23

Application of infrared illumination to assess pupillary response to light

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It is proposed to use infrared illumination to measure the reaction of the eye pupil to changes in illumination, which makes it possible to separate the functions of impact on the eye and registration of its reaction. The corresponding installation allowing to measure the diameter and integral area of the pupil, as well as the rate of its constriction is created. The results of testing of the setup, indicating its technical capabilities, are presented. Keywords: optical measurements, human vision, pupillary response of the eye.

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Introduction

Human vision is adapted to the $0.4-0.8\,\mu$m optical interval, which is known as the visible range. The response of the visual apparatus to light characterizes the state of the human nervous system. Specifically, one important mechanism is the pupillary response, which consists in adaptation of the eye to the incident light flux magnitude by a change in the size of the entrance pupil. A check of a sufficiently fast response is an important diagnostic test for identifying possible anisocoria and determining the disease stage and is characterized by such parameters as pupil response time, constriction/dilation limits, pupil shape and symmetry, and pupil response speed for each eye: OD (oculus dexter) and OS (oculus sinister).

This test is used widely in ophthalmology, and the reason for a non-standard response may be both ophthalmological (e.g., the structure of an eye) and neurological or psychiatric [1–4]. It is also an essential stage of the preoperative examination for refractive surgery. All this demonstrates the importance of the test both from a medical point of view and for the purposes of analysis of professional suitability.

The engineering support of ophthalmological devices is a problematic issue at present. First, there are certain difficulties in maintaining the technical condition of foreign equipment and updating regularly the stock of instruments by replacing outdated ones or those with service life expired. Therefore, the development of simple and effective technical means to solve this problem is presently relevant.

Second, existing instruments, such as an ophthalmoscope or refractometer, lack the function of quantitative assessment of the response to strong and sudden changes in light brightness, which is especially necessary when verifying the professional suitability of individuals permitted to drive vehicles and work under highly variable lighting conditions [5]. There are currently no available instruments designed to diagnose the state of the organ of vision that would determine the pupillary response to intense light. In addition, the rate of pupil change under a several-order-of-magnitude variation in illumination remains virtually unstudied [6]. In this context, the need arises to design specialized equipment that would solve these problems.

Measurement principle

One of the problems in development of devices for pupillary response measurement is that the means of video recording of this response require illuminating the examined object with visible light, which, even at minimum illumination levels, affects the state of the pupil and, consequently, may distort the measured parameters. An alternative measurement idea is to separate the functions of active influence on the pupil and recording of its response. In this case, the pupil illumination system, which allows for sharp changes in brightness, operates within the eye's sensitivity range (specifically, within $0.4-0.75\,\mu$m), and the recording system operates in the near infrared (IR) range. The pupillary response recording system then has no effect on the state of the object and the testing results.

In the process of testing, a specialized source produces a light stimulus of the required type (switching, pulse, periodic blinking), and the eye response is recorded by a system containing an IR illumination source and an IR camera. The results presented in the form of a series of images of the eye are analyzed by a computer and are available for review on a monitor. They may also be stored digitally in an electronic storage system and provided as a printout. If necessary, the test may be repeated, possibly with changes in the impact characteristics: the decision to continue or terminate the research is made by a medical researcher or a laboratory technician in accordance with the results obtained and the testing standards. The entire

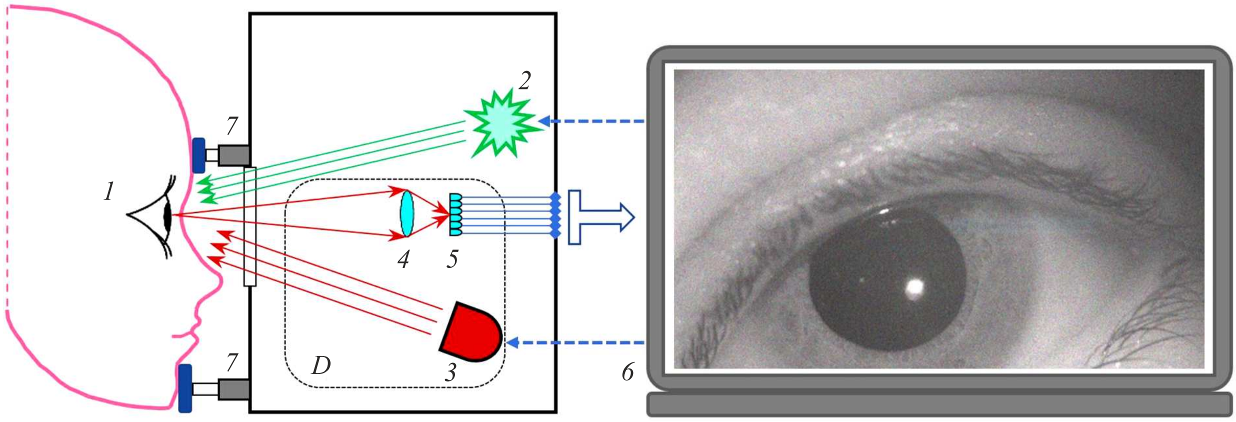

Figure 1. Block diagram of the experimental setup: *1* — eye under study, *2* — white light illuminator, *3* — IR illuminator, *4* — lens, *5* — video camera, *6* — computer with a monitor, and *7* — adjustable stop. *D* — detection subsystem.

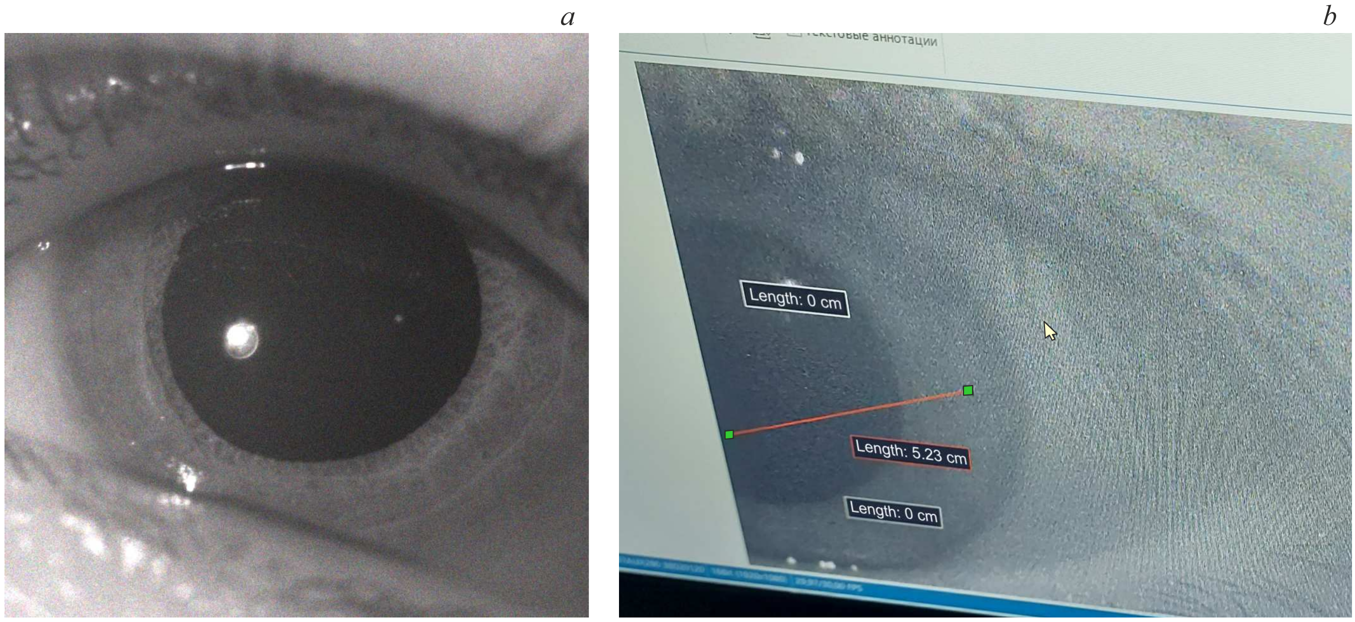

Figure 2. Image of the examined eye obtained with an IR camera (*a*) and shown on a monitor (*b*) in a program for measuring its parameters, which allows one to determine the geometric dimensions of an image.

measurement cycle may be automated if the light source has external control.

Diagram of the setup

A compact desktop setup (Fig. 1) was constructed to study the pupillary response. This setup features two light sources (one produces white light with a power of 1 W and another source emitting at a wavelength of 850 nm), receiving lens *4* with a focal length of 25 mm, and video camera *5* operating in the visible and near IR ranges (DFK 33UX290) and outputting the image to computer screen *6*. The examined eye was always kept in focus through adjustable displacement of the recording system relative to elements *7* fixing the patient's face (i.e., always remained at the same distance).

Following adaptation of eye *1* to darkness, it was exposed to a broad-spectrum light stimulus. Owing to the use of IR illumination, the video camera recorded frames continuously both in the dark and when the eye was exposed to white light. The data processing program evaluated the speed characteristics of pupillary response and the initial and final pupil diameters.

The system was calibrated in the following way. The spatial dimensions of a reference object (mira, ruler) positioned at the eye's location were transferred to the screen, which allowed us to determine the conversion factor in millimeters per pixel. The calibration object was also positioned at the focus of the lens.

The setup was tested (Fig. 2) under illumination with a duration of 1 s and a brightness of 300 cd/m^2. With an initial pupil diameter $d_{\text{start}} = 5.21$ mm and final size $d_{\text{fin}} = 4.89$ mm, the constriction rate was $V_{\text{con}} = 2.98$ mm/s, while the dilation rate was significantly lower ($V_{\text{exp}} = 0.62$ mm/s). The obtained data agree well with those reported in literature [7]. The maximum achievable error associated with pixelization on a typical SXGA monitor is 10^{-3}. Aberrations of the optical system may introduce distortion, but these systematic error components can largely be taken into account in image processing.

Discussion

The proposed approach and the designed setup open up opportunities for solving a number of practically relevant problems. Since the determination of pupillary response to light is an essential procedure used to diagnose pathologies in ophthalmology, neurology, and psychiatry, the construction of such devices with significantly expanded functional capabilities and a conceptually simple design allows one to solve the problem of equipping numerous laboratories and clinical diagnostic centers with analytical instruments of this kind. The assessment of pupillary response may also find applications in narcology, since it provides an opportunity to identify the probable effect of psychotropic or narcotic substances on the body and serve as a basis for subsequent biochemical research.

It should also be noted that the reported studies were conducted with a non-spectral wide-band excitation source, which could not guarantee the evaluation of adaptive characteristics of the pupil in all possible aspects. The illumination spectrum is one of the important factors that should be considered in research. In view of this, we plan to expand the spectral capabilities of the system at the next stage of experiments by installing an illuminator with a variable radiation spectrum (based, e.g., on an acousto-optic tunable filter). This modification should allow us to measure the response of the eye to changes in external illumination in various parts of the visible range, thus providing the data needed for a more accurate assessment of human traits and professional suitability.

Conclusion

The discussed method provides an opportunity to examine the eye response within a wide range of excitation characteristics (brightness, duration, time profile) while excluding the potential influence of measurement conditions on the studied object and the obtained result. Its capabilities in terms of identifying the spectral features of the visual response of eyes may well be expanded (with the use of light filters). The use of acousto-optic tunable filters, which may alter the spectral composition of radiation in a flexible and non-mechanical manner, in the illumination channel is a promising modification.

Compliance with ethical standards

This article does not contain any studies involving animals performed by any of the authors. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] S. Cecil, P.M. Chen, S.E. Callaway, S.M. Rowland, D.E. Adler. J. Chen. Critical Care Nurse, **31** (2), 25 (2011). DOI: 10.4037/ccn2010226

[2] M.D. Larson, M. Behrends. Anesthesia and Analgesia, **120** (6), 1242 (2015). DOI: 10.1213/ANE.0000000000000314

[3] F. Martínez-Ricarte, A. Castro, M.A. Poca, J. Sahuquillo, L. Expósito, M. Arribas, J. Aparicio. Neurología, **28** (1), 41 (2013). DOI: 10.1016/j.nrl.2010.07.028

[4] A.V. Oshorov, E.V. Aleksandrova, K.R. Muradyan, O.Yu. Sosnovskaya, E.Yu. Sokolova, I.A. Savin. Vopr. Neirokhir. im. N.N. Burdenko, **85** (3), 117 (2021) (in Russian).

[5] G.V. Makarichev, E.S. Putilin. Nauchno-Tekh. Vestn. Inf. Tekhnol., Mekh. Opt., **7** (38), 110 (2007) (in Russian).

[6] K.V. Karyaev, E.S. Putilin. Nauchno-Tekh. Vestn. Inf. Tekhnol., Mekh. Opt., **7** (38), 105 (2007) (in Russian).

[7] M.V. Tsimbal, A.L. Kutsalo, N.V. Shteinberg, D.S. Khomich. Vestn. Volgogr. Gos. Med. Univ., **1** (73), 124 (2020) (in Russian). DOI 10.19163/1994-9480-2020-1(73)-124-128

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