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A STABILIZED IMAGE REQUIRING NO ATTACHMENTS TO THE EYE

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During normal vision, the eyes are in constant motion, and this motion causes continuous shifts of the retinal image with respect to the retina. To investigate the effects of such movement, a method called the 'stopped' or 'stabilized image' has been employed in a number of laboratories. This method allows the eye to move normally, but prevents the movements from producing corresponding shifts of the retinal image across the retina.[1] The basic finding is this: when the retinal image of an object is stabilized, the object rapidly fades out and disappears.

The principal difficulty encountered in the use of the 'stabilized image' has been that it requires the observer to wear a tight-fitting contact lens. There is always the possibility that such a lens will slip with respect to the optics of the eye. Another, much less severe, difficulty is that the visual phenomena that result from stabilizing the image cannot be demonstrated to anyone who has not been fitted with a special lens.

Three methods of stabilizing the retinal images that do not require a contact lens have been described in recent years. One involves imaging a point-source at the center of rotation of the eye, and another, the formation of an image of the iris at the retina.[2] Both of these methods overcome the effects of rotational movements of the eye, but each is subject to very profound artifacts caused by unavoidable lateral movements of head and eye. A form of stabilized image not subject to these artifacts was described by Ratliff.[3] He pointed out that Heidinger's brushes, the pattern visible when a uniform field of polarized light is viewed, are stationary with respect to the retina, and quickly disappear unless the plane of polarization is continuously changed.

The present paper describes a simple optical device that presents *O* with

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[1] R. W. Ditchburn and D. H. Fender, The stabilised retinal image, *Optica Acta,* 2, 1955, 128-133; T. N. Cornsweet, Determination of the stimuli for involuntary drifts and saccadic eye movements, *J. opt. Soc. Amer.,* 46, 1956, 987-993; M. B. Clowes and R. W. Ditchburn, An improved apparatus for producing a stabilised retinal image, *Optica Acta,* 6, 1959, 252-266.

[2] J. ten Doesschate, A new form of physiological nystagmus, *Ophthalmologica,* 127, 1954, 65-73; R. W. Ditchburn, D. H. Fender, Stella Mayne, and R. M. Pritchard. A stabilised retinal image of the iris, *Proc. Phys. Soc.,* B. LXIX, 1956, 1165.

[3] Floyd Ratliff, Stationary retinal image requiring no attachments to the eye, *J. opt. Soc. Amer.,* 48, 1958, 274-275.

a stabilized real image without attachments to his eye. He sees a patch of light upon which the gross anatomical features of his retina are superimposed. The retinal image of the patch of light is not stabilized, but the image of the anatomical features, for example blood-vessels, is perfectly stabilized for small movements of the eye. When the apparatus is properly aligned, the blood-vessels rapidly fade out and the patch of light looks homogeneous.

Apparatus. The design of the apparatus involves a few simple principles of geometrical optics. First, for any positive lens (*e.g.* convex on both sides), there is

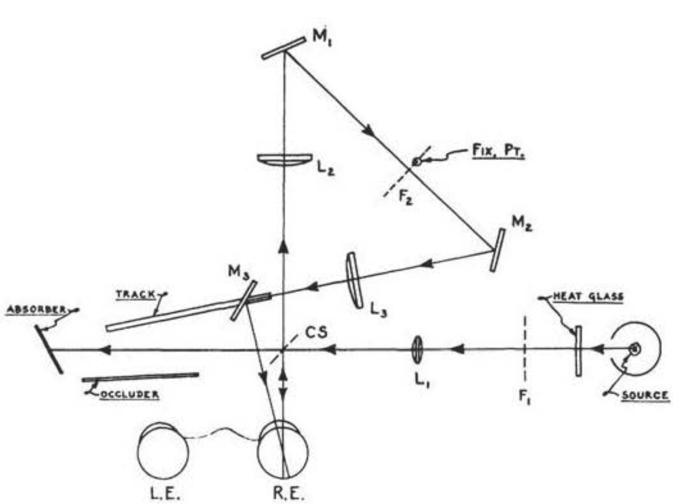

FIG. 1. SCHEMATIC DIAGRAM OF THE OPTICAL SYSTEM
Focal length of $L_1 = 147$ mm.; diameter $= 48$ mm.; focal length of L_2 and $L_3 = 220$ mm.; diameter $= 52$ mm. M_1, M_2, and M_3 are flat first surface mirrors.

a distance, called the focal length of the lens, such that rays of light coming from any point on an object or image placed that far away from the lens will be parallel when they emerge from the other side of the lens. Conversely, any set of parallel rays that enters such a lens will converge to a point at a distance on the other side of the lens that equals the focal length. Secondly, if an object is placed at a distance from a lens that is twice the focal length of the lens, an image of the object will be formed two focal lengths distant on the other side of the lens, and the image will be the same size as the object.

Fig. 1 is a schematic diagram of the apparatus and *O*'s eye. Rays from a small source—*e.g.* tail-light bulb from an automobile—pass through heat-absorbing glass, through Lens L_1 and about 10% of the rays reflected from a cover-slip of a microscope (CS) into the eye. (The other 90% are trapped by a black absorber.) Lens L_1 is placed at twice its focal length from the source, so that it forms an image of the filament of unit-magnification in the plane of *O*'s pupil. As long as this image is smaller than the natural pupil (say less than 2 mm. in diameter), and is centered on the natural pupil, changes in the size of the pupil will not affect the intensity of light at the retina.

When the eye is accommodated for infinity, the optics of the eye will form an image on the retina of any object whose rays are parallel when they enter the eye. Therefore, any object in the plane labeled F_1 (at the focal distance from L_1) will form a sharp image on the retina. In the present apparatus, it is convenient to place a square aperture in that plane, so that a bright square of light is formed on the retina. *O* is instructed to fixate a point that appears off to the left of the incoming beam. Therefore, the square of light is formed on his peripheral retina.

A very small fraction of the light striking the retina is reflected back out of the eye along the same general direction that it entered. About 90% of those rays pass through the cover-slip, travel around the path through lenses L_2 and L_3, and eventually head back toward the eye. The rays from the square will be parallel as they emerge from the eye. Therefore, an image of the square and of the (peripheral) retina under the square will be formed at F_2, the focal plane of lens L_2. The light then continues from Mirror M_2 through Lens L_3, which is at its focal distance from F_2. Therefore, the rays from the retina are again parallel as they reflect from Mirror M_3 and enter the eye. The optics of the eye then reform the image of the square and peripheral retina on the central retina.[4] A very small, dimly lit bulb in the Plane F_2, a little off the axis of the system, serves as a reference for fixation during the alignment of the optics.

As long as the focal lengths of lenses L_2 and L_3 are equal, the image of any peripheral blood-vessel that is formed on the central retina will be the same size as the blood-vessel itself. In other words, the system has a magnification of $\times 1.0$. For this reason, any rotation of the eye will produce an exactly equal shift of the retinal image of the blood-vessel, and as long as there is an odd number of mirrors in the viewing path (in this case three), the shift of the retinal image will be in the same direction as the shift of the retina itself. The image of the blood-vessels is thus stabilized against rotational and torsional eye-movements. It is also true in this system that the image of the retinal blood-vessels is stabilized against translational movements of the head and eyeball. The rays from a blood-vessel are parallel as they leave the eye. Lateral movements of the eye cause the retina and the refractive surfaces of the eye to move equal amounts (by definition). When the rays are parallel, such a movement will produce no shift of the position of the image of the blood-vessel that is formed in the Plane F_2. Conversely, since the rays are parallel as they reënter the eye, lateral shifts of the eye produce no shift of the retinal image with respect to the retina (the image and the retina move through the same distance in the same direction). For these reasons, the optical system produces an image of the retinal structures that is stabilized with respect to all possible movements of the eye: rotational torsional, and translational. The image of the square of light is also visible, but that image is not stabilized against rotational or torsional movements.

As the system has so far been explained, the Lenses L_2 and L_3 are not necessary. The logic above would apply equally well to a system of mirrors alone (except that there must then be an even number of mirrors). If the eye is placed in the correct position in the optical system, as in Fig. 1, but Lenses L_2 and L_3 are simply removed, the image formed on the central retina is of both the peripheral retina

[4] If *O* needs glasses for far vision, he must wear them in this apparatus.

and of the pupil of the eye. One is in sharp focus and the other is a little blurred. In this case, it is possible to see only a very small part of the peripheral retina through the small pupil-aperature. Lenses L_2 and L_3 eliminates this problem in the following way. L_2 is approximately at its focal distance from the pupil, so the rays taken to originate from each point on the pupil are parallel when they strike Lens L_3. Lens L_3 is also approximately at its focal distance from the pupil, so that it forms an image of the pupil at the pupil. Thus the rays from the pupil are altogether out of focus at the retina, and the pupil no longer limits the size of the visible region of retina.[5]

The particular lenses used in this apparatus are not critical, as long as the focal lengths of L_2 and L_3 are equal. The lenses listed in the legend of Fig. 1 are inexpensive. Mirrors M_1 and M_2 should be first-surface mirrors, to avoid doubling the image. Any thin piece of flat glass will do as the cover-slip (*CS*) in Fig. 1.

Adjustment and alignment. The initial alignment involves so many factors that it is rather difficult to accomplish and just as hard to explain. *O*'s chin should be supported in a rest that can be easily adjusted up and down as well as laterally. It is probably easiest to do the first stages of aligning without Lenses L_2 and L_3. When the mirrors are properly positioned, the incoming beam will produce a glare in peripheral vision and, through the viewing path, the viewing eye will be visible, the pupil appearing to be lit with a pink light. The Lenses L_2 and L_3 may then be inserted, and, after some relatively small readjustment of the mirrors, the pink light from the retina will again be visible, but this time the outlines of the pupil will not. Instead, a pink figure the shape of the aperture in Plane F_1 will be visible. This figure is actually the retinal image of the aperture. If the alignment happens to be such that this image falls on a blood-vessel, the vessel will be clearly visible at the same time. If no vessel is visible, one may be brought into view by sliding Mirror M_3 along its track and rotating it appropriately at the same time, thus shifting the bright image across the retina.

When the eye and optical system are perfectly aligned, *O*'s view of his retina will be obscured by a diffuse white haze or a blob of white light, the light reflected directly from the cornea. Moving the head very slightly to one side will misalign the system enough to lose the corneal reflection while retaining the light from the retina itself.

When *O* is properly positioned and the optics correctly adjusted, the retinal structures will disappear so rapidly that the system seems to be going badly out of focus. Eye-movements beyond the field of Lens L_3 and back will restore vision temporarily. Because proper alignment results in poor seeing, it is sometimes easier, during the early stages, to align the system by viewing the retina of the right eye with the left eye. To do this, the occluder is removed, Mirror M_3 is moved along its track until it is roughly in front of the left eye, and it is then rotated until the light passing through L_3 is directed toward the left eye. When this is properly done, it is very easy to see the retinal blood-vessels of the right eye through the left one; and, because the two eyes do not move together in perfect synchrony, the blood-vessels will not disappear.[6]

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[5] This is a verbalization about a fact that can be derived unambiguously from the principles of geometrical optics.

[6] John Krauskopf, T. N. Cornsweet, and L. A. Riggs, Analysis of eye movements during monocular and binocular fixation, *J. opt. Soc. Amer.*, 50, 1960, 572-578.