The use of Haidinger's brushes in the study of stabilized retinal images*

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The entopic phenomenon known as Haidinger's brushes has many advantages as a target for use in the study of stabilized retinal images. Methods of producing the brush pattern as well as a discussion of its principal characteristics are presented. Data are presented illustrating some of the variables which affect its clarity, appearance, and disappearance.

Even when an observer is fixating as steadily as possible, the eye is continually in motion. These eye movements, which consist of microsaccades, tremors, and drifts, tend to shift the locus of the image so that different retinal receptors are stimulated. If we eliminate this effect of eye movements so that the image continues to stimulate the same cells, we have produced a stimulus condition known as a stabilized retinal image. The first attempts to stabilize the retinal image in order to investigate the effects of optic nystagmus upon perception were by Ditchburn and Ginsborg (1952) in England, and Riggs, Ratliff, Cornsweet, and Cornsweet (1953) in the United States. They reported that stabilized targets rapidly faded and disappeared from view.

A number of techniques have been used to stabilize the retinal image, the most exotic of which involves actually rendering the eye immobile by paralyzing the extraocular muscles with injections of an appropriate drug (Kornmuller, 1931). Most other procedures of image stabilization involve compensation for the effect of eye movements on retinal image locus rather than elimination of eye movements themselves. The methods which have achieved the most widespread use involve an optical lever system or targets mounted directly on the eye. In optical lever systems such as those used by Riggs and Ratliff (1951) or Clowes and Ditchburn (1959), a target is projected onto a mirror mounted on a contact lens worn by the S. This image is then viewed from a screen or in Maxwellian view. Targets may be mounted directly on the eye by means of a miniature projection system mounted on a stalk

on a contact lens (Ditchburn & Pritchard, 1956; Pritchard 1961a, b). Since the additional weight and extent of the attachment add to the inertia of the system, suction collars have been occasionally used to prevent slippage of the image with eye movements (Yarbus, 1967; Gerrits, 1967). Both of these systems are quite complex and expensive; also, the population of Ss is limited to those who are willing or able to wear contact lenses bearing the necessary apparatus. Perfect stabilization is often difficult to obtain in these systems. Optical lever systems require precise alignment of the S and careful calibration, while direct attachment systems frequently suffer from lens slippage (Barlow, 1963). Accurate foveal placement of the target is complicated since the optic axis and foveal locus do not coincide (Gerrits, 1967).

The desire for a simple, inexpensive, and reliable means of image stabilization has prompted some investigators to use afterimages as stabilized targets (Evans & Mardson, 1966). Since the afterimage does not alter its retinal locus with eye movements, it is perfectly stabilized. Afterimages as stabilized targets suffer from several drawbacks: (1) Ss must be thoroughly dark-adapted to obtain strong afterimages; (2) the placement of the afterimage on the retina is frequently imprecise due to fluctuations of eye position around the fixation point in the moments before presentation of the flashed stimulus; (3) the image quality in afterimages is never very good and degrades with time; and (4) a reasonable amount of time must elapse between successive presentations in order to allow all traces of previous stimulation to dissipate.

Some investigators have utilized entopic structures as stabilized image targets. Campbell and Robson (1961) have used both the shadows of the retinal capillaries and the appearance of the macular pigment under appropriate lighting conditions. The appearance of these targets is somewhat variable since there are large individual differences in the size and

shape of the phenomena. Their use as stabilized targets is complicated by the fact that they are frequently difficult for untrained Ss to see.

Ratliff (1958) suggested the use of Haidinger's brushes as a possible entopic target which might be employed in the study of stabilized images. This suggestion has not been seriously pursued. Haidinger's brushes are an entopic phenomenon which appears in plane or moderately elliptical polarized light. Under these lighting conditions, when looking at a uniformly illuminated field, the normal eye can see a pattern which looks like two yellow tufts radiating from the center of fixation. This percept probably is caused by the radial orientation of the crystals of macular pigment which results in stronger absorption of linearly polarized light in some regions than in others. The long axis of the brush is seen in an orientation which is approximately perpendicular to the direction of vibration in the polarized light beam. The phenomenon is most easily seen when blue polarized light is used. Here the brush pattern appears as a black hourglass-shaped figure. Visibility may be further heightened by rotating the plane of polarization which results in rotation of the pattern (Boehm, 1940). Since we are looking at a structural feature of the eye, it is perfectly stabilized. Its shape and size are relatively constant across Ss. Its foveal locus, ease of production, plus the possibility of image movement with changes in the plane of polarization, make it an attractive target for use in image-stabilization work.

PRODUCTION OF HAIDINGER'S BRUSHES

The basic requirements for the production of Haidinger's brush phenomenon are quite simple. One needs polarized blue light and some sort of projection field. We have found that quite visible brushes can be produced using Corning Filter No. 5113, or Kodak Wratten Filter 78AA in front of a light source, and Polaroid Sheet Film No. 328 or its equivalent to provide linear polarization.

A convenient small system for the production of the brush pattern uses a 100-W superwhite Sylvania or General Electric light bulb. The heavily frosted coating on the bulb provides a uniform field of high luminance. The sheet Polaroid and blue filter are simply mounted in front of the bulb.

For a system where the brushes are to be viewed in conjunction with nonstabilized targets, a slide projector with a 500- to 750-W projection bulb can be used. The projector illuminates

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Fig. 1. Mean magnitude estimates of the clarity of the Haidinger brush phenomenon is plotted against the speed of rotation of the plane of linearly polarized blue light.

a screen and can be used to project the nonstabilized targets. The S views the field through a blue filter and sheet Polaroid. This system has the advantage of producing a phenomenally larger pattern than the system above through the operation of size constancy.

The visibility of the Haidinger brush pattern is at its maximum when the plane of polarization is rotated. Boehm (1940) has demonstrated that with blue light and a rotating plane of polarization, almost all normal eyes can see the dark brushes which appear as a spinning black propeller on a blue ground. The rotation of the plane of the polarized light is effected by simply rotating the sheet Polaroid. The film may be mounted on a ring or tube which is then rotated in a bearing mount, while S observes the projection field through the rotating film; or the Polaroid may be cut out in disk form, a hole punched in the center, and then mounted on the shaft of a motor. In this latter case, S views through a radial portion of disk. Instead of viewing the field through the rotating Polaroid film, it is possible to project the polarized light onto a nondepolarizing metallic screen.

It can be shown mathematically that a birefringent plate, producing a retardation of approximately half the wavelength of the blue light, inserted between the eye and the source of polarized light should reverse the direction of rotation of the brushes. A simple substitute for a half-wave plate is a piece of clear cellophane. When

inserted between the eye and the Polaroid sheet, this rapidly and silently reverses the direction of rotation of the brushes without necessitating a change in direction of the motor.

Haidinger's Brushes AS A STABILIZED TARGET

If the Haidinger brush phenomenon is to be used as a stimulus in research on stabilized images, it is important to ascertain its characteristics, such as size and locus, as well as some indication of the factors which affect its appearance, clarity, and disappearance. In order to do this, a number of studies, reported below, were conducted.

Size of the Image

Since the brush phenomenon appears to be centered around the point of fixation, the retinal locus of the image is taken to be foveal. The size of the image may be estimated by projecting the pattern against a screen upon which a scale calibrated in visual angle has been provided. Twelve Ss, all graduate students well practiced in psychophysical judgment, were asked to view a rotating Haidinger brush pattern projected upon a fixation point on a screen illuminated by 0.25 m^L of blue light produced by projection through a 78AA Kodak Wratten filter. Around the fixation point, there was a concentric circle drawn in heavy black ink. The radius of the circle was varied from trial to trial in 0.25-deg steps. Ss were asked to judge whether the rotating brush

pattern was larger or smaller than the concentric circle. The median judged brush size corresponded to a diameter of 3.75 deg, with a range of 3.5 to 4.5 deg.

Visibility of Haidinger's Brushes

Sloan and Naquin (1956) have shown that 96% of their normal Ss were able to detect the rotating brush pattern when tested with photopic luminance levels. In order to verify the visibility of the Haidinger brush pattern produced by the methods we have outlined above, 50 naive Ss were tested. All had normal vision, as tested with a Keystone Telebinocular. The brush pattern was viewed against a field of blue light (Wratten 78AA) with a luminance of 0.25 m^L. The plane of polarization was rotated at a speed of 360 deg/sec. Forty-nine of the 50 Ss, or 98% of the sample, were able to see the pattern.

Visibility and Speed of Rotation

Since rotation of the plane of polarization seems to improve the visibility of the brush pattern, it seems reasonable to expect that the speed of rotation will be systematically related to its perceived clarity. To test this hypothesis, eight sophisticated Ss were asked to estimate the clarity of the pattern, produced in the same apparatus used above, as a function of speed of rotation of the plane of polarization. A magnitude estimation task, modeled after the procedures used by Stevens (1956), was employed. Six speeds of rotation were tested, ranging from 110 to 600 deg/sec. Two measures were taken at each speed. The mean estimates of clarity as a function of speed of rotation of the plane of polarization are shown in Fig. 1. It is clear that, as the speed of rotation increased, the pattern became clearer, although the curve appears to be approaching an asymptote at around 600 deg/sec. All Ss show increased clarity estimates with increasing speed up to 360 deg/sec, but for the highest speed tested some Ss report a decline in visibility.

Disappearance of the Brush Pattern

The most frequently reported perceptual event associated with stabilized retinal images is that after a short time they fade and finally disappear (Heckenmueller, 1965). To verify the disappearance of the stabilized Haidinger brush pattern, 16 naive Ss were tested under the same conditions reported above. The brushes were made visible by rotating them at a speed of 360 deg/sec. The

rotation was then stopped, activating a timing circuit. Ss indicated when the target had completely disappeared by depressing a lever which stopped the interval timer. Each S was given three trials. The median time to disappearance was 2.3 sec (mean = 3.28 sec), with a range from 0.1 to 18.3 sec (standard deviation = 3.1 sec).

Since fragmentation of the stabilized target is frequently reported before total disappearance (Pritchard, Heron, & Hebb, 1960; Evans & Wells, 1967), it is interesting to note that none of the Ss reported disappearance of disconnected parts of the figure. The general percept was that the figure gradually became more indistinct and then vanished. Some Ss reported that the figure became smaller, or that the wing tips appeared to move inward before disappearance.

Campbell and Robson (1961) have reported that a moving stabilized image will also disappear. They used the shadow of retinal capillaries as their stimulus. To see if moving Haidinger's brush stimuli will also disappear, 18 naive Ss were tested. Using a brush pattern rotating at 360 deg/sec, with a field luminance of 0.25 mL, Ss were asked to observe the brush pattern steadily and to report any changes in their appearance. For six of the Ss, the brush remained visible throughout the 15-min session, although a large decrease in clarity was noted. For the remaining 12 Ss, the brush pattern eventually disappeared completely. For the 12 Ss for whom the brush disappeared, the mean time to disappearance was 220.6 sec, with a range from 138 to 310 sec. Thus, it is clear that although the moving brush pattern may disappear with inspection, it is considerably more resistant to fading than is the stationary pattern. These results, then, partially replicate those of Campbell and Robson.

CONCLUSIONS

Our discussion has centered around the means of production and the parameters which affect the visibility of Haidinger's brush phenomenon. As a stabilized target for research use, it appears to have certain useful properties: (1) it is easily and inexpensively produced; (2) it is perfectly stabilized and not subject to slippage; (3) it is foveally located; (4) it is easily seen by normal Ss; (5) it may be easily moved while still remaining stabilized relative to eye movements; (6) it is of reasonable size; and (7) it seems to demonstrate the same perceptual properties as other stabilized targets.

The major disadvantage is that one is limited to one target size and shape. Many types of experimentation will not find this restriction too limiting, given the other advantages of using Haidinger's brushes as a stabilized image target.

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