Published as a separate and in *The Journal of Psychology,* 1959, 47, 317-330.

THE INFLUENCE OF AREA ON THE CRITICAL FLICKER-FUSION THRESHOLD*

The Psychiatric Institute, New York

William C. Roehrig[1]

A. Introduction

Despite the enormous number of articles on the critical flicker-fusion threshold (*CFF*) (18), there have been very few experiments concerned with the influence of one of its basic determinants, the area (*A*) of the test-patch. The few studies that have dealt with this matter have varied *A* over only a narrow range, with the largest area illuminating but a small fraction of the entire retina. In view of the fact that *CFF* is being used more and more frequently as a clinical diagnostic tool in the ophthalmological, psychological, and medical clinics (2, 3, 8, 15, 16, 20, 25), it would seem highly desirable to further explore its major determinants. The dearth of studies of the influence of *A* on *CFF* might perhaps stem from the technical difficulties of homogeneously illuminating a large test-patch with intermittent pulses of light, particularly when high test-patch luminance is desired.

In 1930, Granit and Harper (10) studied the effect of area on *CFF* at the fovea and 10° in the periphery, using six test-patches ranging from 0.9° to 5° of visual angle (*va*) in size. They found that (*a*) the increase in frequency (*F*) with intensity (*I*) was greater, the larger the test-patch; (*b*) *Fmax* (the maximum *F* possible with optimal *I*, under a given set of conditions) was higher, the larger the test-patch; (*c*) the increase in *F* with *A* was greater at 10° in the periphery than at the fovea; and (*d*) the increase in *F* with log *A* was linear over the range tested. They expressed the latter relationship in the form $F = c \log A + d$ (Granit-Harper law), where *c* and *d* are constants. Granit and Harper believed, however, that the linear equation was only an approximation, that the true relationship between *F*

*Accepted for publication by Carney Landis of the Editorial Board, received in the Editorial Office on February 3, 1959, and published immediately at Provincetown, Massachusetts. Copyright by The Journal Press.

[1]This study is based in part on a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Faculty of Pure Science, Columbia University. This investigation was, in part, made possible by funds granted by the Carnegie Corporation of New York and by grant M-872 from the National Institutes of Health, USPHS.

and log *A* was probably sigmoid, tending to become horizontal below *ca* 1° *va* and above *ca* 5° *va*. Piéron (22) was next to attack the problem, using test-patches ranging from 30″ to 0.5° *va*. His results showed only a slight trend toward becoming horizontal below about 4′ *va*. Hecht and Smith (13), with test-patches of 0.3°, 2°, 6°, and 19° *va*, got contradictory results with two observers (Hecht and Smith). Allen (1) varied the area of the test-patch from about 0.2° to 6° *va* and found not one straight line but a series of straight lines with breaks which he attributed to changes in the retinal distribution of rods and cones. Kugelmass and Landis (17) used a series of 36 test-patches ranging from 1.27° to 14.60° *va* and tentatively agreed with the conclusion of Granit and Harper, that the *F-log A* function was linear from 1° to 5° *va*, becoming negatively accelerated for larger test-patches. However, they failed to find evidence confirming Allen's hypothesis of discontinuities in the *F-log A* function associated with retinal histology.

No fewer than 16 investigators have performed experiments designed to determine what portion of the retina yielded the highest *CFF* values; seven found *CFF* to be highest in the fovea, whereas nine found *CFF* to be highest at various points in the periphery. The reason for these apparently discrepant results was indicated by the following three experiments. Granit and Harper's study (10) showed that with test-patches larger than about 2° *va*, *CFF* was higher 10° in the periphery than at the fovea, whereas with smaller test-patches the reverse was true. Creed and Ruch (6) found *CFF* to be higher in the fovea with a 12′ *va* test-patch, and higher at 4-7° in the periphery with 2° and 8° *va* test-patches. In 1942, Hylkema (15) made a systematic perimetric study of *CFF* with test-patches of 0.5°, 1.5°, 3°, and 10° *va*. He found that with test-patches of 1.5° *va* or smaller, *CFF* was highest in the fovea, whereas larger test-patches yielded higher *CFF* values in the periphery, the highest being approximately 45° out from the fovea, temporally.

Hylkema found that at all portions of the retina tested, the larger the test-patch, the higher the *CFF*. The highest *CFF* (75 *cps*) was considerably higher than has been obtained by most investigators. In an effort to go still higher, Hylkema (14) adjusted his apparatus for its maximum luminance (2.2 *log mL*) and test-patch size (30° *va*). With this combination he obtained an *Fmax* of 82 *cps*, which, to the best of the present writer's knowledge, is the highest that has been reported in almost 50 years. In recent times, other investigators who have reported values nearly as high were Ségal, 79 *cps* (24), and Lloyd, 74.83 *cps* (19). In 1863, Fick (7) performed an experiment with parallel lines on a revolving drum and found an *Fmax* of 170 *cps,* however, this dropped to 40 *cps* if an exit slit was used. Cords (5), in 1908, obtained a *CFF* of 157 *cps,* using no exit slit. Grünbaum (11) published curves in 1898 showing improbably high *F* values of over 650 *cps.* The present writer has so far been unable to decipher Grünbaum's description of his apparatus, and can offer no suggestion as to why his *F* values were so many times greater than those obtained by any of the other hundreds of investigators.

In brief, then, the available evidence indicates that as the area of the test-patch is increased, and particularly as more peripheral portions of the retina are illuminated, *CFF* increases. However, it is unknown how much *CFF* may be made to increase, and what the nature of the relationship between *A* and *CFF* is for other than very small areas. Hence, the two experiments of the present study were designed to (1) investigate the effect of area on *CFF* using foveally-fixated test-patches considerably larger than heretofore used, and with diurnal and day-to-day variability eliminated from the measurements, and (2) determine *Fmax* for practiced observers when area and intensity of the test-patch were as great as the available equipment would permit.

B. Apparatus

The light source was provided by a glow modulator tube (Sylvania Type R1131C). This tube was powered by an electronic driver which caused it to deliver square pulses of light of carefully controlled duration and frequency of intermittence. A block diagram and details of the driver may be found in Kugelmass and Landis (17). Frequency of intermittence was calibrated with an events-per-unit-time meter and was accurate to 0.1 *cps.* Flash duration was calibrated with an oscillator and oscilloscope and adjusted until accurate to 10 μ sec. To insure continuously accurate performance, the driver was always monitored by an oscilloscope. The current to the glow modulator tube, adjustable by means of a potentiometer, was held at 10 *ma* and continuously monitored by a milliammeter. The light-dark ratio was maintained at 1/9 by the proper settings of the dials controlling the duration of the flash and the frequency of repetition.

The optical system used to view the stimulus-patch was a Bausch and Lomb binocular microscope (Model TBV-8L). Mounted rigidly on the stage was an "area-template" which consisted of a brass strip in which accurately spaced holes of increasing diameter had been bored. By means of a rack and pinion gear, the strip could be so moved that one hole at a time was presented and each was accurately centered with respect to the visual axis of the microscope. The areas of the test-patches were defined by these holes. Mounted beneath the stage of the microscope and directly below the area-template was the substage condensing lens of the microscope. Below this lens was a calibrated neutral density wedge having a range of 4 log units, which could be moved back and forth by means of a rack and pinion gear. The top of the glow modulator tube was rigidly fixed below the neutral density wedge in such a way as to be centered with respect to the axis of the optical system. The beam of light emitted by the tube travelled through the neutral density wedge, the condensing lens, the hole in the area-template, and into the head of the microscope which was focused on the edge of the hole. The diameters of the holes in the area-template were measured through the microscope by means of an eyepiece micrometer. Their visual angles were calculated taking into consideration the combined constant magnification of the objective and oculars (30X) and the projection distance which was 250 mm. No artificial pupil was needed since the system of stops in the microscope so limited the cone of light that the diameter of the image of the test-patch at the cornea was less than the smallest natural pupillary diameter.

In order to obtain *Fmax* for as large an area as possible, a second apparatus was used which delivered more light, and was basically different in design from the first. The light source for this apparatus was a 100 *CP* Pointolite lamp, operated with *DC* rectified current having a ripple factor of less than 0.2 per cent which is well within the tolerable limit. By means of a lens system the light was brought to a focus at a point limited by a field stop to 0.1 inch in diameter, where it was chopped by a sector disc which had equal open and closed 90 degree sectors. This disc was turned by a split-phase, four-pole, variable frequency synchronous motor (Electric Indicator Co. Type 450) which would "lock in" with the applied frequency which was precisely controlled by an electronic oscillating unit accurate to 0.1 *cps.* Two separate and complete calibrations of the motor speed were undertaken before the experiment was begun, once with a Strobotac, and once with a built-in calibrating unit which also provided for frequent checks during the course of the experiment. After being chopped by the sector disc the light passed through a filter box and onto a frosted glass screen. In front of this screen was mounted the binocular head of the microscope used in the first apparatus. The area of the test-patch was defined by the system of stops in the microscope, i.e., the largest test-patch area it was possible to obtain. Different luminances were obtained by inserting into the filter box Wratten neutral density filters which had been calibrated with a Martens Densitometer.

All experiments were carried out in a sound-deadened, air-conditioned room in which the level of illumination was approximately three foot-candles.

Data were obtained from three practiced observers, *DD, JL,* and *WR* who were 29, 27, and 28 years old, respectively. For Experiment 2, data were obtained from two additional *O*'s, *CL*, and *JC*, who were 58 and 41 years old, respectively.

C. Method

1. *Experiment 1*

The purpose of this experiment was to investigate the effect of area on *CFF* over a large range of areas, the range to include as large an area as the apparatus would permit. Since there was no a priori reason to assume, especially with the large range of *A* to be employed, that the relationship would be the same at all *F* or *I* levels, it was thought desirable to obtain *F-log I* contours for each of the test-patch areas employed. The resultant family of curves could then be "cut" at as many *F* (or *I*) levels as desired and the obtained values plotted against log *A*, thus giving rise to other families of curves which should show any change in the log *A-log I* (or *F-log A*) relationship with increase in *F* (or *I*). If the *F-log I* contours for all the test-patches were not determined at one sitting, it is possible that both diurnal and day-to-day variability might tend to obscure the true relationship between *F* and log *A*. However, since all threshold determinations were to be made at a single sitting, it became necessary to consider carefully the problem of fatigue. Since observation of a flickering light is both unpleasant and fatiguing, threshold determinations in both experiments were obtained only by the method of descending order, that is, from fusion to flicker. Granit and Hammond (9) demonstrated that although *CFF* is affected by duration of observation, there is no further increase in *CFF* values for durations greater than 1 sec. It was concluded from the results of a preliminary experiment not to be reported here, that the results of Granit and Hammond also applied over the range of test-patch areas that were employed in this study. Accordingly, a 3 sec test-duration was used because it was less fatiguing than continuous observation, more comfortable than a 1 sec duration, and gave maximal *CFF* values. The number of threshold determinations at each point was two, in accordance with Hecht's finding (12) that two readings gave as reliable results as 10 or more readings with, of course, far less fatigue. And finally, the number of test-patches was limited, since *F-log I* contours were to be gotten for all at a single sitting.

The test-patches used were chosen so that the portions of the retina they stimulated would correspond approximately with the zones of the retina as defined by Polyak (23, pp. 211-218, and 426). However, note the following by Polyak: "It should be kept in mind, however, that even from a purely morphological standpoint the boundaries between the contiguous regions are more or less arbitrary. In the greater part of the retina the arrangement of the cellular and fibrous elements is essentially the same, the abrupt transitions being absent except in a few places, the change from region to region usually being gradual, almost imperceptible" (23, p. 197). The sizes of the test-patches and the zones of the retina which they stimulated are listed in Table 1. The largest area extended into only a small part of the largest zone of the retina, the far periphery, but it was the largest test-patch possible with the apparatus used.

TABLE 1
TEST-PATCH SIZE AND ZONES OF RETINA STIMULATED

Test-patch diameter in degrees va	Zones of retina and number of degrees va subtended by their outer boundaries (Polyak)		
3.4	I	Inner Fovea	5.0
6.9	II	Parafovea	6.7
17.4	III	Perifovea	16.0
23.5	IV	Near Periphery	24.0
39.7	V	Middle Periphery	40.0
49.6	VI	Far Periphery	

Before beginning the observations, *O* rested his face on a "hood" over the oculars of the microscope through which he made all his observations, adjusted the interocular distance to provide optimal binocular fixation, and adapted to the level of constant illumination for about five minutes. The frequency of intermittence of the test-light was set at 25 *cps*, the lowest frequency used, the area-template set for a 3.4° *va* test-patch, the smallest area of the series, and the neutral density wedge adjusted so that the test-light would appear fused. By pressing his key, *O* presented himself with the test-light for 3 sec, and then made a judgment, either "Flicker" or "Steady." The experimenter increased the luminance in steps of approximately 0.02 log units until the judgment was "Flicker." In this manner, two readings of the critical flicker-fusion luminance (I_c) were taken for each of the six test-patch areas. *O* then rested for several minutes and the procedure was repeated at 35 *cps*, and similarly for 45, 55, 65, 75, 80, and 85 *cps*. The smaller test-patches were eliminated one by one from the series when the next highest frequency setting exceeded *Fmax* for that size test-patch for a given observer. The highest frequency was 85 *cps* for the larger test-patches because the apparatus would not provide sufficient luminance for higher frequencies.

2. *Experiment 2*

The main purpose of this experiment was to utilize the extra light afforded by the second apparatus to determine the nature and extent (*Fmax*) of the *F-log I* contour for the 49.6° *va* test-patch at higher luminances than were possible with the first apparatus. The second apparatus employed the conventional episcotister arrangement, and a light-dark ratio of 1/1. Viewing conditions were similar to those used by the majority of *CFF* investigators, namely, observation was continuous, and *I* was fixed and *F* varied. The diameter of the test-patch was 49.6° *va*, the largest the apparatus would permit. Five *O*'s were used in this experiment.

Before beginning the observations, *O* adapted for about five minutes to the lowest luminance level to be used, with the frequency of intermittence set well above fusion. Then the frequency was lowered slowly and continuously until *O* judged "Flicker," whereupon the frequency was raised well above fusion and the procedure repeated until five readings had been obtained. Similarly for each of 11 succeeding luminance levels which increased by steps of approximately 0.3 log units.

D. Results

1. *Experiment 1*

Table 2 presents, separately for the three *O*'s, the means, in log *mL*, of two determinants of I_c for each of the six test-patches at seven frequencies of intermittence. These data are presented graphically in Figure 1 and have been plotted in the conventional manner with *F* on the ordinate and log I_c on the abscissa, even though in this experiment I_c was the dependent variable. It is seen that the larger the test-patch, the lower was I_c at a given frequency, and the less the increase in I_c with *F*. These results are similar to those of Granit and Harper (10) for small areas (5° *va* or less). The *F-log I* contours all appear to be linear. The negative acceleration usually seen at the top of *F-log I* contours was not found for the small test-patches because the frequency settings were fixed far enough apart to obscure the phenomenon (the *F-log I* contours for the larger test-patches were not extended to their upper limits due to the previously mentioned apparatus limitations).

The data from Table 2 have been replotted in Figure 2 with log I_c as a function of log *A*. It is seen that the relationship was essentially linear over the range tested for all *O*'s. However, as frequency increased, the slopes of the curves increased, i.e., log I_c decreased with increase in log *A* at an increasing rate. This may also be seen in Figure 1 in that the *F-log I* contours spread apart as F increased. Also, for a given frequency, the slope of the log I_c-*log A* curve differed slightly from *O* to *O*. This too may be noted in Figure 1 in that for a given frequency, the spread of *F-log I* contours appears greatest for *DD*, less for *WR*, and least for *JL*. Thus, with increase in log *A*, log I_c decreased in a linear fashion, but at a different rate for different *O*'s and different frequencies.

TABLE 2

CFF Thresholds, I_c (log mL), for Six Test-Patches (Diam. in Degrees va, and Log A mm² of Test-Patch), Eight Frequencies of Intermittence (cps), Three Observers, *DD, JL,* and *WR*

	Diam. Log *A*	3.4° 2.21	6.9° 2.85	17.4° 3.66	23.5° 3.93	39.7° 4.41	49.6° 4.62
25 *cps*	*DD*	—0.72	—0.78	—1.05	—1.07	—1.10	—1.17
	JL	—0.71	—0.78	—0.94	—1.01	—1.10	—1.16
	WR	—0.96	—1.15	—1.36	—1.32	—1.42	—1.57
35 *cps*	*DD*	0.06	—0.13	—0.38	—0.48	—0.59	—0.71
	JL	—0.30	—0.47	—0.54	—0.60	—0.68	—0.74
	WR	0.05	—0.17	—0.58	—0.75	—0.81	—0.79
45 *cps*	*DD*	0.84	0.68	0.39	0.23	0.08	—0.04
	JL	0.50	0.35	0.08	—0.06	—0.09	—0.21
	WR	0.98	0.63	0.25	0.08	—0.05	0.00
55 *cps*	*DD*	1.90	1.77	1.03	0.73	0.51	0.41
	JL	1.40	1.16	0.75	0.59	0.51	0.39
	WR	1.77	1.36	0.94	0.79	0.51	0.44
65 *cps*	*DD*	—	—	1.89	1.46	1.04	0.90
	JL	—	1.91	1.45	1.29	1.20	1.08
	WR	—	—	1.57	1.47	1.20	1.02
75 *cps*	*DD*	—	—	—	2.20	1.62	1.41
	JL	—	—	2.16	1.91	1.81	1.73
	WR	—	—	—	—	1.63	1.46
80 *cps*	*DD*	—	—	—	—	1.79	1.64
	JL	—	—	—	—	2.14	2.01
	WR	—	—	—	—	—	—
85 *cps*	*DD*	—	—	—	—	—	2.08
	JL	—	—	—	—	—	—
	WR	—	—	—	—	—	2.10

Figure 3 represents an attempt to translate the measurements obtained by Piéron (22), Allen (1), and the present writer into the same terms for purposes of direct comparison. The *F-log A* contours from the present study were obtained by "cutting" the family of *F-log I* contours for *WR* in Figure 1 at luminance values corresponding to those used by Piéron, 24.5 *mL*, and Allen, 5.3 *mL*. The legitimacy of comparing these "derived" *F-log A* contours rests on the assumption that the *CFF* threshold is the same, whether gotten by varying *F* or by varying *I*. In view of the intra- and inter-individual variability of *CFF* data, and the very different experimental procedures used by Piéron, Allen, and the present writer, examination of Figure 3 would seem to justify the conclusion that the *F-log A* relationship is linear from —5.34 to 2.18 log *A* mm^2 on retina, a range of 7.52 log units.

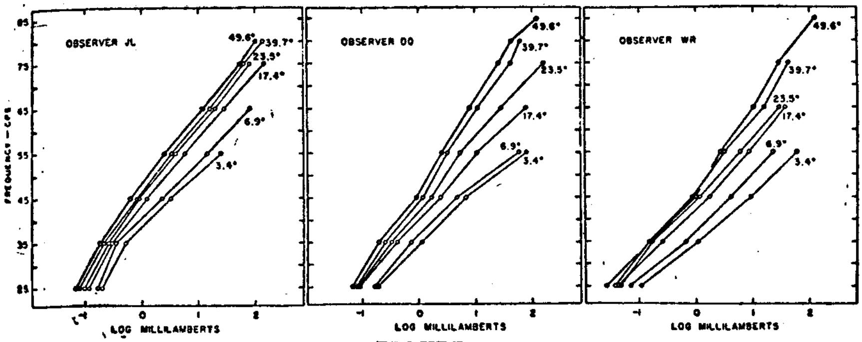

FIGURE 1

F-log I CONTOURS FOR SIX TEST-PATCHES, THE DIAMETERS OF WHICH ARE INDICATED TO THE RIGHT OF THE CURVES IN DEGREES OF VISUAL ANGLE

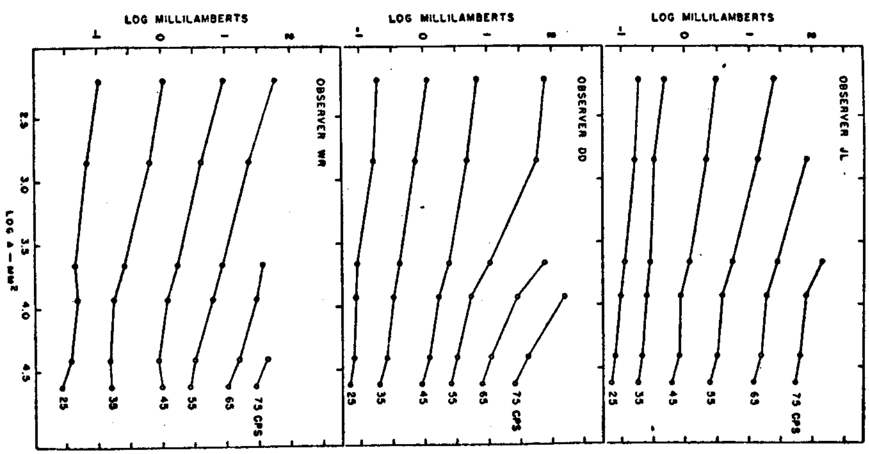

FIGURE 2

LOG I_c-LOG A CONTOURS FOR SIX FREQUENCY LEVELS INDICATED TO THE RIGHT OF THE CURVES

2. *Experiment 2*

The results of the second experiment have been presented in Table 3 which lists separately for five *O*'s, the means of five threshold determinations at each of 12 luminance levels. When presented graphically as in Figure 4,

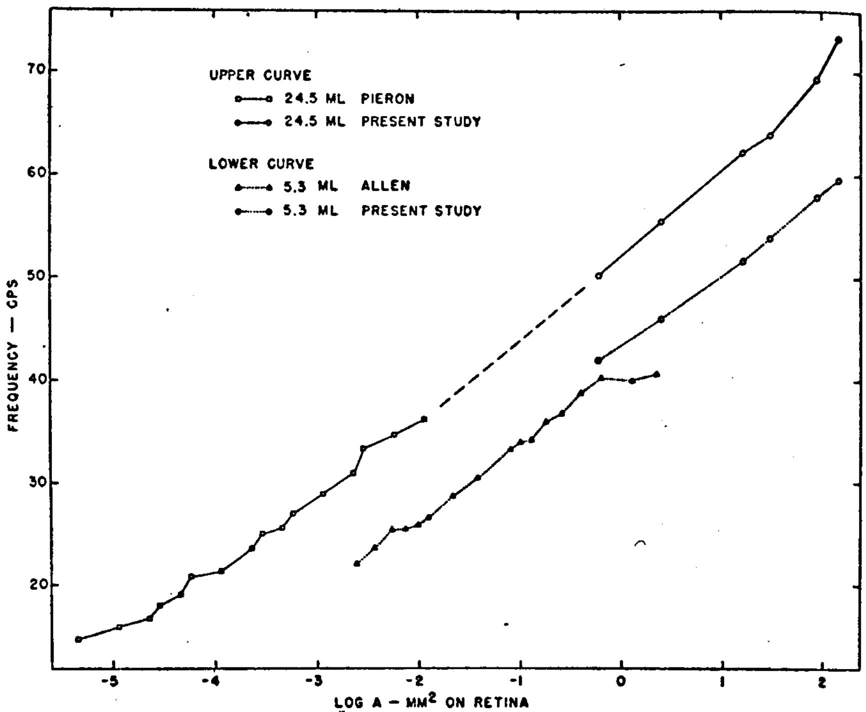

FIGURE 3
A COMPARISON OF *F-log A* CONTOURS FROM THE PRESENT STUDY WITH THOSE OBTAINED BY TWO PREVIOUS INVESTIGATORS

TABLE 3
CFF THRESHOLDS (*cps*) FOR FIVE OBSERVERS (AGE IN PARENTHESES) AT 12 LEVELS OF LUMINANCE (log mL) WITH A 49.6° va TEST-PATCH: EACH THRESHOLD IS THE MEAN OF FIVE DETERMINATIONS

	Observers				
Log mL	*CL* (58)	*JC* (41)	*JL* (27)	*DD* (29)	*WR* (28)
—0.72	24	25	27	28.5	32
—0.37	27	30	33	35	40
0.12	37	40.5	42	43.5	46.5
0.42	44	45	46	49	51.5
0.77	46.5	50	51	53.5	57
1.05	53.5	54.5	56.5	61	65
1.35	58.5	61	62	68	69
1.70	64	66	70	76	77.5
2.12	70	74	78	84	90
2.43	76.5	82	83	90	99
2.64	79.5	86.5	87	95	105
2.77	80	90	89.5	96	107

it may be seen that the *F-log I* contours were all essentially linear over their extent. Although with the added luminance afforded by the second apparatus it was possible to extend considerably the *F-log I* contours for the 49.6° *va* test-patch, the upper limit was still not reached. This will be discussed further in the next section.

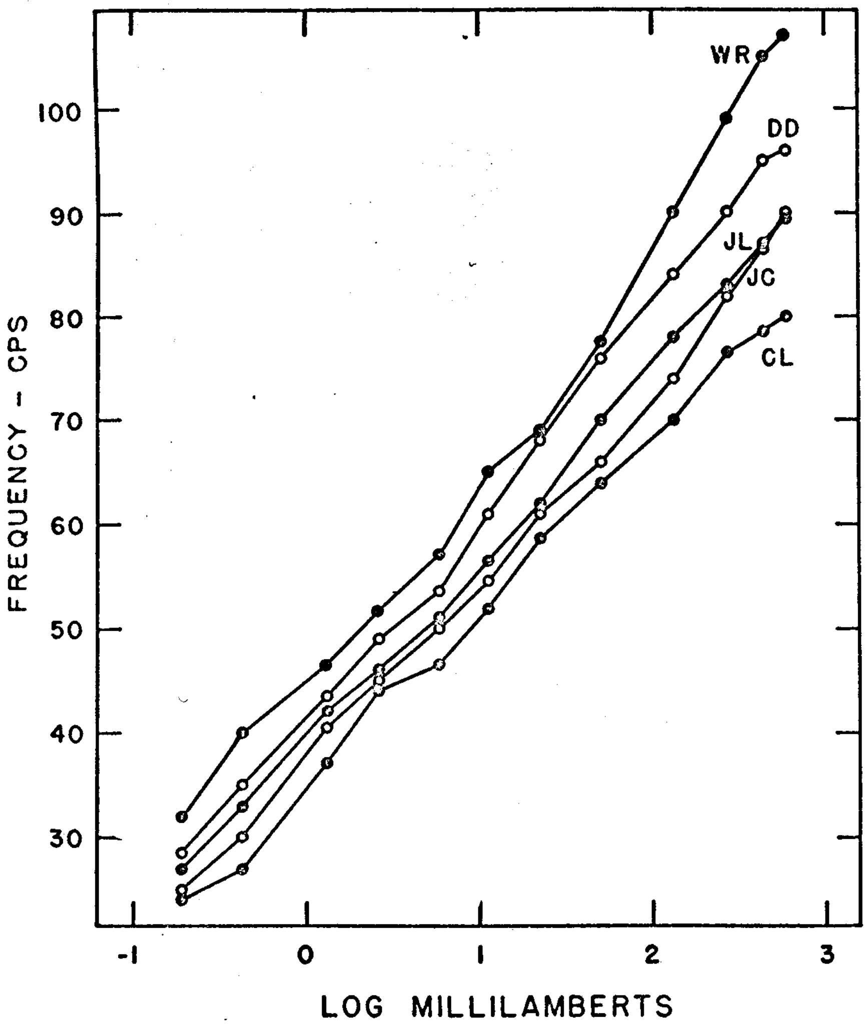

FIGURE 4
F-log I Contours for Five Observers with a 49.6° va Test-Patch

Two investigators (4, 21) have reported that *CFF* declines with increase in chronological age; however, Misiak found a great deal of individual variability, obtaining *CFF*'s at age 82 as high as at age 7 and *CFF*'s at age 7 as low as at age 80. In the present study, *O*'s *DD, WR,* and *JL* differed but little in age and their *F-log I* contours might have been expected to lie above that of *JC,* whose contour might in turn have been expected to lie above that of *CL.* This was seen to be the case.

E. Discussion

Judging from the fact that the curves in Figures 2 and 3 have not begun to decelerate, it seems clear that the limits of the linear *F-log A* relationship have not yet been reached. It is conceivable that *CFF* would continue to increase with *A* until the whole retina is illuminated. However, since Hylkema's perimetric study (15) showed that for each test-patch area used there was a position on the retina which yielded a maximal *CFF,* one could equally well argue that there is a limit beyond which further increases in *A* would not raise *CFF.* The answer to this question will have to await the surmounting of the technical difficulties alluded to in the introduction. But in any case, the results of the first experiment have demonstrated that the Granit-Harper law covers a much wider range than heretofore believed.

The results of the second experiment show that it is possible to obtain *F* values considerably above the commonly accepted ceiling of 82 *cps*, and since the curves in Figure 4 have not begun to decelerate, it seems reasonable to assume that still higher values might be obtained by further increasing *I.* In fact, temporal resolution by the eye seems to get better and better as *A* and *I* are increased, and the present experiments suggest that *CFF*'s far in excess of 100 may be possible. It should be remembered that with a test-patch of 10° *va,* Hylkema found the maximum *CFF* 45° from the fovea, and the largest test-patch of the present study extended only 25° from the fovea, and covered only a small fraction of the largest zone of the retina, the far periphery.

It is worth noting the linearity of the *F-log I* contours in Figures 1 and 4. As *A* is increased, the *F-log I* contour is extended and its linear portion constitutes an increasingly great proportion. Otherwise stated, the Ferry-Porter law applies to *F-log I* contours for large test-patches as well as small, and describes a greater proportion of the contours for the former.

F. Summary

In the first of two experiments, the effect of area on *CFF* was investigated, using foveally-fixated test-patches considerably larger than heretofore used, and with diurnal and day-to-day variability eliminated from the measurements. When the data were plotted in the form of *F-log I* contours, it was seen that the larger the test-patch, the lower was I_c at a given F, and the less the increase in I_c with F. When the data were plotted with log I_c as a function of log A, it was seen that log I_c decreased linearly with increase in log A, and at an increasing rate with increase in F. At a given F, the rate of decrease in log I_c with increase in log A differed slightly among the three *O*'s; but for all *O*'s the relationship was linear over the range of A investigated. Data from this study were compared with those from two previous investigators and it was concluded that the Granit-Harper law was valid for all test-patch areas so far investigated, i.e., with test-patches from 30″ to 49.6° *va* the relationship between F and log A was linear. It was also suggested that the limit of applicability of the Granit-Harper law had not yet been reached.

It was demonstrated in the second experiment that with a test-patch of 49.6° *va*, *CFF* values considerably above the commonly accepted top value of 82 *cps* could be gotten, the highest obtained being 107 *cps*. Because the *F-log I* contours had not yet begun to decelerate, it was suggested that had the apparatus been able to deliver larger test-patches and higher luminances, still higher *CFF* values might have been obtained. It was noted that the *F-log I* contours in this study all appeared linear, and hence the Ferry-Porter law applies to *F-log I* contours for large test-patches as well as small.

References

1. Allen, F. The delineation of retinal zones with dark tube vision. *Canad. J. Res.*, 1945, **23A**, 21-31.
2. Brill, H. M., Golden, M. J., Woolf, H. L., Klawans, A. H., & Long, J. S. The preclinical recognition of toxemia of pregnancy. *Amer. J. Obstet. & Gynaec.*, 1951, **62**, 614-620.
3. Brill, H. M., Long, J. S., Klawans, A. H., Golden, M., & Seaman, I. The nitroglycerin flicker fusion test in the toxemia of pregnancy. *Amer. J. Obstet. & Gynaec.*, 1952, **64**, 1201-1210.
4. Coppinger, N. W. The relationship between critical flicker frequency and chronological age for varying levels of stimulus brightness. (Unpublished Ph.D. dissertation, Tulane University, 1951.)
5. Cords, R. Über die Verschmelzungsfrequenz bei periodischer Netzhautreizung durch Licht oder elektrische Ströme. *v. Graefes Arch. Ophthal.*, 1908, **67**, 149-161.
6. Creed, R. S., & Ruch, T. C. Regional variations in sensitivity to flicker. *J. Physiol.*, 1932, **74**, 407-423.

7. Fick, A. Ueber den zeitlichen Verlauf der Erregung in der Netzhaut. *Arch. Anat. Physiol.*, 1863, 739-764.

8. Golden, L. H., & Cordasco, E. M. Flicker photometry and electrocardiography: A correlation. *N. Y. S. J. Med.*, 1952, **52**, 2157-2158.

9. Granit, R., & Hammond, E. L. Comparative studies on the peripheral and central retina: V. The sensation-time curve and the time course of the fusion frequency of intermittent stimulation. *Amer. J. Physiol.*, 1931, **98**, 654-663.

10. Granit, R., & Harper, P. Comparative studies on the peripheral and central retina: II. Synaptic reactions in the eye. *Amer. J. Physiol.*, 1930, **95**, 211-228.

11. Grünbaum, O. F. F. On intermittent stimulation of the retina: I. *J. Physiol.*, 1897, **21**, 396-402.

12. Hecht, S., Shlaer, S., & Verrijp, C. D. Intermittent stimulation by light: II. The measurement of critical fusion frequency for the human eye. *J. Gen. Physiol.*, 1933, **17**, 237-249.

13. Hecht, S., & Smith, E. L. Intermittent stimulation by light: VI. Area and the relation between critical frequency and intensity. *J. Gen. Physiol.*, 1936, **19**, 979-991.

14. Hylkema, B. S. Fusion frequency with intermittent light under various circumstances. *Acta Ophthal.*, 1942, **20**, 159-180.

15. ———. Examination of the visual field by determining the fusion frequency. *Acta Ophthal.*, 1942, **20**, 181-193.

16. Krasno, L. R., & Ivy, A. C. The response of the flicker fusion threshold of nitroglycerin and its potential value in the diagnosis, prognosis, and therapy of subclinical cardiovascular disease. *Circulation*, 1950, **1**, 1267-1276.

17. Kugelmass, S., & Landis, C. The relation of area and luminance to the threshold for critical flicker fusion. *Amer. J. Psychol.*, 1955, **68**, 1-19.

18. Landis, C. An Annotated Bibliography of Flicker Fusion Phenomena Covering the Period 1740-1952. Armed Forces National Research Council, Vision Committee Secretariat, University of Michigan, Ann Arbor, Michigan, 1953.

19. Lloyd, V. V. A comparison of critical fusion frequencies for different areas in the fovea and periphery. *Amer. J. Psychol.*, 1952, **65**, 346-357.

20. Miles, P. W. Flicker fusion fields: II. Technique and interpretation. *Amer. J. Ophthal.*, 1950, **33**, 1069-1077.

21. Misiak, H. The decrease of critical flicker frequency with age. *Science*, 1951, **113**, 551-552.

22. Piéron, H. L'influence de la surface rétinenne en jeu dans une excitation lumineuse intermittente sur la valeur des fréquences critiques de papillotement. *C. R. Soc. Biol.*, 1935, **118**, 25-28.

23. Polyak, S. L. The Retina. Chicago: Univ. Chicago Press, 1941.

24. Ségal, J. Le méchanisme de la vision en lumière intermittente. *J. Psychol., Norm. & Path.*, 1939, **36**, 451-539.

25. Young, K. H. Critical flicker frequency. *In* F. A. Mettler (*Ed.*), *Selective Partial Ablation of the Frontal Cortex.* New York: Hoeber, 1949. (Pp. 257-263.)

The Psychiatric Institute
722 West 168th Street
New York 32, New York