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Dynamic recording of the binocular point spread function of the eye optical system*

J. Santamaría, A. Plaza, J. Bescós

Instituto de Optica, Serrano 121, Madrid-6, Spain.

A method for the dynamic recording of the retinal mages of both eyes simultaneously is presented. The double passage method through the optic media of the eye is used to form the binocular image of a point object on a microchannel light intensifier. By a longitudinal shift of the intensifier, the corresponding images of the two eyes are separated. In this way binocular and monocular point spread functions of the eye optical system can be visualized and studied as well as the interactions and correlations between both eyes.

1. Introduction

Although the process of image formation by the human eye is, in general terms, the same as that in the conventional imaging systems there are some special characteristics, in the former case, that make its study more difficult. First the image plane is not accessible, therefore, the double passage method must be generally used. In this method, the image of a test object is formed on the retina and becomes the object for a second imaging process through the eye optical system by which an aerial image is obtained in the object space. The method is very useful, but the light leaving the eye is a very small fraction of the incoming light on the retina.

The second characteristic is the presence of internal movements in the eye, such as the microfluctuations of the accommodation [1, 2], due to which recording or measurement times must be short, otherwise only averaged states of the eye would be obtained. This factor limits even more the amount of the available energy.

In the double passage method lines, edges and gratings are generally used as test objects [3]. The point test is not used, mainly due to the small amount of energy that can be supplied (it always ranges within the energies that can enter into the eye without damage). The image of the point test is, however, of great interest, because it carries most of the information about the behaviour of the imaging system.

A method for the cinematographic recording of the point test has been previously reported [4], and in this paper we present a system for the dynamic

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recording of the binocular point spread function of the eye. The retinal images of a point test are visualized and recorded in real time with both eyes simultaneously and in this way the dynamic aspects of the image formation process as well as the interactions and correlations between both eyes can be studied. The system is described in detail and some typical results showing the binocular image of the point are presented.

2. System description

The method for the dynamic recording of the binocular point spread function is in essence a conventional double passage method that has been adapted for binocular observation. The system is schematically represented in Fig. 1. The

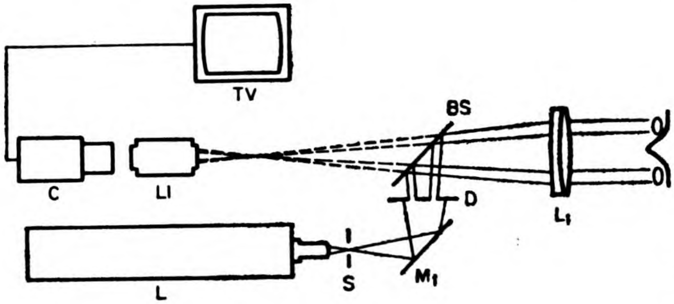

Fig. 1. Scheme of experimental set-up

observer looks with both eyes at the pinhole of a spatial filter (S) illuminated by a low power He-Ne laser beam (L). The light reflected in a first mirror (M_1) and in a beam splitter (BS) enters into the eye and in each retina an image of the point is formed. The lens (L_1) projects the point test at the desired distance from the observer and two diaphragms (D) placed in the optical path and at variable interdistance allow the selection of two small beams illuminating just the eye pupils, thereby eliminating most of the unuseful and disturbing light.

The light, reflected back from the retinas, after a second passage through the optical media of the eyes forms two aerial images regardless the position of the observer's head that does not require any special fixation. These two images are fused together at the symmetrical plane of the point object with respect the beam splitter, and the binocular point spread function is obtained. In fact, this image is the coherent addition of the two monocular point spread functions and includes the effects of the ocular interdependence.

In this plane a microchannel light intensifier (LI) is placed so that the image can be in real time comfortably visualized from the phosphor screen of the light intensifier or in a TV monitor through a video camera. In this last case the dynamic effects can be also studied in a video recording system. If the light intensifier is shifted out of focus, the two monocular components become separated in the display, without noticeable changes in their structure due to the high depth of focus. In this way, it is possible to evaluate each monocular component of the binocular image as well as their interactions and correlations.

It must be pointed out that the recorded images are not strictly the point spread function of the eye, since in the double passage the energy is two times perturbed by the optical media of the eye and once by the retina. If the retina is treated as a rugous reflecting surface represented by the amplitude reflectance $R(x, y)$, the monocular intensity distribution at the photocathode of the light intensifier, corresponding to a point object, can be expressed as

$$I(x, y) = \left|\left(P(x, y)R(x, y)\right) \otimes \tilde{P}(x, y)\right|^2$$

where $\tilde{P}$ is the Fourier transform of the amplitude transmission of the pupil and the symbol $\otimes$ means convolution.

From this expression and even more from the recorded images it is difficult to obtain quantitative information about the instantaneous state of the aberration wave or about the internal structure of the actual point spread function, since in the latter case the nonlinearities introduced during the recording step should be considered. However, the resulting images are most useful for evaluation and comparison purposes, as well as for the study of the dynamic behaviour of the eye during the accommodation process.

3. Experimental results

Figure 2 shows typical retinal images of the point test photographed directly from the screen of the light intensifier. This figure shows first the binocular point spread function for a subject with a normal visual acuity. In the middle there are the corresponding monocular point spread functions, i.e., the images obtained with the left eye and the right eye closed, respectively, and at the bottom, the two monocular components of the binocular point spread function. A segment corresponding to the angle of 5 minutes is also included in this figure and in the following (10 min.) for the estimation of the size of the images on the retina and for comparative purposes.

The speckle structure that can be observed in these figures is due to the coherence of the light and the rugosity of the retina. The next figures show consecutive images of a movie film taken at 25 i/s from the video screen. For this reason the speckle structure is lost, although it can be perfectly visualized in the TV monitor.

Figure 3a shows the images corresponding to an emmetropic observer with very high visual acuity, thus the images are very small and round. This case is, however, unusual and a more normal one is to obtain images of the type shown in Fig. 3b that correspond to an observer with the normal visual acuity of 1.

The effect of the microfluctuations of accommodation is shown in Fig. 4a. The constantly changing accommodation of the observer's eye is followed by changes of the residual astigmatism orientation. Figure 4b illustrates the in-

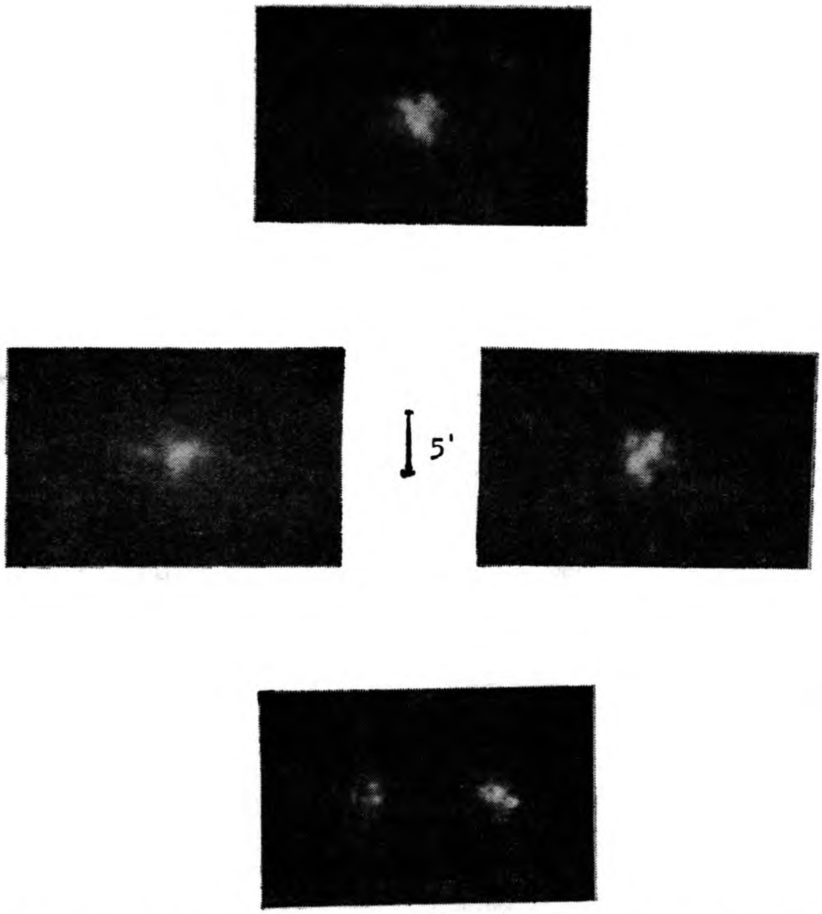

Fig. 2. Retinal images of the point test from the screen of the ight intensifier

fluence of an eye on the state of the contralateral, showing that for some persons it is important that the observation, recording and optometric refraction be made with the two eyes simultaneously. In the case shown in this figure the influence of one eye on the quality of the image of the other eye is obvious. When the observer occludes the right eye, the other eye suddenly changes its accommodation and the orientation of the residual astigmatism. After one second, the image becomes almost a perfect astigmatism focal line in the perpendicular direction.

Finally, by means of the lens L_1, the point test can be placed at six meters distance from the observer. In this way, with the help of a phoroptor or trial lenses, the system can be used as an objective refractometer [5]. If the observer is not able to accommodate on the point, the image either does not appear on the screen, or it is enlarged and diffused by defocusing, or deformed by astig-

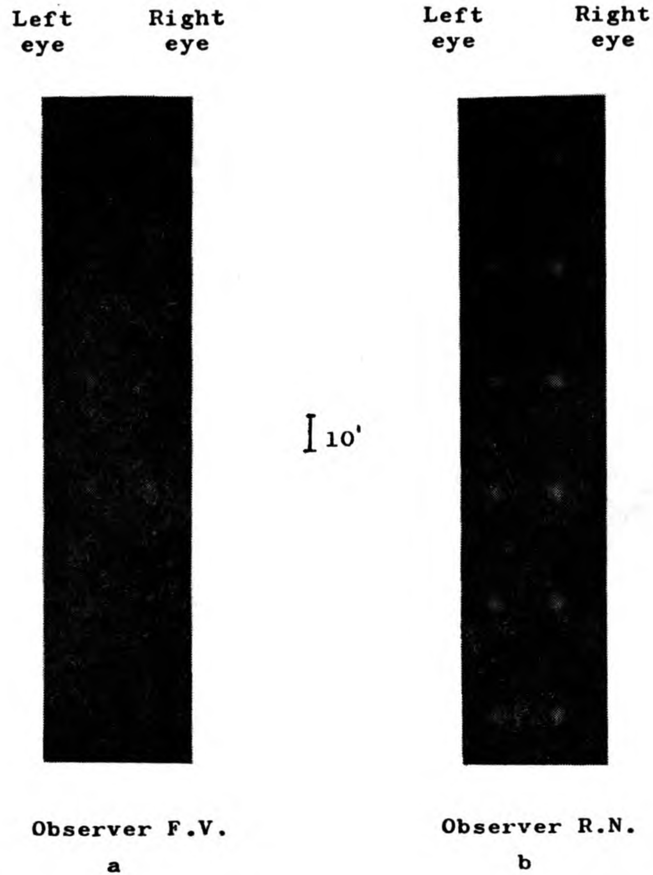

Fig. 3. Retinal images corresponding to observers with high (a) and normal (b) visual acuity

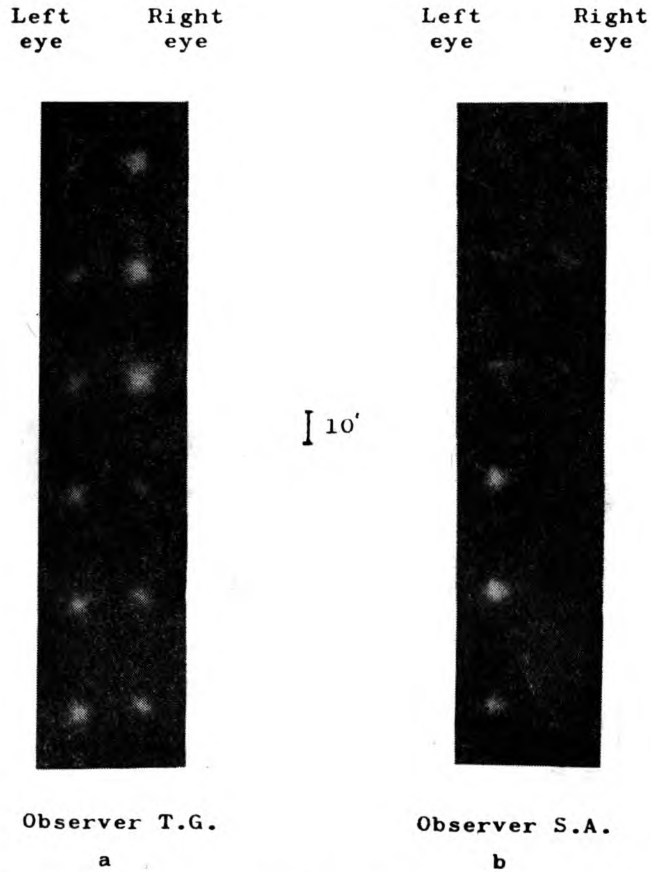

Fig. 4. Microfluctuations of the accommodation (a). Influence of the eye on the contralateral (b)

matism. By a successive introduction of ophtalmic lenses the best image and the correction of the observer are very quickly and easily found in an objective way. Figure 5 shows the images of an astigmatic observer before and after correction made by this method.

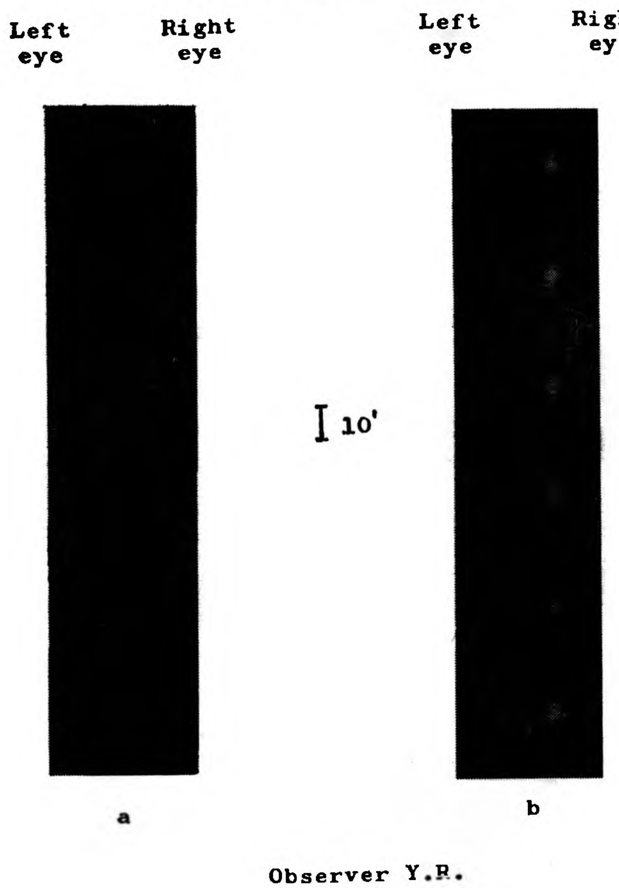

Fig. 5. Retinal images for an astigmatic observer before (a) and after correction (b)

4. Conclusions

The formation of images by the human eye is a dynamic process for the recording of which and study of the instantaneous retinal image and its variations with time, require adequate methods. Therefore, in the present paper a method for the dynamic recording of the binocular and monocular retinal image of a point in real time has been presented. In this method the retinal images are comfortably visualized on a TV monitor, the effects of the accommodation changes and the microfluctuations of the accommodations on the image, as well as the correlation and interdependence between the two eyes are evidenced.

Although only foveal retinal images have been presented, the method also allows the recording and study of extrafoveal images just by means of a fixation test.

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Динамическая запись расплывчатой функции для оптической системы глаза во время двухглазного наблюдения

Представлен динамический метод записи изображений, возникающих одновременно на сетчатках обоих глаз. Применен метод двойного перехода через оптический центр глаза для образования двухглазного изображения пунктирного объекта на микроканальном усилителе света. В результате применения продольного смещения усилителя соответственные друг другу изображения в обоих глазах разделяются. Таким образом возможны визуализация и исследование как одноглазной, так и двухглазной пунктирных расплывчатых функций для оптической системы, а также взаимодействия и корреляция обоих глаз.

Перевела Малгожата Хейдрих