Pinhole Glasses

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Eye aberrations are commonly corrected by lenses that restore vision by altering rays before they pass through the cornea. Some modern promoters claim that pinhole glasses are better than conventional lenses in correcting all kinds of refractive defects such as myopia (nearsighted), hyperopia (farsighted), astigmatisms, and presbyopia. Do pinhole glasses really give better vision? Some ways to use this question for motivation in teaching optics have been discussed.[1] For this column we include a series of experiments that students can complete using a model of the eye and demonstrate issues related to pinhole vision correction.

The investigation of the effects on vision of pinhole glasses, both theoretical and experimental by use of a simple eye model, provides an interesting medical context to teach introductory principles of optics.

Pinhole glasses[2] consist of a standard spectacle frame in which perforated, opaque sheets instead of lenses are mounted (Fig. 1). The discs have an array of pinholes, each of which has a 0.9-mm aperture in front and 1.2 mm in the rear. The pinholes are separated horizontally and vertically by 3 mm.

Pinhole effect

The ideal eye would image every light point of an object to a corresponding small point on the retina. If the light passing through all parts of the pupil of the eye is not accurately focused, it will fall on a spot on the retina rather than a single point, and the object will appear blurred.[3] For example, in a hyperopic eye, light from a point source P would be in focus at F behind the cornea and thus forms a blurred circle S on the retina (Fig. 2). The size of this circle, and thus the amount of blur perceived, is proportional to the degree of refractive error and the size of the pupil of the eye.

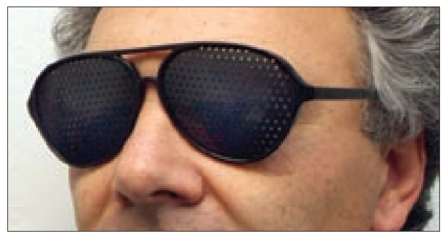

Fig. 1. Pinhole glasses.

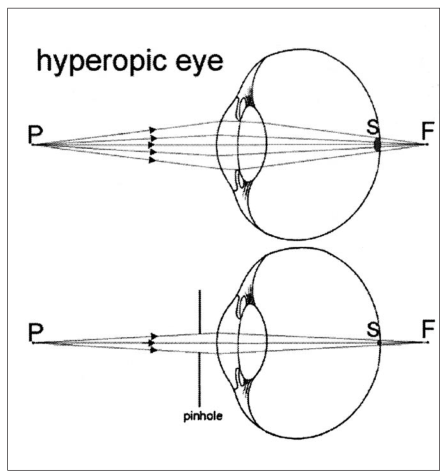

Fig. 2. Blurred retinal image S (above) without and (below) with pinhole.

A pinhole (diameter of about 1 mm) in front of the pupil (diameter of 3 to 4 mm) does not alter the focus of the eye but reduces the size of the blurred circles and thus improves vision.

However, adequate sensitivity and resolution cannot be obtained simultaneously by using a single pinhole; a bright image requires a large pinhole aperture, while a sharp image requires a small pinhole aperture. Moreover, as the hole gets smaller the size of the

DOI: 10.1119/1.2823996

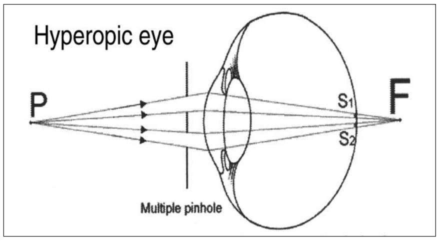

Fig. 3. With two closely spaced pinholes, two retinal images (S1 and S2) can be formed from one light point P.

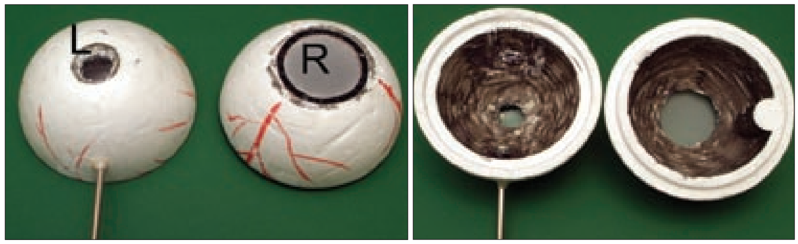

Fig. 4. Outside (left) and inside (right) of the eye model.

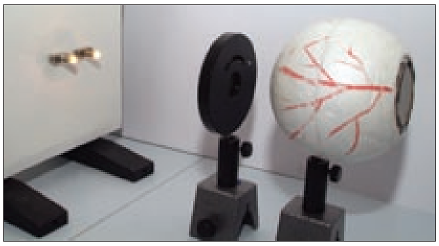

Fig. 5. Experimental device with a pinhole between the light source and the eye model.

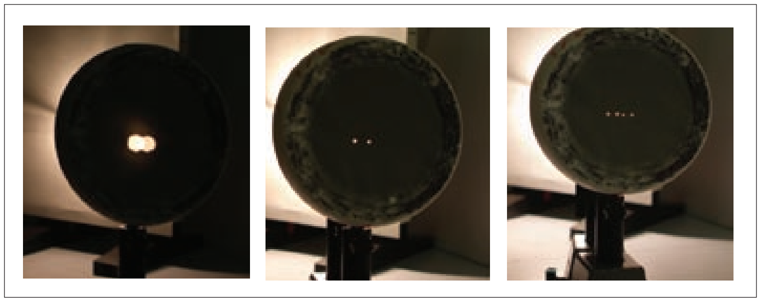

Fig. 6. Image of two light sources on the eye model without pinhole (left), with one pinhole (middle), and with two pinholes (right).

blurred circle becomes smaller, but diffraction effects must be considered.[4,5]

A simple calculation shows the importance of diffraction. When a light beam from a distant point source passes through a round hole, it produces a diffraction pattern, which will include a central disc (Airy disc) containing 84% of the total amount of light. Assuming that the hole is close to the cornea, the Airy disc has a radius about $r = 1.2\, f\lambda/d$, where $f = 2.3 \times 10^{-2}$ m is the distance of the hole from the retina, $\lambda = 5 \times 10^{-7}$ m is an average wavelength of visible light, and $d = 1 \times 10^{-3}$ m is the diameter of the hole, then $r = (1.2 \times 2.3 \times 10^{-2}\text{ m})(5 \times 10^{-7}\text{ m})/10^{-3}\text{ m} = 1.4 \times 10^{-5}$ m. The distance between receptors on the retina is about 5×10^{-6} m. Thus, the Airy disc covers a few of receptors and diffraction effects are important.

Pinhole Glasses

Multiple pinholes increase the vision angle and the amount of light that reaches the retina. Moreover, they eliminate the need for the wearer to hunt out the single small aperture.

However, because of the multiplicity of holes, more images can occur on the retina. If two pinholes are separated by less than the diameter of the pupil aperture, two pencils of ray coming from one light point pass through the pupil and form two retinal images (Fig. 3). Also, too large of a separation will result in dead spots in the field, while too small of a separation will produce multiple images.

It is impossible to produce a separation that is optimum for all refractive defects and pupil sizes that vary both from person to person and with illumination. Use of relatively small separation is probably preferable because of the reduced likelihood of localized field obscuration. Multiple images can be reduced easily by minor head rotation. Thus, pinhole glasses with carefully selected variables may be able to provide improved vision. With this analysis, students can be motivated to investigate experimentally the optics of these glasses.

Experimental Device

For the experimental device we use a large eye model, which consists of a hollow Styrofoam sphere representing the ocular globe (Fig. 4). A hole of about 6-cm diameter on the surface of the sphere is covered with semi-transparent plastic film, *R*, that represents a portion of the retina. On the opposite surface, a hole is covered with a lens *L* of about 4-cm diameter and simulates the optical refractive power of both cornea and crystalline lens. The focal length of the lens must be longer or the same as the axis length of the model eye. In the first case the model represents a hyperopic

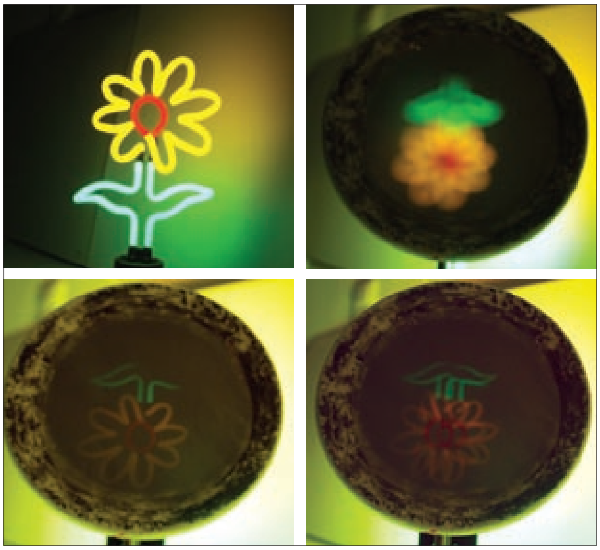

Fig. 7. A luminous object (above left) and its images on the eye model: without pinhole (above right), with one pinhole (below left), and with two pinholes (below right).

eye; in the second case it represents a presbyopic eye that does not focus on near objects.

To show qualitatively the effects of pinhole glasses, the pupil of the model is pointed toward luminous objects, showing the image that is formed on the semi-transparent surface representing the retina of the model (Fig. 5).

a) Image of light point sources

Two light point sources produce two circle-images of light on the retina of the model eye. If the two point sources are near enough, the two circle-images are partially overlapping. By covering the lens of the model with a pinhole, the circle images become smaller and appear separate; however, the brightness diminishes drastically. Two pinholes separated by less than the diameter of the "pupil" of the model will produce four images (Fig. 6).

b) Image of extended objects

By framing an extended object, the model produces a bright but unrecognizable image. By gradually reducing the diameter of the pinhole the clarity of the image improves, but the brightness diminishes drastically. Two pinholes will produce a double image (Fig. 7).

Clearly, if the experiments are performed as above but with a model of a myopic eye that focuses the image, the pinhole does not improve the clarity of the image.

Conclusion

Pinhole glasses increase the depth of focus so that even when the eye is not correctly focused, objects will appear as if in focus. Moreover, they eliminate scattering of light to the retina and hence improve vision.

However, pinhole glasses do not correct but only avoid the utilization of the complete area of the pupil. Single pinhole glasses block most of the light rays that would otherwise reach the eyes; they reduce the size of the visual field and are effectively useless in seeing in dim lighting. Glasses with multiple pinholes block less light than the single pinhole glasses but can cause the wearer to see multiple images.

Pinholes reduce the amount of accommodation and cause a permanent dilatation of the pupil; in the literature no research legitimates the use of pinhole glasses in reduction or prevention of eye aberrations.

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PACS: 01.50.My, 42.00.00

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