, the pupil regulates the amount of light falling on the retina, and the muscles of the eyeball ensure its continuous movement.

The human visual system consists of a peripheral part, represented by the optical visual tract in the eyeball, pathways that include the optic nerve, the axons of the optic neurons, and the central part of the system in the brain. The central section consists of the subcortical centers and the cortical visual center of the occipital lobe of the brain.

For the perception of electromagnetic radiation in the visible range, which is the basis

of vision, are the receptors of a protein nature contained in the photoreceptor membrane of the cells of the retina of the eye - rhodopsin and iodopsin. The visual pigments of the cones are iodopsins, which are tuned to different parts of the spectrum, and the rods have only rhodopsin, which can distinguish only the emerald part of the spectrum from colors.

The retina is formed by two main types of visual cells - rods with light-sensitive rhodopsin (about 120 million cells per human retina) and cones with light-sensitive iodopsin (about 7 million cells). Cones, concentrated predominantly in the central region of the retina (called the fovea), function only in bright light and are responsible for color vision and sensitivity to small details, while the more numerous rods are responsible for vision in low light and turn off in bright light. Thus, of all existing mammals, only the higher primates, including humans, have trichromatic vision. The presence of two photoreceptor systems (cones and rods), differing in light sensitivity, provides adjustment to the changing level of external illumination.

The absorption of a light quantum by rhodopsin leads to a number of its photochemical transformations - photolysis. Photolysis occurs in several successive stages, each of which has a corresponding duration. The primary event associated with the absorption of a photon by rhodopsin takes about 200 fs. This event is followed by the formation within milliseconds of several intermediate forms of rhodopsin, each of which is characterized by its own absorption spectrum.

Light activation of rhodopsin is the only light-dependent process. All other stages of photolysis are light-independent; they are associated with molecular conformational rearrangements and are a consequence of this primary act of light absorption. The electrophysiological response of a photoreceptor cell to a light stimulus lasts for hundreds of milliseconds and then stops due to the existence of mechanisms responsible

for turning off the light-dependent cascade and restoring the dark state.

The cones located in the central part of the retina provide central shaped vision and color perception. Central shaped vision is the ability to discern the shape and details of the object in question due to visual acuity. The retina of the mammalian eye is called an inverted organ because photoreceptors, which are the first working link of the retina, are located in the lower layer, and above them are two layers of neurons that collect information from photoreceptors and transmit it to the brain.

The most important area of the retina is the macula or macula, which determines visual acuity. The spot diameter is 5-5.5 mm, it differs in color from the surrounding tissues, since the underlying pigment epithelium is more intensely colored here. In the center of the macula is the fovea, or fovea, which forms as a result of the thinning of the retina. The central fossa makes up 5% of the optic part of the retina, but up to 10% of all cones are concentrated in it. In the middle of the central fovea lies a dimple - a depression with a diameter of 0.2-0.4 mm, it is the place of the greatest visual acuity, it contains only cones (about 2500 cells).

In humans and other great primates (but not all mammals), the fovea reaches about 700 micrometers in diameter. In the fovea, the greatest visual activity is observed in comparison with other parts of the retina, which is caused by structural and compositional changes in this region. A feature of this zone is the shift of the cells of the proximal retinal neurons to the side, so that the light reaches the photoreceptors with minimal distortion. Fovea consists mainly of cones, the number of which increases as it moves towards the foveola (light point in the center of the fovea). This system provides a very high resolution of visual information, which is caused by another interesting mechanism: each cone in the fovea is connected to only one bipolar and one ganglionic cell. In other parts of

the retina, each bipolar and ganglionic cell works with multiple photoreceptors, rather than one, as in the fovea.

An unusual anatomical feature of the retina is that it is directed by photoreceptors to the pigment epithelium. This enables photoreceptors to efficiently restore visual pigments. Photoreceptors are very sensitive to the environment, as they constantly have to deal with the effects of a large stream of photons and free radicals. Stacking photosensitive elements in the outer segment of photoreceptors makes possible the daily planned restoration (renewal) of these elements. In this case, new structures are collected at the base of the photoreceptors, while the old elements at the apex are destroyed by neighboring cells of the retinal pigment epithelium. Complete renewal of the outer segment takes ~ 10 days in higher vertebrates and 6-9 weeks in lower vertebrates.

Visual acuity is the ability of the eye to perceive two points located at a minimum distance from each other as separate. The minimum distance at which two points are visible separately depends on the anatomical and physiological properties of the retina. If the images of two points fall on two adjacent cones, they will merge into a short line. Two points will be perceived separately if their images on the retina (two excited cones) are separated by one unexcited cone. Thus, the diameter of the cone determines the magnitude of the maximum visual acuity. The smaller the diameter of the cones, the greater the visual acuity. For most people, the threshold angle of view (angular size of an object) corresponds to one minute. All tables for the study of visual acuity are built on this principle.

The electrophysiological effect of a photoreceptor cell on a light stimulus lasts for hundreds of milliseconds and then stops due to special mechanisms that "turn off" excitation and restore the "dark" state. The most difficult thing in the process of returning the photoreceptor to the dark state is the restoration

of the photosensitivity of rhodopsin. The slowest reaction is the breakdown of the rhodopsin complex.

From the retina, an electrical signal is transmitted along the optic nerve to a specialized cell cluster located deep in the brain - the so-called external (lateral) geniculate body. The signal then enters the visual cortex located in the back of the brain. Initially, information enters the primary visual zone, from where, after passing through several layers of synaptically connected cells, it is transmitted to neighboring zones of a higher order, where, ultimately, the image of the object we are looking at is formed.

Visual functions are closely related to each other and constitute a single whole, called the act of vision. At the same time, rods and cones cannot perceive and transmit information to neurons about the movement of a visual signal in one direction or another.

The oculomotor apparatus and binocular vision are a complex sensorimotor mechanism, the physiological significance of which is determined by its two main functions: motor (motor) and sensory (sensitive). The motor function ensures the guidance of both eyes, their visual axes and the central pits of the retinas to the object of fixation; sensory - fusion of two monocular (right and left) images into a single visual image.

The position of each eye is controlled by six separate muscles, two of them - the outer line and the inner line - control the horizontal rotation of the eyes, carried out when looking from left to right or from close objects to distant ones. The other eight muscles, four in each eye, control the raising and lowering of the eyes, i.e. turn in the vertical plane.

Any movement of one eye is almost always part of a more complex set of movements. If we look at an object very close, both eyes turn inward. If we look to the left, the right eye turns inward and the left eye turns outward. If we look up or down, both eyes turn up or down together.

All these movements are controlled by the brain. Almost every movement that is performed is the result of the joint contraction of many muscles and the relaxation of many others.

It would be natural to expect that when examining the world around us, our eyes will smoothly scan the entire scene with continuous movements. In fact, when fixing an object, the eyes are set so that the image of this object falls into the region of the central fovea of both eyes. Then the eyes are held in this position for a short time, and then the eyes jump abruptly to a new position and fix a new target, which is located somewhere else in the visual field and attracts attention by moving somewhat relative to the background or having some then an interesting shape. During such a jump, or saccade, the speed of eye movement is so high that the visual system does not have time to respond to the movement of the image along the retina and we simply do not notice it. (It is possible that vision is disabled during the leap period by some kind of neural circuitry that links the oculomotor centers to the main visual pathway).

Jumping eye movements (saccades) occur when looking at stationary objects. Rapid turns of the eyeball (10-80 ms) alternate with periods of motionless fixation of the gaze at one point (200-600 ms).

Thus, the process of examining the visual field while reading or simply looking at the surrounding space consists of a series of rapid jumps from one point to another.

The task of the oculomotor system, apparently, is not to keep the image motionless on the retinas, but to prevent its smooth continuous displacement.

When tracing a moving scene, the gaze fixes some object and maintains its fixation by smoothly moving the eyes until the object leaves the field of view. Then a jump is made and a new object is fixed. This sequence of eye movements - a smooth tracing movement in

one direction, and then a saccade in the other is called nystagmus.

When considering a motionless scene and fixation at any point, this fixation is not absolutely motionless. Despite all attempts to rigidly fix the point, the eyes do not remain completely at rest, but perform continuous micromovements, called microsaccades. They occur several times per second and are directed more or less randomly, reaching an amplitude of 1–2 arc minutes [1].

It is known that if the image on the retina is artificially stabilized by special methods, eliminating its displacement relative to the retina, then the visual image after about a second seems to "fade" and the field of view becomes completely empty! (The simplest way to stabilize is to attach a point light source to a contact lens; when the eyes move, the light source also moves and the light spot quickly becomes invisible.) If, after stabilization, the image on the retina is even slightly displaced, the light spot immediately reappears.

Thus, the visual system ensures that cells are insensitive to stationary objects. At the same time, microsaccades are necessary in order to continuously see stationary objects. It can be assumed that complex cells of the cortex, which are especially sensitive to the movement of the stimulus, are involved in this process, but, probably, cells with directional selectivity are not involved, since microsaccades are clearly randomly distributed in directions.

On the other hand, the directional selectivity mechanism should be useful for detecting the movement of objects relative to a stationary background, signaling the presence of movement and its direction. In order to follow a moving object against a stationary background, you need to fix the object and move your gaze with it. In this case, the image of the entire scene will move along the retina. The movement of all the details of the stationary background along the retina should lead to a violent activity of the cells of the cerebral cortex.

Therefore, the mechanism of how the image of reality is formed in the brain is not only optics and chemical reactions occurring on the retina. Our brain plays the most important role in creating this picture - and not only the visual cortex, which makes the figures three-dimensional, separates them from the background and paints them in the desired colors, but also the other departments that are responsible for vital functions.

The purpose of this work is to study the individual characteristics of the human visual apparatus using a special technology for recording eye movements, which allows one to clearly demonstrate all the features of the behavior of the oculomotor apparatus. This technology is widely used in various tasks related to the visual system, research in the field of psychophysiology, psychology, cognitive linguistics, medicine and other areas of science, technology, and even sports, and even in marketing research to assess the effectiveness of print advertising and design.

2. EYETRACKING TECHNOLOGY

EyeTracking (eye tracking or tracking the movement of the eyes) is a method that determines the coordinates of the gaze: the point of intersection of the optical axis of the eyeball and the plane of the observed object or screen, on which some visual object is located. The Eye Tracker recognizes and records pupil positions and eye movements. It can be worn on the head (glasses) or stationary (a special stand in front of the monitor screen). There are several technologies available to record eye movements. Currently, a special high-precision infrared camera is most often used, which captures the pupil and the direction of the respondent's gaze [2].

The studies were carried out on the iView X™ HiSpeed 1250/500 device of the German company SMI (HSSMI), designed for high-speed video recording of eye movements in the infrared range. It consists of a recording high-speed video camera, an infrared light source, a

column-column with a head rest and a chin rest, a monitor for displaying graphic objects, a personal computer, and a software package. Assessment of the directionality of eye movements is based on video information about the relative location of the centers of the pupil and corneal flare (Pupil center / corneal reflex method). The frequency of video recording of the surface of the eyes in monocular mode is 1250 or 500 Hz. In the video recording system, the subject's head is fixed using an ophthalmic frame, which avoids additional calculations associated with the subject's head movement [3].

Although, in general, the EyeTracking equipment satisfactorily reproduces micro- and macro-eye movements, there are disturbing influences that distort the picture of fixations and targeted saccadic eye rotations. The high frequency of video recording of the surface of the eyes is in itself insufficient for an adequate display of the oculomotor processes. A procedure is needed to separate the actual movements from the totality of events occurring inside the eye and on its surface. Analysis of the raw data of the coordinates of the center of the pupil and the center of the infrared flare shows that distortions are generated when the coordinates of the center of the pupil change, but with practically unchanged coordinates of the center of the flare. Since the flare mobility is considered as the main sign of the extraocular muscles work, the registered distortions are not of an oculomotor, but of some other nature. Most likely, they are caused by dynamic processes taking place inside the eyeball, for example, by the microdynamics of the structure of the pupil during sharp eye movements, or by the peculiarities of the operation of the mathematical model underlying the eye image processing program. In any case, we are talking about external factors that distort the actual picture of oculomotor activity [4].

Already the first studies have shown that the formal task assigned to the subject has a huge impact on the result of an eye-tracking experiment. A series of experiments showed

that the result of the experiment depends not only on the visual stimulus, but also on the task assigned to the subject, as well as on the information that the subject expects to receive from the visual stimulus [5].

Recordings of the trajectories of eye movements showed that only a small part of the image elements attracts the subject's attention and his eyes fixate on these elements. The eye movement process reflects the human thinking process. The gaze, with some lag, follows the point where the subject's attention is directed. Thus, it is quite simple to determine which elements of the image attract the subject's attention, in what order and how often [6].

However, the records of the trajectory of eye movement show that the trajectory of the gaze and the fixation points often pass by the objects to which attention was actually drawn and only sometimes show short fixations. Thus, it was shown that it is impossible to unambiguously link directly the course of cognitive processes in the brain with the results of eye tracking experiments [7]. However, the analysis of eye movement trajectories associated with the process of accommodation in the fixation area allows one to investigate an algorithm that uses a "video processor" located in the brain to control involuntary movements of the oculomotor apparatus during visual perception of graphic information, as well as to investigate the individual physiological characteristics of the visual system of various people.

3. INDIVIDUAL FEATURES OF FIXATIONS IN THE PERCEPTION OF GRAPHIC IMAGES

Localization and identification of objects by the visual system occurs in the process of accommodation - the ability of the eye to focus on objects at different distances. At the same time, various accommodation mechanisms are triggered, providing good clear vision. The lens capsule is deformed, as a result of which the refractive power of the eye changes. The light

beams are focused on the retina, making objects clear. The oculomotor apparatus carries out micromovements of the eye in the region of the central part of the retina when the gaze fixes any object that attracts attention, while the fixation is not absolutely motionless [8].

It is known that oculomotor reactions have a decisive influence on visual acuity [9]. High visual acuity is extremely important in various life situations and for many professional tasks, from confident object recognition to driving cars and airplanes. It is well known that the optical and anatomical characteristics of the eye contribute to good vision and spatial resolution, however, the influence of individual characteristics of reflex eye movements on the characteristics of vision has hardly been studied.

3.1. GEOMETRIC PARAMETERS OF FIXATIONS

An example of recording the trajectory of eye movement when examining an object is shown in **Fig. 1**. In the experiments, all graphic objects were demonstrated on a 295×520 mm monitor with a resolution of 1920×1080 pixels. In this

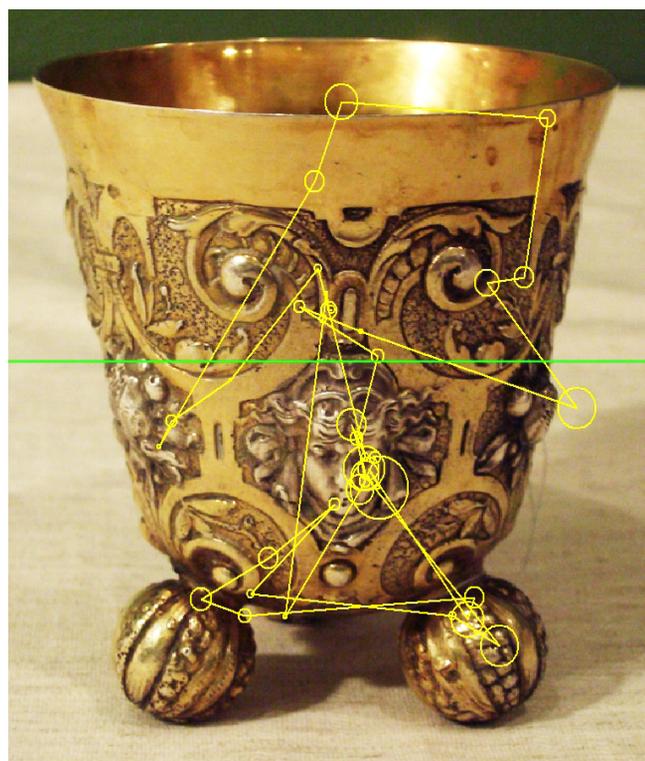


Fig. 1. The trajectory of eye movement when looking at a graphic object. The circles indicate the areas of eye fixation.

case, the distance from the eyes to the screen was 800 mm.

There are various integral criteria for determining individual differences in eye movement of different observers when looking at identical images [10]. In turn, the size of the fixation in the perception of graphic images can also reflect the individual characteristics of the visual apparatus of various observers.

The external contours of fixations on real tracks have, as a rule, a rather complex configuration. In order to roughly estimate the area occupied by the fixture, it is necessary to simplify the geometry. In the first approximation, by the fixation area we mean the area of the rectangle described around the fixation, i.e. in each fix, you can find the maximum and minimum values for each coordinate, find the difference between them, and get the area of the rectangle. Estimates calculated in this way will be overestimated, but as a first approximation they give an objective idea of the real areas (sizes) of fixations and their ratio.

In **Fig. 2** shows the results of such studies in the form of area distributions for three subjects E, O and V, considering three different graphic images with different structures of T, F and W at eight different orientations, differing by rotation counterclockwise by 45° (total 24 images). The total number of fixations recorded on the tracking for all subjects is 1723. For individual subjects, this number was distributed as follows:

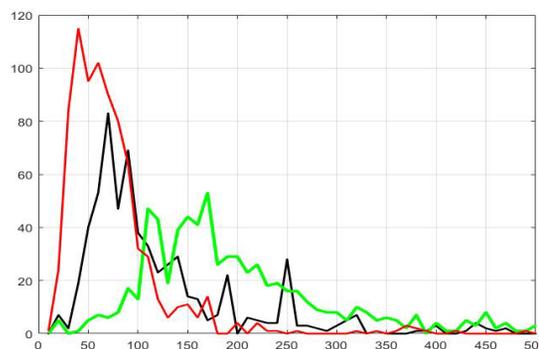


Fig. 2. Distributions of fixations by area size for three subjects E (green), O (black) and V (red). The fixation area is plotted on the horizontal axis in mm².

E - 551, O - 485, V - 687. It is natural to assume that the size of fixations is determined by the diameter of the fovea. when viewed, to provide a clear, specific portion of the image, it must be projected onto the fovea. In this case, a specific fragment of the image can have a variety of sizes and is not always projected onto the entire fovea area.

Fig. 2 demonstrates that all three distributions have a similar, very characteristic shape: a small number of fixations with a small area, a characteristic maximum, and a rather long tail.

If we estimate the diameter of a circular area with such an area, we get a value of about 30 mm. For the diameter of the fovea, taking into account the geometric data of the installation and considering the focal length of the lens of the order of 20 mm, we obtain approximately 750 μm , which is a somewhat overestimated value. The latter result is easily explained by a very crude method of calculating the areas of fixations.

The characteristic maxima of the distributions of individual fixation sizes for subjects E, O and V, taking into account the focal length of the lens of the eye of the order of 20 mm, fall on areas of 150, 75, and 50 mm^2 . Estimation of the size of the fovea for these values of the areas of fixation gives values of the order of 400, 250, and 200 μm , respectively, which is close to its real size. The geometrical dimensions of the fixings are given in the screen coordinate system.

The size of the commits depends on the type of object being monitored. This can be shown by comparing the process of accommodation in the perception of graphic objects with different sizes. In **Fig. 3** shows the distributions of all fixations over the area for two subjects A and V. The subjects were asked to read 12 short texts. Fixations on the eye movement trajectory were analyzed. We also used the validation data before the start of measurements, when each subject undergoes an individual adjustment of the recording process by forcibly fixing

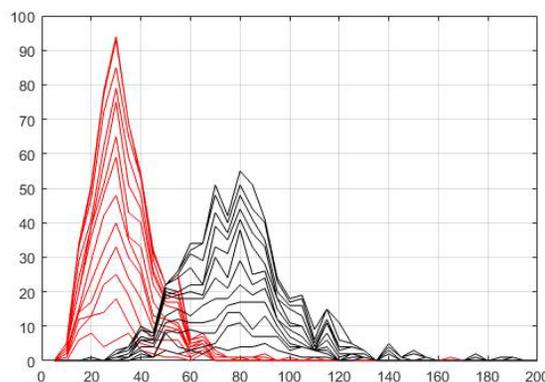


Fig. 3. Distributions of fixations by area size for two subjects V (red) and A (black). The fixation area is plotted on the horizontal axis in mm^2 .

his gaze at the control points of the monitor screen. When plotting the graphs in Fig. 3, the distribution for fixations of the given text was added to the distribution for the previous text. The result is a cumulative distribution for the 12 texts and commits that took place in the validation. It can be seen from the figure that for each subject the distributions of fixations for all texts are extremely similar, the maxima of the distributions practically do not change their position, and the half-width of the distributions remains practically unchanged. If we compare the distribution for subject V, obtained by examining three graphic plots in eight different angular positions (Fig. 2 - red curve) with the distribution obtained for the same subject during reading, it can be noted that the maximum of the distribution has shifted towards smaller areas (from 50 to 30 mm^2) and the distribution half-width also decreased from approximately 80 mm^2 to 30 mm^2 . The decrease in the size of fixations can, apparently, be explained by the fact that when reading the text, only the central region of the fovea is involved - the foveola, because letters are significantly smaller than grayscale elements.

The case of perception in the absence of an image (imitation of fog), when the subject looks into the distance through a white sheet, is quite interesting. In **Fig. 4** shows the general distribution of lengths in fixations and saccades in the gaze trajectory for one subject in the case

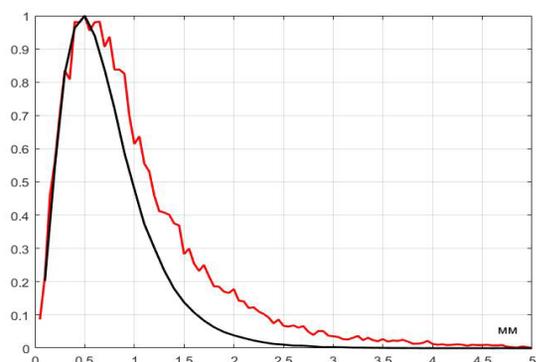


Fig. 4. Distributions of displacements in all fixations along the length, normalized to their maximum, for one subject in the case of perception of a halftone image and in the absence of an image.

of perception of a halftone image and in the absence of an image.

The figure shows that in the absence of an image, the video processor of the oculomotor apparatus works according to the standard algorithm, but the distribution of lengths in fixations and saccades becomes almost twice as narrow.

3.2. DURATION OF FIXATIONS

Various elements of the visual apparatus are involved in the perception of graphic information. In this case, the duration of fixations may be associated with some individual characteristics of the process due to both the physiological structure of the eyeball and the processes occurring in the brain [11].

From **Fig. 5** it can be seen that the maximum in the distribution of fixations by their duration for subjects in three half-tone graphic images for all subjects is approximately in the same place (0.25 s), which slightly exceeds the same value in the case of reading [12].

Fig. 6 shows the distribution of the number of fixations by their duration when reading six short texts by eleven subjects (*a, b, c, ... k*). At the same time, text no. 1 is grammatically flawless, while the rest were distorted in terms of increasing reading difficulties. Thus, 66 trajectories were processed and a separate distribution was constructed for each tracking.

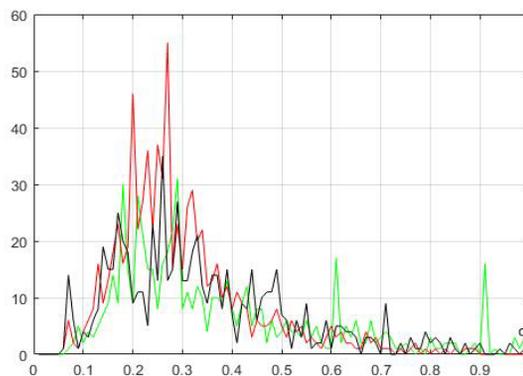


Fig. 5. Distributions of fixations by their duration for subjects E (black), O (green) and V (red), in three graphic images rotated at eight different angles. Time is plotted along the horizontal axis in seconds.

In this case, all distributions were the same (they contained 100 points with a step of 0.02 s), so they could be added. Such summation was performed for each text for all eleven subjects, and it is these total distributions that are shown in **Fig. 6**. It can be seen that due to the uniformity of the problem (reading the text) the maxima for all distributions lie within 0.2–0.25 s. At the same time, the distribution according to the first

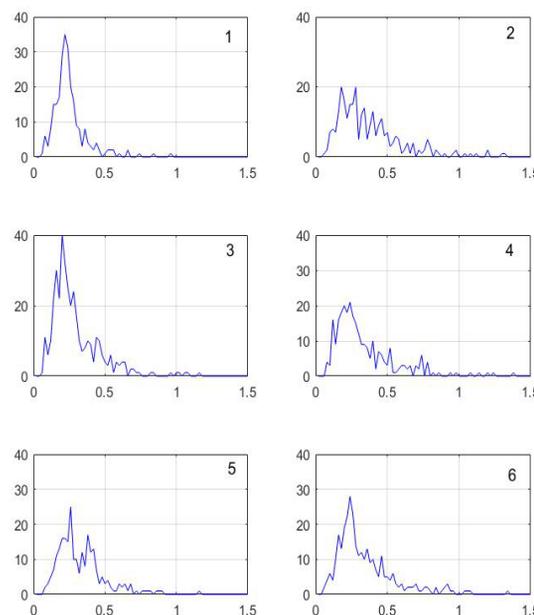


Fig. 6. The total distribution of fixations by their duration when reading six short texts (the text number is indicated in the upper right corner) by eleven subjects (*a, b, c, ... k*). On the horizontal axis - time in seconds.

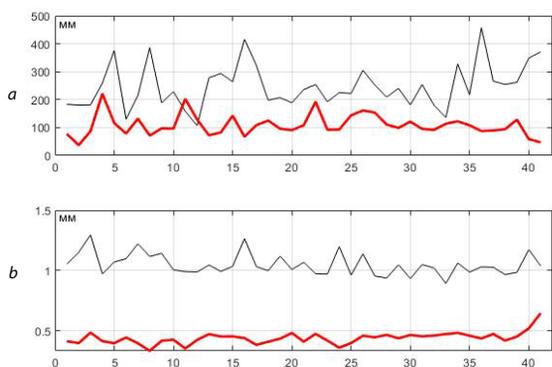


Fig. 7. *a* - total length in each fixation, *b* - average value of displacement in each fixation for two subjects *A* (black) and *V* (red) when reading undistorted text.

(undistorted) text turned out to be the most compact. The analysis takes into account the total number of commits in the distribution.

In **Fig. 7** shows the results of fixation analysis for two subjects *A* and *V* when reading undistorted text. Shown is the total length for each fixation and the average offset for each fixation.

In **Fig. 8** shows the results of the analysis of fixations for subject *V* when reading the remaining five texts and points of forced fixation at checkpoints during the validation process. The figure shows that all fixation parameters for subject *V* are practically identical to the results and repeat the results obtained in the analysis of the first undistorted text.

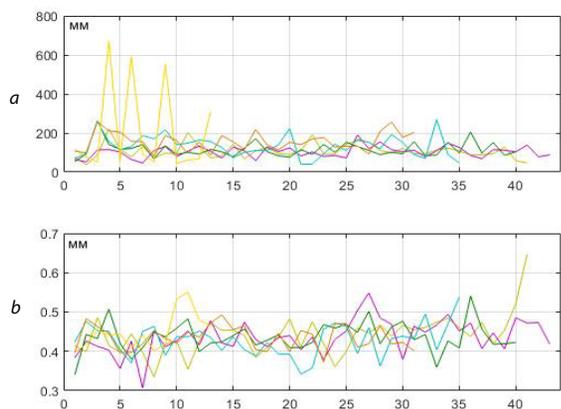


Fig. 8. *a* is the total length in each fixation, *b* is the average value of the displacement in each fixation for the subject *V* when reading five texts and points of forced fixation at checkpoints and during the validation process.

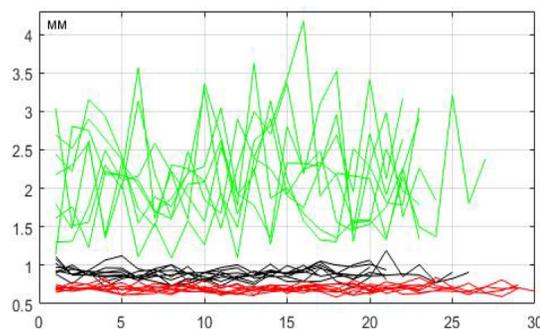


Fig. 9. Average value of displacement in each fixation for three subjects *E* (green), *O* (black) and *V* (red) upon perception of eight variants of the test image **Fig. 10** rotated at various angles.

It should be noted that when performing the task of forced fixation, when the eye is deliberately held for some time at one point, the total fixation length increases several times (maxima in the initial section of the upper graph). Although forced fixation is fundamentally different from the reading process and requires additional efforts when fixing the eye, the average value of displacement in these fixations also remains practically unchanged.

In **Fig. 9** shows the results of the analysis of fixations on the trajectory of eye movement for three subjects *E*, *O*, and *V* when perceiving eight variants of the test grayscale image **Fig. 10** rotated at various angles. Explicit vertical and horizontal details of this drawing allow you to demonstrate the individual characteristics of the perception of a complex graphic image.



Fig. 10. Test graphic image.

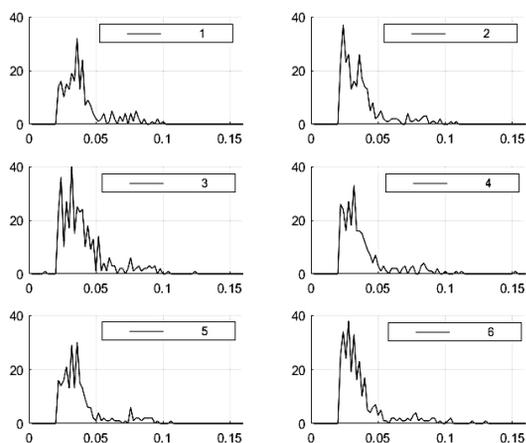


Fig. 11. Distribution of the number of saccades in 6 texts by their duration for 11 subjects.

All the above studies of the fixations of various subjects on the basis of various images showed that the oculomotor system, taking into account the physiological characteristics of the visual apparatus, is equally controlled by the "video processor" of the brain when the eye is accommodated to the image elements. The only objective individual feature of human vision that unambiguously characterizes the perception of graphic information is the value of the average displacement in fixation. It is she who is the "visiting card" of the subject and remains practically unchanged both when reading, and when examining halftone images, and in test validation with forced fixation of the gaze.

In Fig. 11 shows the number of saccades in six texts according to their duration for eleven subjects [13]. Summation was performed for each text for all subjects. And in this case, the most compact is also the first cumulative distribution referring to the undistorted text. This distribution clearly shows two maximums. The first (0.03 s) is defined by lowercase saccades (intervals between words in a line). The second (0.06-0.08 s) is determined by interlinear or reverse saccades. It is also seen that due to the uniformity of the problem (reading the text), all distributions are quite similar.

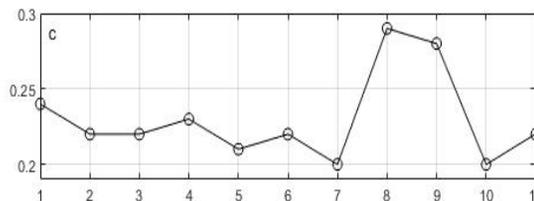


Fig. 12. Average duration of fixation for each of 11 subjects.

3.3. DYNAMIC FEATURES OF THE PERCEPTION OF GRAPHIC INFORMATION

It is convenient to investigate the dynamic features of the perception of graphic information on tasks when reading texts. Apparently, the speed of reading is determined by the duration of the stay of the gaze in fixations, since the gaze is in them about 80% of the time and the main time saving can only be in fixations.

For example, analyzing the first (undistorted) text for eleven subjects, one can draw some conclusions about the individual characteristics of the reading speed. The research results are presented in Fig. 12. According to this parameter, subjects No. 7 and No. 10 are the best, respectively, their average gaze dwell time in fixations is 0.1965 and 0.1973 sec.

In Fig. 13 shows the dependences of the duration of each fixation for all subjects. The figure shows that the number of fixations in subjects varies from 17 to 31, and the time spent on reading, from 4.94 to 10.2 sec.

From Fig. 13, it can be concluded that all subjects spend practically the same time on

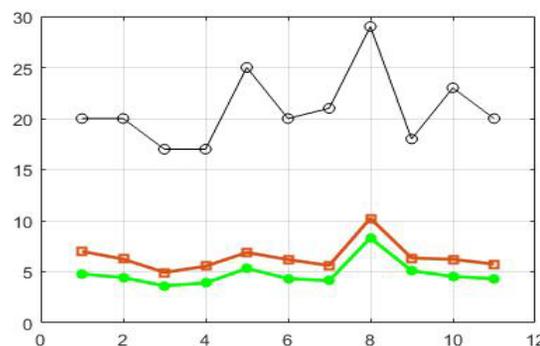


Fig. 13. Eleven subjects read the same undistorted text. The black curve is the number of fixations in the text, the red curve is the reading duration, the green curve is the duration of all fixations in seconds.

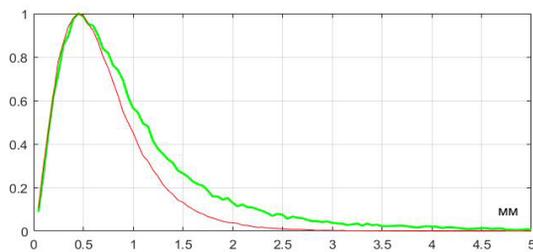


Fig. 14. Total distributions of gaze displacements along the length in fixations, normalized to their maximum, for subject V from five different images with a break of six years.

saccades, since the difference between the total reading time and the total duration of all fixations for them is almost constant and amounts to 1.5-2 sec.

In Fig. 14 shows the total shift of gaze in fixations normalized to its maximum, for subject V from five different images with a break of six years [13]. It can be seen from the figure that the general nature of the perception of graphic information has not practically changed.

The duration of fixations is directly related to the total length of the gaze trajectory in fixation, which can be recorded with sufficient accuracy by the EyeTracking equipment.

In the upper images Fig. 15 shows the gaze tracking of three subjects for the image in Fig. 10.

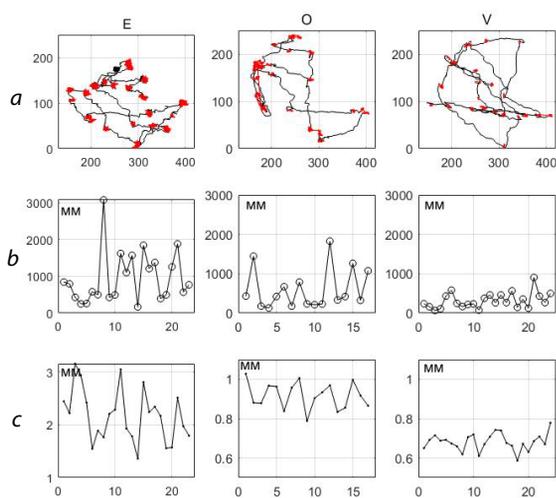


Рис. 15. a - gaze tracking of three subjects for the image in Fig. 10, b - the total length of all displacements in a particular selected fixation, c - the value of the average gaze displacement in a specific selected fixation.

The middle plots show the cumulative length of all displacements in a particular fixation selected, and the bottom plots show the amount of average gaze displacement at a specific fixation selected.

From Fig. 15 clearly shows the individual characteristics of the subjects in the perception of this image. In subject E, the area, the total average length of the track, and the average shift in gaze in fixation are significantly greater than in subjects O and V. The average shift in gaze in fixation for E is 2.1 mm, for O this value is 0.9 mm, and for V it is approximately 0.7 mm.

3.4. INTERNAL STRUCTURE OF FIXATIONS

The gaze trajectory in fixation has an internal heterogeneous structure, which is visible on the time base of the fixation track. This structure of reactions of the oculomotor apparatus, apparently, is completely determined by the physiological characteristics of the eyeball and the algorithm of the accommodation process, which is regulated by the "video processor" of the brain when perceiving graphic information.

In Fig. 16 shows the trajectory of subject V's eye movement during forced fixation during the validation process.

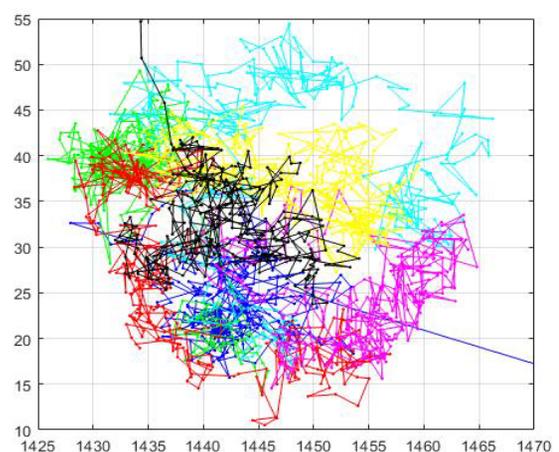


Рис. 16. The trajectory of subject V's gaze movement during forced fixation during the validation process. The entire fixation is sequentially divided into 7 fragments of 314 points, the tracking of each fragment in the figure is represented by its own color. The sequence of colors from the first to the last fragment: blue, green, red, cyan, magenta, yellow, black.

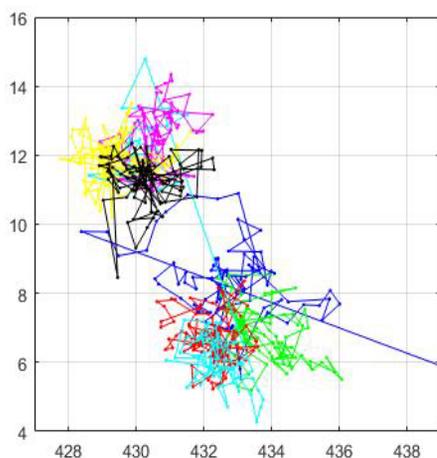


Fig. 17. The initial segment of the gaze trajectory during forced fixation during the validation process. The segment is also divided into 7 fragments of 100 points, the tracking of each fragment in the figure is represented by its own color. The sequence of colors from the first to the last fragment: blue, green, red, cyan, magenta, yellow, black.

In Fig. 17 shows the initial portion of the eye movement trajectory during forced fixation during the validation process.

From Fig. 16 and 17, it can be seen that the trajectory of the shift of the gaze in fixation has an internal non-uniform structure. The total trajectory of eye movement in the fixation area is determined by a set of successive clusters, which are clearly visible in the figures. Such a fixation structure is apparently associated with the individual structure of the fovea and the processes of restoration of the photosensitivity of rhodopsin in the retinal photoreceptors.

4. CONCLUSION

The work is devoted to identifying the individual characteristics of the human visual apparatus associated with the anatomical and psychophysiological parameters of the body. Based on the EyeTracking technology, the physiological aspects of the perception of visual information by the oculomotor apparatus, which are not associated with active cognitive activity, have been investigated. The individual features in the size of fixation when reading text and examining halftone graphic objects in various people have been investigated. The

time durations of fixations in different people, associated with the process of accommodation, as well as the internal structure of fixations, were investigated.

It is shown that the trajectory of the gaze shift in fixation has an internal heterogeneous structure. The total trajectory of eye movement in the fixation area is determined by a set of successive clusters. Such a fixation structure is apparently associated with the processes of restoration of the photosensitivity of rhodopsin in the photoreceptors of the retina.

All the above studies of the fixations of various subjects on the basis of various images showed that the oculomotor system, taking into account the physiological characteristics of the visual apparatus, is equally controlled by the "video processor" of the brain when the eye is accommodated to image elements and the only objective individual feature of human vision that uniquely characterizes the perception of graphic information is the amount of the average displacement in the fixation. It is she who is the long-term "visiting card" of the subject and remains practically unchanged both when reading and when examining halftone images and in test validation with forced fixation of the gaze.

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