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QUANTITATIVE STUDY OF VISUAL AFTER-IMAGES*

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MUCH has been written on the persistence of visual sensation after the light stimulus has been removed—the so-called visual after-image (Helmholtz, 1924 ; Duke-Elder, 1932). The after-image may be positive, in which the light and dark parts correspond to those of the object, or negative, in which the light and dark parts are reversed. Similarly, in the positive after-image of a coloured object, the colours roughly correspond to those of the object, whereas in the negative after-image complementary colours are said to appear.

With a very bright stimulus, the after-image may persist for several minutes or perhaps longer, whereas under more normal conditions the duration is short, and may be studied by experiments on flicker and persistence of vision. Whilst the short-period phenomena have received considerable attention, the long-period after-images have mainly been studied qualitatively, and no comprehensive quantitative experimental work appears to have been done.

Craik (1940), and later Cibis and Nothdurft (1948), have described experiments from which they conclude that after-images are of retinal origin, and Misiak and Lozito (1951) show that some central modification of after-images occurs. To decide, however, on the mechanism of after-images, and on their relation to other phenomena of vision seems premature until more experimental data is available. Pannevis (1947; 1948) has made measurements on the brightness variation of long-period after-images, although the amount of work is not great. His method was to re-stimulate the retina and induce a negative after-image equal in apparent brightness to the positive after-image, so that no resultant image could be seen. The assumption that the positive after-image is not affected by re-stimulation is probably unjustifiable. Probably the reason for the lack of adequate quantitative data is due to the difficulty of evolving a technique for making adequate measurements.

The author has found that, by using the binocular matching technique of Wright (1946), measurements could be made of the retinal illumination of one eye which caused a sensation of brightness equal to that of the positive after-image in the other eye. Also he has found that by taking a sufficient number of observations, significant quantitative data can be obtained.

Work has been done with white light† stimuli only, on a dark-adapted eye.

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† Colour temperature 2900°K.

The comparison matching stimulus was also white, but no great difficulty was experienced since the after-images were only slightly coloured, and this colouration could be ignored. Measurements could only be made of positive after-images, but since negative after-images are usually caused by re-stimulation, they did not appear under the conditions of the experiments.

Method

The apparatus (Fig. 1) consists of two similar optical systems. The first provides the stimulus for the left eye. Light from a line-filament lamp S_1 is collimated by lens L_1. A photographic shutter E used for timing the exposure to the stimulus, and a neutral density filter F_1 for varying the luminance of the stimulus, are placed in the parallel beam of light. The diaphragm B_1 defines the image field, and has a rectangular opening subtending an angle of $2° \times 1°$ at the eye. This diaphragm is in the first focal plane of the lens L_2, and can thus be viewed by the unaccommodated eye. A pinhole A_1 (1 mm. diameter) is placed in the second focal plane of L_2, and thus the light passing into the eye must have passed through B_1 parallel to the axis.

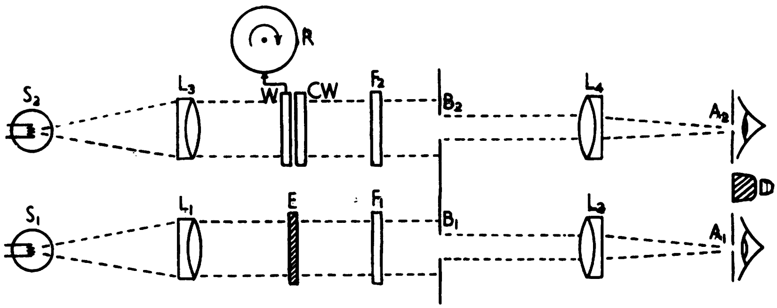

FIG. 1.—Apparatus.

The second system provides the comparison field of variable luminance for the right eye. It is similar to the first, except that the diaphragm B_2 provides a $2° \times 1°$ rectangular comparison field which appears slightly above the stimulus field, when they are viewed binocularly. This is in order that the two fields shall not be fused. The luminance of the comparison field can be varied by rotating a knob which moves a logarithmic photometric wedge W. In order to provide a uniform field luminance a fixed compensating wedge CW is used. The range of luminance can be changed by introducing neutral density filters at F_2. The position of the wedge W is a measure of the luminance of the comparison field, and thus (since a constant pupil is used) of the retinal illumination, and this is recorded continuously on a drum R which is rotated by a synchronous electric motor. The instrument is calibrated in retinal illumination by matching the apparent brightness of a white diffusing test surface within the instrument, with that of the field of the instrument. The white diffusing surface is illuminated by a standard lamp at a known distance, and thus its luminance can be calculated. The retinal illumination is calculated from the luminance and the pupil area. The position of the observer's head is rigidly fixed by a dental impression D.

After a period of dark-adaptation the left eye is stimulated by opening the shutter E. Four red fixation dots are provided at the four corners of the rectangular stimulating patch before the exposure, in order that the stimulus should always affect the same area of the retina. These fixation dots are extinguished immediately after the end of the stimulus. The position of the wedge is then continually adjusted to maintain equality of sensation of brightness between the comparison patch and the after-image.

Results

Owing to the difficulties of the technique and the large number of observations needed to obtain significant results, all the results are those of one observer, the author. It was thought that detailed results from one observer would be more valuable than less detailed results from a number of observers.

The first experiments were concerned with the effect upon the after-images of the period of dark-adaptation of the eye. It was found by experiments performed with the eye dark-adapted for times varying from 5 to 30 minutes that little difference in the after-image occurred after an adaptation time of 10 minutes. All the subsequent experiments were carried out with 10 minutes dark-adaptation. The interval between separate experiments was never less than half an hour, and during this time the eye was exposed to light and then dark-adapted again. This ensured that faint after-images did not affect the next experiment.

Experiments were next carried out on the reproducibility of the results. Figures 2(*a*) to 2(*h*) show actual curves from the apparatus of log. of the retinal illumination in trolands* (R) of the right eye which causes a sensation of brightness which balances the after-image sensation in the left eye, plotted against the time (*t*) in seconds which has elapsed from the beginning of the stimulus. The stimulus producing the after-image was a retinal illumination of 2,000,000 trolands for one second. The curves show eight separate determinations, the eye having been dark-adapted for 10 minutes before each experiment. It was found that the mean-ordinate curve of eight separate determinations yielded a curve which was consistently reproducible for the same exposure conditions. This mean curve is shown in Fig. 3.

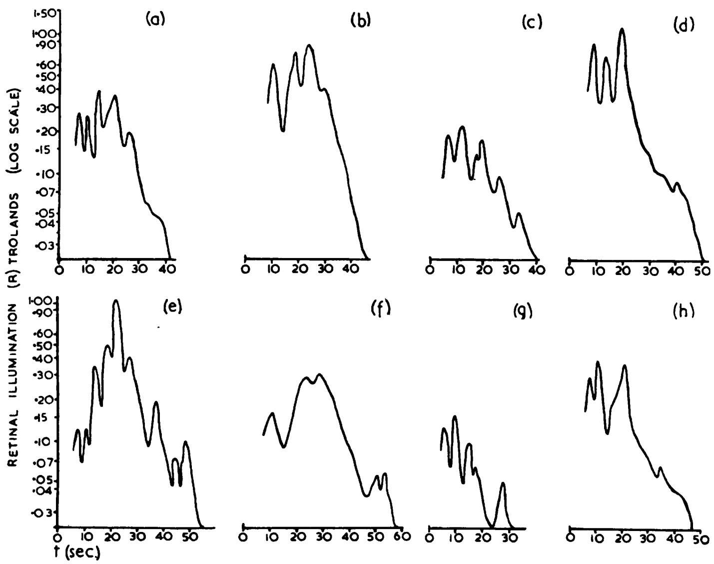

FIG. 2.—After-images produced by a stimulus of 2,000,000 trolands for 1 sec.

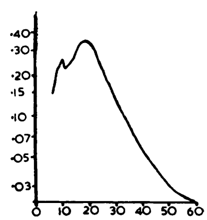

FIG. 3.—Mean-ordinate of curves in Fig. 2.

* The retinal illumination is 1 troland when a surface of luminance 1 candel/sq. m. is viewed through a pupil of area 1 sq. mm.

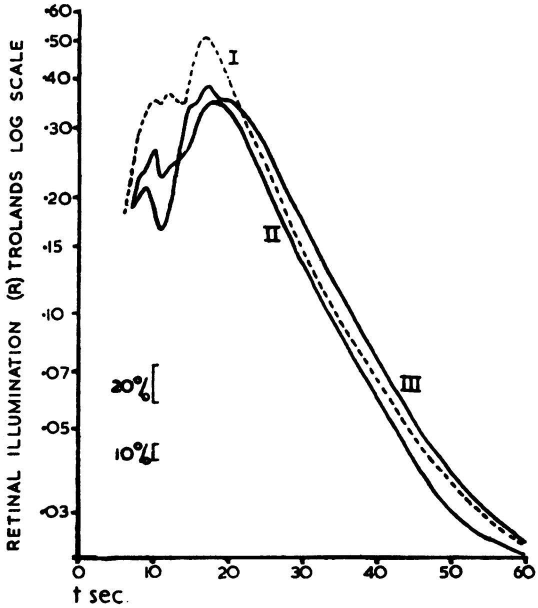

FIG. 4.—Mean-ordinate curves for three separate determinations.

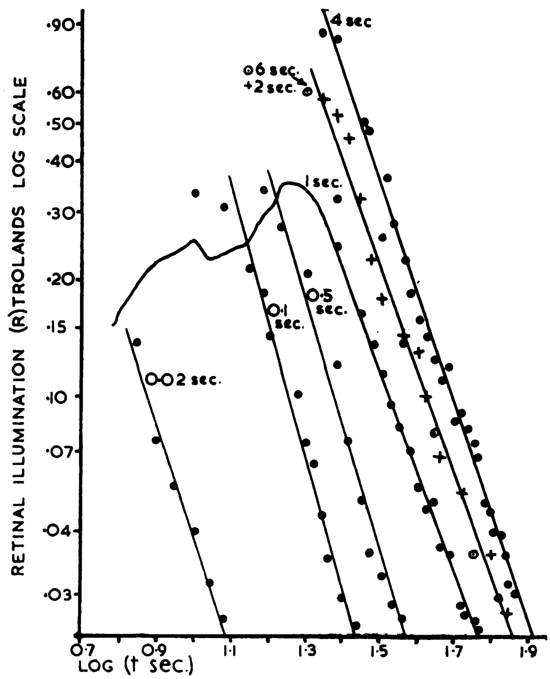

FIG. 5.—After-images produced by a stimulus of 2,000,000 trolands for various exposure times.

In order to ascertain whether the reproducibility was maintained over a long period, the eight experiments were repeated three times, with an interval of three months between the first and second, and of one month between the second and the third. The mean curves from these three experiments are shown as curves I, II, and III in Fig. 4. The ordinate intervals corresponding to a variation of retinal illumination of 10 and 20 per cent. are shown. The total variation between these curves is mostly of the order of 20 per cent. in retinal illumination. This consistency was considered sufficiently high to justify further experiments.

It was found that by plotting log. R against log. *t* an approximate straight line resulted. These graphs are shown in Fig. 5 for after-images produced by a stimulus of retinal illumination 2,000,000 trolands. The time of exposure to the stimulus is indicated on each curve. The 1-second curve, which is shown in full, was the mean of 24 determinations. The decay parts only of the other curves are shown, and each is the mean of eight determinations. The points used for the log. log. plots are taken at arbitrary intervals from the experimental curves. It can be seen that the sensation of brightness and duration of the after-image increases up to 4 seconds exposure. With longer exposures the after-image is fainter and less persistent ; the after-images produced by a 2-second and a 6-second exposure are practically identical. With still longer exposures linearity no longer exists. Curves for 10- and 20-second exposures are shown in Fig. 6.

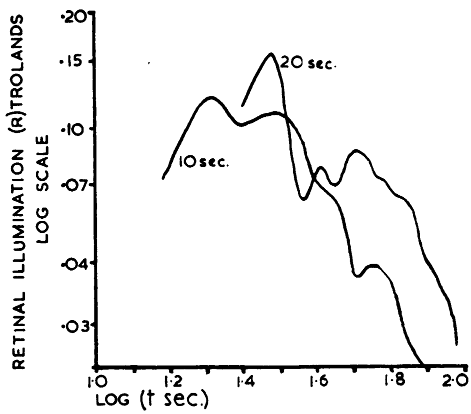

FIG. 6.—After-images produced by a stimulus of 2,000,000 trolands for 10 and 20 sec.

The mean gradient of the straight lines shown in Fig. 5 is about —3.0. This suggests that the decay part of the variation can be represented approximately by the relation log. R = —3 log. t + c, where c is a constant ; we thus have $R \alpha t^{-3}$. Pannevis (1947 ; 1948) obtained similar straight lines in some experiments, although his experimental method was quite different, and hence his results cannot be compared with those of the author.

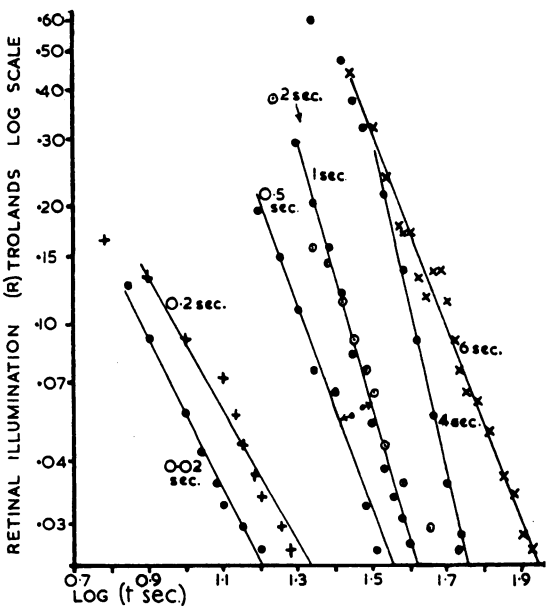

FIG. 7.—After-images produced by a stimulus of 1,200,000 trolands for various exposure times.

Fig. 7 shows a similar series of graphs for after-images produced by a less intense stimulus of retinal illumination 1,200,000 trolands. These results are less consistent than with the more intense stimulus. The mean gradient is —2.8, giving an approximate relation $R \propto t^{-2 \cdot 8}$ for the decay part of the curves.

No theory is suggested to explain these results since it is considered premature until more data are acquired. It is intended to extend this work to obtain information for after-images produced by monochromatic stimuli throughout the visible spectrum.

The work does show, however, that significant quantitative measurements on positive after-images can be obtained by using Wright's binocular matching technique.

Summary

Wright's binocular matching technique has been applied to the quantitative study of positive visual after-images. The sensation of brightness of the after-image in one eye is balanced binocularly by the sensation caused by a comparison light stimulus in the other eye. It is shown that by using this technique significant quantitative measurements can be obtained.

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