PERCEPTIONS OF SUBFUSIONAL PHOTIC INTERMITTENCIES UNDER VARIOUS INTENSITIES AND PULSE-TO-CYCLE FRACTIONS

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ABSTRACT

PERCEPTIONS OF SUBFUSIONAL PHOTIC INTERMITTENCIES UNDER VARIOUS INTENSITIES AND PULSE-TO-CYCLE FRACTIONS

by Jane Ellen Ranney

Previous work has shown that subfusional photic intermittencies are effective in producing phenomena such as brightness enhancement, color changes, subjective figures, etc. And many researchers have reported incidental observations of changes in the appearance of intermittentness. In this research six classes of intermittentness were defined, flash, coarse flicker, fine flicker, ripple, flutter, and fusion, and the thresholds determined by the method of limits under four intensities ranging from 3630 c/ft^2 to 36.3 c/ft^2 and five pulse-to-cycle fractions (PCF), 1/8 to 7/8. Three observers determined thresholds under each combination of PCF and intensity for observations of the target, and of the surrounding field.

Analysis of variance showed that PCF, intensity, threshold, and observer were all significant variables. However, shapes of curves for the three observers were very similar, and when one of the observers adjusted the setting of another for any given threshold, only one or two pulses per second difference was found. Results of observations made on the target or surround differed with intensity. At low intensities flicker persisted longer in the target, at high intensities, in the field. This also depended upon the PCF, greater differences being observed with higher PCFs.

It was shown that the existence of the several thresholds could not be attributed to the effects of rise time (onset) of the stimulus, since rise and fall time were too brief to be effective. From the alternation of response theory as presently stated, one would not predict discrete stages in the appearance of flicker as pulse rate is increased, but only a gradual change in appearance. It is only necessary to assume that all channels in the optic pathway may not be equivalent, in order to account for the phenomena. Differences in latencies and discharge rates of on and off responses, and the relations between on and off responses were suggested as providing a mechanism for the experience of several thresholds. That is, on or off responses may drop out at one pulse rate as pulse rate is increased, producing one threshold. As pulse rate is further increased, the remaining response occurs with each stimulus up to the point where it no longer responds to every pulse, producing another threshold. Finally a point is reached where no response occurs to any pulse, the fusion threshold.

Suggestions were made for further research.

Approved: Stephen S. Bartley

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By

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INTRODUCTION

Most research on intermittent photic stimulation involves the effects of variables such as intensity on (1) single pulses, (2) double pulses, or (3) trains of pulses producing fusion. Relatively little work has been done concerning trains of pulses at subfusional rates. In spite of this, there have been some important effects observed at subfusional rates of stimulation. For example, brightness enhancement occurs at subfusional rates (Bartley, 1938, 1939b, 1951; Bartley & Wilkinson, 1952; Bartley, Paczewitz & Valsi, 1957), and similar rates affect visual acuity (Senders, 1949, Nachmias, 1958; Bartley, Nelson & Soules, (1963), and size (Nelson, Bartley & Wise, 1963). Other interesting phenomena may occur within this range. Color changes (Bartley & Nelson, 1960; Nelson & Bartley, 1961; Bartley, Nelson & Mackavey, 1961), rotatory and other movement (Zapparoli & Ferradini, 1960) and forms of subjective figures (Segal, 1939) have all been investigated under various rates of intermittent photic stimulation. But changes in the appearance of intermittentness or "flicker," although frequently mentioned, have not been systematically described for a wide range of stimulus conditions. That is the task of this research.

Many investigators have reported changes in the appearance of intermittencies (flicker) below fusion (Rood, 1863); Schenk, 1897; O.F.F. Grünbaum, 1897, 1898; A. A. Grunbaum, 1917; Brecher, 1937; Bartley, 1939a; Duke-Elder, 1942), and in 1927, Haack published a review of reports to that date.

From observing a rotating black and white disc, Schenk, (1897) reported the following:

> Beobachtet man eine halb schwarze, halb weisse Kreiselscheibe bei allmählich zunehmender Drehuns'Geschwindigkeit, so sieht man zunächst noch das Weisse und das Schwarze getrennt von einander, wenn auch die Grenzen zwischen ihnen nicht mehr deutlich zu erkennen sind. Darauf tritt ein Stadium ein, in dem man die ganze Scheibe schon grau sieht, aber durchaus noch nicht gleichmässig: Intensitätssschwankungen kommen bald hier bald dort vor--man hat den Eindruck, als ob Schatten uber die Scheibe huschten. Schliesslich sieht die Scheibe in allen Theilen gleichmässig grau aus. (p. 32)

Thus he differentiated between what he called "flackern" (course flicker) and "flimmern" (fine flicker). Similarly, Brecher (1937) described one stage in which pulses were seen as clearly separated light flashes, a second stage in which the pulses no longer were seen as separate, and the third stage, fusion. The transition point between stages one and two he called the "flacker-flimmer" boundary, or the boundary between course and fine flicker. O. F. F. Grünbaum (1897, 1898) described the intermediate stage between flicker and fusion as "molecular movement," "Brownian movement," or "glitter."

Rood (1863) noted that as a black and white sectored disk is rotated slowly, "the figure remains undistorted." The perception at about 10 pulses per second he described as a "loss of definition," and at 30 pulses per second, as "glittering." Glitter he described as

> lustrous, with rapid variations in the intensity of the light. . . . the strong objective light is seen through the weaker fading subjective impression, and the latter is of course at regular intervals perceived distinct by itself, so that the eye is in effect acted on by two masses of light of unequal intensity, and is also sensible of their separate presence. (p. 358)

Similarly, Bartley (1939a) described a stage with one phase behind another. Duke-Elder (1942) also desdribed three stages below fusion: (1) a stage in which each stimulus is experienced separately, (2) a coarse, unpleasant stage, and (3) a fine tremulus sensation of flicker.

A. A. Grünbaum (1917) described seven stages: (1) a displacement of dark contours; (2) a rhythmic change, but with motionlessness of the field of view; (3) "flackern," a sudden brightening and darkening, an impression of irregularity; (4) further unification; (5) "flimmer," a restlessness, trembling in the visual field, center darker, periphery brighter, with a circular movement around the center; (6) center brighter, edges darker, brightness changes perceived as movement in various directions; (7) target predominantly bright with no movement.

These observations indicate that there is no regular transition from flash to fusion. There may be several important distinctions in the continuum, distinctions which may be relevant to the neurophysiology of vision. However, most of the foregoing descriptions were based on incidental observations, rather than on systematic studies.

The only attempt to systematically describe the changes in perception of intermittency as pulse rate varies from fusion to zero was by Bartley (1939a). He listed nine stages for targets viewed with dark surround as rate is decreased from high frequencies:

> (1) a steady field or fusion. . . . (2) slight flicker in relatively steady fields; (3) a mottling of the test-field, and coarser flicker; (4) flicker in the field surrounding the test-object when it subtends a small or medium visual angle, and the beginning of an appreciable amount of gamma movement; (5) flicker is seen over the whole visual field outside the test-object, and vigorous flicker within the test-field when it subtends a large visual angle, gamma movement becoming vigorous; (6) the Brücke maximum; (7) the development of definite ocular tension; (8) the emergence of the dark phase of the cycle; (9) the emergence of the flashes and dark intervals as entities. (p. 465-466)

He further noted that the appearance in the last stages was affected by the pulse-to-cycle fraction (PCF), and that with PCF's other than 1/2, with increase in intensity, the maximum ocular tension increased to a maximum and then fell. However, he presents no data for direct comparison of PCF's, although he does compare several unspecified intensities. In addition, similar observations were made for targets with illuminated surround.

Bartley noted changes in both the test-object and the surrounding field. Support for this distinction is provided by Hecht and Schlaer (1935-36). More importantly, they found that with the 19° central target they used, the relation between the critical flicker frequency (CFF) of target and field depends upon the intensity of the target. That is, they found that the field flickered after the center had fused at low intensities, and at higher intensities flicker persisted longest in the center. At still higher intensities, flicker may disappear last from any part of the field. Support is provided by Crozier and Wolf (1941) who found that at about the kink in the flash frequency-log intensity curve (the change from rod to cone function) there is a transition from a condition where the final flicker occurs in the periphery of the field to one where it occurs in the center of the target. With a 1° test object, Bartley (1936) found that CFF for the target was higher than for the field, and that as the intensity increased to 2500 c/ft^2, these thresholds approached each other.

It seems then that two problems need study. First, natural distinctions in the perceptions produced by the continuum from slow to rapid photic pulse frequencies must be delineated. Second, the effects of several variables on the transition points between these categories of perceptions must be determined. That is the task of this research. Once suitable categories of intermittentness were decided upon, transition points or thresholds between them were measured under various conditions of intensity and PCF. Also these observations were made both on the target itself, and on the surrounding field or "halo" which surrounds a bright target. Some suggestions will be made for neurophysiological explanations of these phenomena.

METHOD

Apparatus. A 6 volt, 18 amp General Electric ribbon filament lamp mounted in a housing with an opal glass front provided an intensity of 3630 c/ft^2. In addition, Kodak Wratten neutral density filters 0.2 plus 0.3, 110, and 2.0 reduced the intensity to 1143, 363 and 36.3 c/ft^2 respectively.

A single-open-sector 25.6 cm. plastic episcotister disk (PCF 1/8, 1/4, 1/2, 3/4, or 7/8) was rotated in front of the photic source. Rotation rate was regulated by the observer with a Variac which controlled the motor driving the shaft and disk. Voltage from a Weston DC voltage generator driven from the same shaft was adjusted by a potentiometer calibrated to provide pulse rate directly in pulses per second. Data were recorded by punched tape output from a digital voltmeter. A lever depressed by the observer activated the recorder which recorded the data automatically. This eliminated the need for an experimenter to record data, and permitted recording to one-tenth pulse per second.

Observing position was maintained 76 cm from the target by the dental impression method. The target was a 2 cm. by 1 cm. trapezoid whose long nonparallel sides were the radii of a circle, subtended 1^{o} 30' by 45' visual angle. A reduction screen with a .8 cm. circular opening was placed 12 cm. in front of the observer.

Observers. Three women served as observers. One undergraduate and one graduate student served as paid observers in addition to the author. Each spent about eight hours observing before systematic data collection began.

Terminology. In our early observations we found we could distinguish six stages in the continuum from flash to fusion for most conditions. These stages are described below and depicted in Fig. 1.

(1) Flash. This is a stage with definite dark and light periods. There are definite on and off portions, and each may have finite duration. For conditions below PCF 1/2 it is a flash of light. With PCF 1/2, light and dark periods appear nearly equal in duration. With PCF's above 1/2, the effect is that of a "dark flash." The light appears interrupted by dark rather than vice versa as in the lower PCFs.

(2) Coarse flicker. The light and dark "blend in." There is no clear boundary between light and dark. The target darkens and lightens, or dims and brightens.

(3) Fine flicker. There is less difference between the dim and bright stages. The change is much faster, although speed was not to be used as a criterion. As one observer described it, "The alternation becomes too rapid to have dark and light phases."

(4) Ripple. The light is constant with a little ripple or undulation overlaying it. The variation is regular in contrast to that of flutter.

(5) Flutter. The target is almost completely steady; it quivers only occasionally. The movement is irregular and may appear in different portions of the target. The target is basically steady, but every now and then a little movement appears somewhere in the target.

(6) Fusion. The target is steady.

Basically the same descriptions apply to observations of the field surrounding the target. However, at least for the author, the field possessed a spatial aspect as well as temporal. Gamma movement played a large role. Thus in flash, the light in the field "moved back into the target," as when an incandescent light is turned off. With coarse flicker this movement was incomplete, and in fine flicker, restricted to the edges of the field. In ripple, this movement was

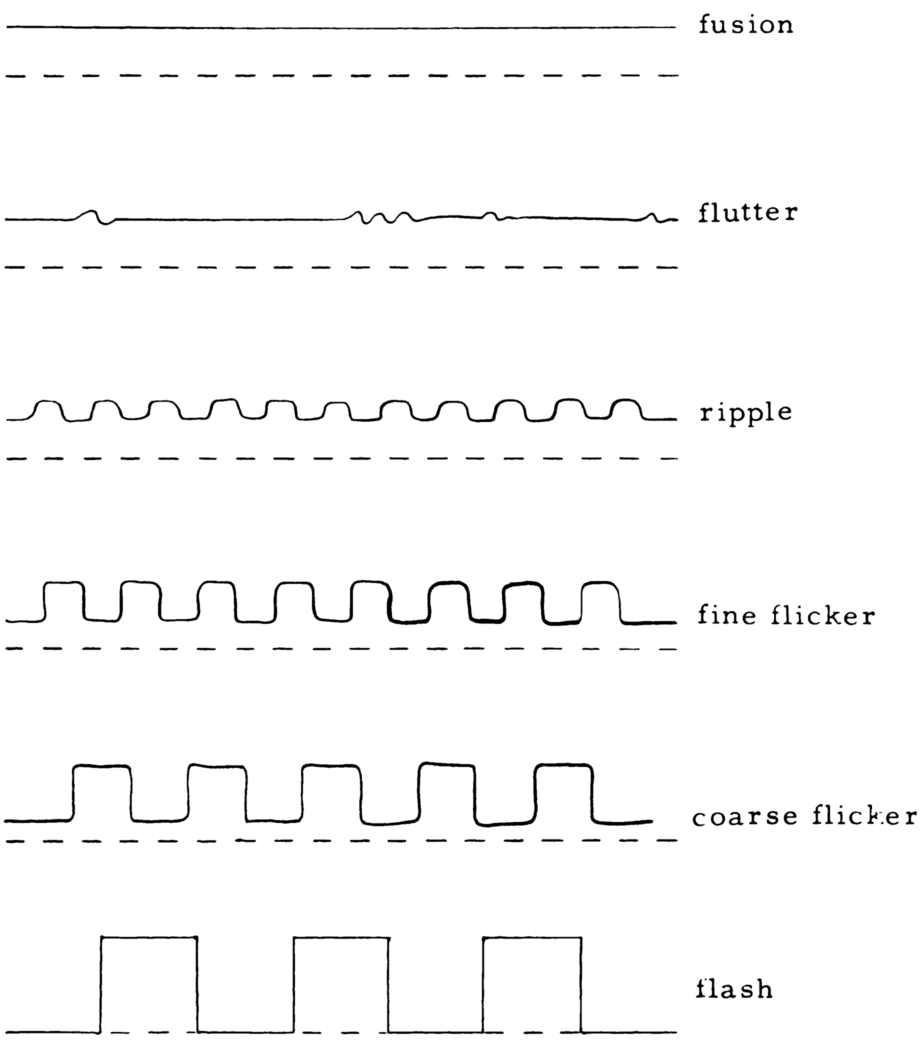

Figure 1. Schematic diagrams of the six descriptive classes of intermittentness. Base line in each diagram indicates zero brightness.

completely gone. In its place were rapidly fluctuating rays, like spokes of light. The lower portions of this stage may be what Grünbaum has called glitter.

Once these stages and their descriptions were decided upon, systematic observations could begin. The observations were made on the transition points between stages ("thresholds"). Preliminary examination showed that the observers were able to repeat observations quite reliably. In addition, if one observer adjusted the rate for a particular "threshold," when the others examined the target, adjustments of at most only a few pulses per second were necessary to satisfy them.

Procedure. Each of the five pulse-to-cycle fractions (PCF), 1/8, 1/4, 1/2, 3/4, and 7/8, was combined with each of the four intensities (I), 3630, 1143, 363, and 36.3 c/ft^2, making a total of 20 conditions. These will be referred to here as PCF-I conditions to distinguish them from conditions of observing, *i.e.*, field or central. Since all PCF-I conditions were observed under two observing conditions, there were 40 conditions in all.

All observations were monocular in a darkened room. The observer increased and then decreased pulse rate to observe the changes and become oriented to each condition before recording any data for that condition. Thus the observer was light adapted. Then the observer increased the pulse rate to the first threshold, depressed the lever activating the recorder which automatically recorded the pulse rate on punched tape. Then the observer continued to increase pulse rate toward the one producing the next threshold, and so on. The ascending readings for all thresholds under one PCF-I condition were obtained, followed by all descending readings for that condition. Ascending and descending observations were made first on the target, and second, on the surrounding field for each PCF-I condition.

A total of ten readings, five ascending, five descending, were obtained for each threshold under each condition for one observer; and four readings, two ascending and two descending for the two other observers. That is, one observer made five replications of the series of conditions and two observers made two replications. PCF-I conditions were randomized within each replication. From two to eight PCF-I conditions were observed at a sitting.

RESULTS

Means and standard deviations for each observer were computed by the CDC 3600 computer for each condition. See Appendix. Group means are plotted in Figures 2 and 3 where the lines in each case indicate the transition points or thresholds between the classes of intermittentness. That is, the region of ripple, for example, is defined by the flutter-ripple and fine flicker-ripple thresholds. The observer means were then used in computing an analysis of variance. Since the coarse flicker-fine flicker threshold was not observable under some conditions, this threshold was omitted from the analysis. The results of this analysis are presented in Table I. Main effects and interactions not involving observers were tested using mean squares for the next higher order interaction involving observers. Since Bartlett's test showed the variances of three- and four-way interactions involving observers not homogeneous (corrected $\chi^2 = 33.05$, df = 5, $p < .01$; corrected $\chi^2 = 16.71$, df = 3, $p < .01$), and no logical basis for using any other mean square could be determined, interactions involving observers were not tested. The observers main effect was tested with each of the four-way interactions involving observers and found to be significant in each case ($p < .001$).

Several factors may have contributed to the differences between observers: (a) Differences in neurophysiological functioning; (b) Factors such as brightness out-of-doors may have contributed more to the results of the two observers who made only two pairs of observations on each condition. (c) Slight differences in the criteria, both between observers, and from day to day. (d) One observer (RB) wore contact lenses. However, Boynton (1963) tested the effect of contact

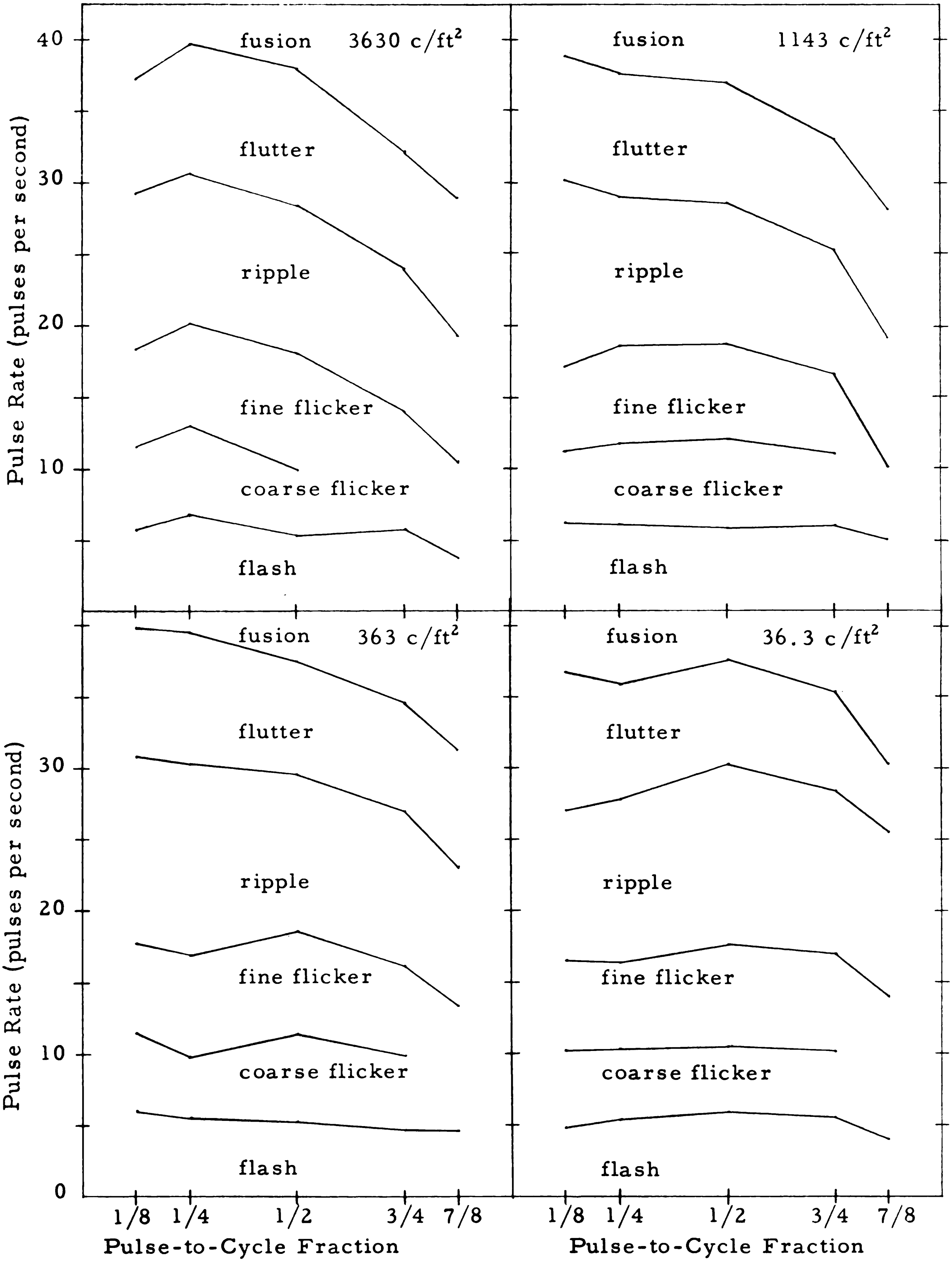

Figure 2. Graphs of mean pulse rate for each threshold as a function of PCF when the center was observed.

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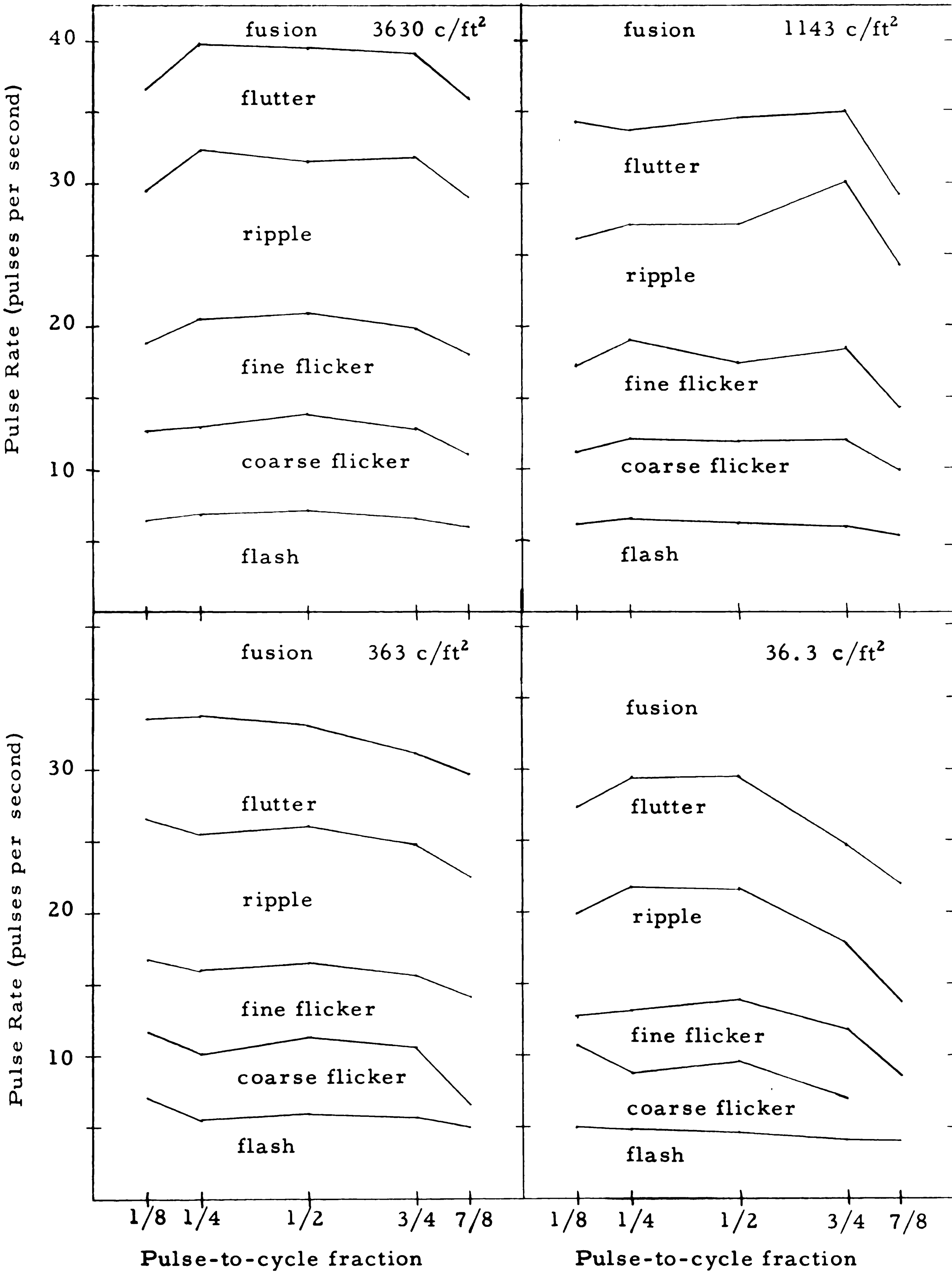

Figure 3. Graphs of mean pulse rate for each threshold as a function of PCF when the field was observed. Each intensity is graphed separately.

Table I. Summary of analysis of variance based on mean for each observer under each condition.

Source	df	MS	F
Pulse-to-Cycle Fraction (PCF)	4	358.8522	24.68***
Intensity (I)	3	339.9093	9.16*
Threshold (Th)	3	18416.1418	69.80***
Field-Center (F-C)	1	158.0108	2.95
Observer (O)	2	76.3864	****
PCF x I	12	7.7676	.93
PCF x Th	12	25.7926	17.35***
PCF x F-C	4	38.8638	3.38
I x Th	9	22,1329	4.91**
I x F-C	3	391.9156	29.69***
Th x F-C	3	63.9650	2.13
PCF x O	8	14.5385	
I x O	6	37.1267	
Th x O	6	263.8585	
F-C x O	2	53.5022	
PCF x I x Th	36	1.1652	.63
PCF x I x F-C	12	18.5410	5.65***
PCF x Th x F-C	12	5.1954	2.86*
I x Th x F-C	9	37.6980	5.65**
PCF x I x O	24	8.3131	
PCF x Th x O	24	1.4863	
PCF x F-C x O	8	11.5142	
I x Th x O	18	4.5037	
I x F-C x O	6	13.1999	
Th x F-C x O	6	30.0278	
PCF x I x Th x F-C	36	2.7624	2.10***
PCF x I x Th x O	72	1.8433	
PCF x I x F-C x O	24	3.2798	
PCF x Th x F-C x O	24	1.8190	
I x Th x F-C x O	18	6.6750	
PCF x I x Th x F-C x O	72	1.3174	
Total	479		

* $P < .05$

** $P < .005$

*** $P < .001$

**** Each four-way interaction involving Observers was used as the error term, with $p < .001$ in each case. See text.

lenses in his research on stray light and reported that

> The glare effect, independent of wavelength, was greater by about 0.35 log unit with the lens in than with the lens out. . . . There was no indication, however, that scatter contributed either by the lens or its effects was of appreciable magnitude compared to stray light resulting from reflection and scattering in the normal media of the eye. (p. 446)

(e) One observer (JR) had had far more previous experience as an observer in flicker experiments, and consequently her variance was less than that of the less trained observers (Nelson, Bartley, & DeHardt, 1960).

Examination of Figures 2 and 3 along with the analysis of variance table reveals several things. First of all, PCF is a significant variable ($p < .001$). In addition, PCF by intensity by Field-Center is significant at the .001 level. Another finding is that PCF is less effective for lower thresholds than higher. Some support for this conclusion is provided by the significant PCF by Threshold interaction ($p < .001$).

The most obvious result is, of course, that it is possible to distinguish the six stages described on page 6. While only four of the thresholds between these categories were included in the analysis of variance, as explained above, the effect of thresholds was significant at the .001 level.

Figure 4, which presents the differences between mean thresholds for target and surrounding field for four thresholds, and the significant intensity by Field-Center interaction ($p < .001$) indicate that the relation between target and surrounding field is not as simple as Bartley (1936) indicated. In Figure 4, the coarse flicker-fine flicker threshold was again omitted because of the number of missing observations. Bartley's curve is only for PCF 1/2, and shows CFF for test object and field becoming nearly identical at about 2500 c/ft^2. In Figure 4 all positive

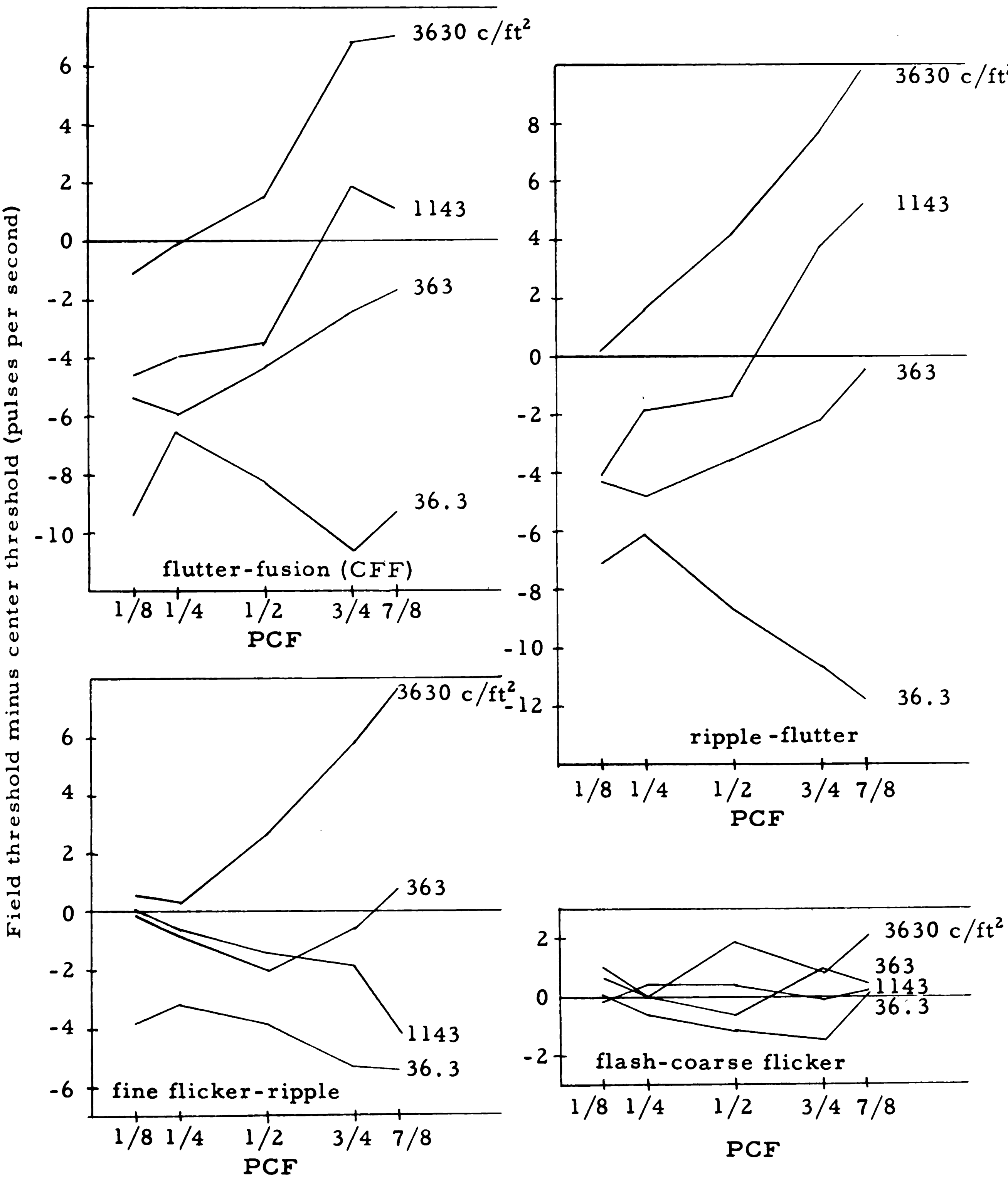

Figure 4. Mean field threshold minus mean center threshold as a function of PCF for each intensity of four thresholds.

points indicate that the threshold for the field was greater than that of the target. It is apparent from the figure that not only do the CFFs become equal, but the field CFF exceeds that of the target for the highest intensity tested here (3630 c/ft^2) at PCF 1/2 and higher, and for intensity 1143 c/ft^2, PCF 3/4 and 7/8. One-sided t tests showed the difference significant, $p < .05$ for PCF 1/2 ($t = 1.85$, df = 17), $p < .001$ for PCF 3/4 ($t = 4.16$, df = 25 by Welch's formula, Walker & Lev, 1953), and $p < .001$ for PCF 7/8 ($t = 4.92$, df = 17) at 3630 c/ft^2. At 1143 c/ft^2, differences were not significant. Comparison of Figures 2 and 3 shows that intensity is more effective in observations of the field than of the center. The lack of a significant Field-Center main effect is attributable to the high Intensity by Field-Center interaction.

These results combined with those of Hecht and Schlaer (1935-36) and Crozier and Wolf (1941) seem to indicate that at low intensities (scotopic level) flicker persists longer (CFF is higher) in the periphery than in the target. When intensity is above the inflection point between rod and cone function CFF is higher in the target. But as intensity increases further, a point may be reached when CFF is again higher in the periphery or surrounding field. One might suppose that the rods are again being stimulated. Bartley (1936) found that flicker in the field was produced by entoptic stray light, which would stimulate rods. Indeed, Boynton (1953) has found both image and stray light components in the electroretinogram (ERG), and compared the effects of stray and direct illumination on the ERG. He found that to elicit a given b wave in the ERG a small stimulus required four times as much luminous flux as a large stimulus.

The differences between field and target for the ripple-flutter and fine flicker-ripple thresholds show similar relationships to that of CFF. However, the lower thresholds, coarse-fine flicker, although not graphed here, and flash-coarse flicker, are irregular. This difference is brought out by the significant Intensity by Threshold by Field-Center interaction ($p < .005$). This may be complicated by the fact that data for the flash-coarse flicker threshold may be somewhat skewed. These observations were difficult to make because the low speeds required could not be readily maintained. This difference then provides further evidence for differences between rods and cones, _i.e._, a difference in the response (perception) to low and high pulse rates.

DISCUSSION

The existence of the several thresholds might be attributable to the effects of less-than-square pulses produced by the episcotister at low pulse rates. Indeed a great deal of work has been done on the role of temporal gradients of intensity in retinal response. In the light-adapted eye, with intensity of 100 lux, both size and shape of the ERG changed with rise times greater than 100 msec. whereas no remarkable changes were produced when the rise time was varied between 1 and 70 msec. (Ronchi & Grazi, 1956). Ronchi & Moreland (1957) report no change in the ERG with change in rise time, with constant exposure time and peak intensity. The results of a study comparing effects of stimuli with rise times of 50-75 msec. or 2 sec. recorded from ganglion cells in the cat (Enroth-Cugell & Jones, 1961) provided support for this position. However, Bornschein (1961), varying rise time from 7 to 180 msec., found the amplitude of the ERG decrease nearly linear to about 50 per cent in the cone retina of the European Ziesel (Suslik, Cason or earless marmot). With human subjects using red light, the x-wave of the ERG was influenced by a stimulus gradient of between 8 and 30 msec. (Bornschein, 1962b). In another study (Bornschein, 1962a) the reciprocity of the antagonistic on-center and off-center neurons of the cat was shown to partially disappear with increase in the rise or fall time of the stimulus. In a complementary psychophysical experiment, humans distinguished stimuli with rise times of 7 and 100 msec. (intensity 830 c/m^2). Fall time was significantly more often identified correctly than rise time for this intensity and for a log reduction of 1.5 (Bornschein, 1962c).

However, when the pulses used in this study were monitored with a Tektronix oscilloscope model 502A with a solenium photoemissive type photocell at the observer's normal eye position, it was found that the rise time at 3 pulses per second was 4 msec., and decreased rapidly to 1.2 msec. at 10 pps. Since in all cases these are briefer rise times than those which have been shown to produce changes in ERG, or responses of ganglion cells, or to be perceptually distinguishable, it is safe to conclude that the existence of the several thresholds distinguished in this study cannot be explained by effects of gradients of intensity produced by the episcotister.

The alternation of response theory (Bartley & Nelson, 1963) postulates a number of channels in the optic pathway (individual fibers in the optic nerve) which may be activated in groups. At very slow pulse rates, with sufficient recovery time between pulses, and with sufficient intensity, all channels will be activated simultaneously. When pulse rate or PCF is such that there is not sufficient recovery time for all channels, only those channels which have recovered will respond. Thus after a number of pulses, channels will have distributed themselves to an alternating pattern. This continues as pulse rate is increased, distributing activity so that fewer and fewer channels respond to any one pulse in a train. This theory accounts very nicely for the changes in brightness as pulse rate is increased to fusion where the Talbot-Plateau law is effective. However, from this theory one would predict a very gradual change in the appearance of flicker. Yet many earlier observations have indicated relatively discrete changes in appearance. This research distinguished five classes of intermittentness over all the conditions investigated. These results are not explained by the alternation of response of the channels in the optic pathway. Some additional mechanism must be responsible for the effects.

One possible explanation of the existence of the several thresholds is derived from Enroth's data (1952) from dark adapted eyes, supported by data of Ogawa, Levick & Bishop (1962), and Dodt and Enroth's data (1953) from light adapted eyes, in which they recorded from the individual ganglion cells in the cat retina. Several stages can be seen in their records, particularly those of elements responding to both on and off of the stimulus. In this case, generally one or the other is the dominant, i.e., the discharge rate is higher and the latency shorter. As pulse rate is increased, at some point the on and off responses "clash," and the weaker response disappears, leaving only the dominant, which may be either the on or off, depending on the particular unit being measured. The dominant response continues as pulse rate is increased, and then becomes arrhythmic, responding only to some pulses, and then finally ceases to respond at all. Thus there are four stages in a fiber responding to both onset and offset of pulses: (1) both on and off responses occurring, (2) only the dominant occurring, (3) an arrhythmic response of the dominant, and (4) no response. The similarity of these last two stages to those of the subjective stages is obvious.

Enroth (1952) has distinguished "fixed" and "labile" off responses, the difference being that the "fixed" type of discharge responds completely to the first pulse, whereas the "labile" off discharge requires a number of pulses before full response, for example, seven pulses. Unless the differences in this respect between cat and human are much greater than might be anticipated, the difference in these two types most likely does not contribute to the thresholds for two reasons: (1) a number of pulses generally had been observed in a given pulse train before a threshold was reached, (2) if the lower threshold(s) were attributable in some way to this difference, then the threshold(s) should not be observable on descending trials. Of course this was not the case.

Similarly, the non-sustained type of on response would be eliminated within the first few pulses, and since it depends on the total time of light exposure as well as the pulse frequency, would not contribute in any regular manner to any threshold.

The fact that in flutter, movement seemed to occur now here, now there in the target suggests that this arrhythmic firing of elements may be responsible for the sensation.

The implication of this for alternation of response theory is that, because of the differences in on and off responses, the channels in the pathway are not necessarily equivalent. This has never been explicitly stated by Bartley, even though he has used the inhibition of the off response as an explanation for the occurrence of fusion at higher PCFs (1939b). This explanation suggests that fusion results when the null periods between pulses are so brief that the succeeding pulse inhibits the off response from the preceding, leaving only the on response. But if the Enroth, and Dodt and Enroth results are correct, that an <u>off</u> response may persist beyond the elimination of the on response, the question becomes one of the subjective meaning of a train of off responses.

It may be that the meaning of a response depends upon other activity in the system. At a high pulse rate where either on or off responses have dropped out, the remaining response may be interpreted as either. It may simply indicate change.

It was originally thought that the curves for the various thresholds might be of different shapes, and therefore offer some explanation for the diverse results that various authors have obtained. That is, some of the differences in the curves of critical flicker frequency could be attributed to differences in the criteria of fusion. Schenk (1897) suggested this possibility when he discussed his replication of Sherrington's work. He noted that what he called "flackern" Sherrington called "flicker," and likewise what he called "flimmern," Sherrington denoted as "steady sensation." The upper two thresholds are most likely to be defined as CFF. From Figure 2 it appears that these thresholds do not produce different shaped curves. The thresholds are nearly parallel. In spite of this, the PCF by Threshold interaction was significant at the .001 level. However, this difference may be contributed largely by the difference between the upper and lower thresholds, particularly flash-coarse flicker.

The finding of differences in field and target observing at high intensities does have one implication for methods used in CFF studies. That is, at high intensities care must be taken that the observers are instructed to observe the target, and report fusion, or flicker, in the target rather than surround. At high intensities the flicker in the surround is overwhelming. However if results are to be comparable to those for lower intensities, this distinction must be observed. Otherwise the problem becomes a different one, as fusion is defined as the disappearance of any variation anywhere in the observed area, and a different portion of the retina is involved.

With well trained observers, this sort of study should be repeated using the method of single stimuli. Such a study may show that distinctions between coarse and fine flicker should be dropped. For some of the conditions in this study these were not distinguishable. In using the method of limits, what was responded to was a change in appearance, and the preceding perception affected the determination of the threshold. The method of single stimuli would eliminate this problem. For a trained observer, though I believe five of the categories, omitting fine flicker, could be distinguished using single stimuli.

Another possibility is that what has been designated here as the flash-coarse flicker threshold, at the higher PCFs, might more properly be the coarse-fine flicker threshold. The curves in Figure 2 would indicate that this may be the case, since if a line is drawn from the last observed point for coarse-fine flicker to the value for flash-coarse flicker for the next higher PCF, the curves are roughly parallel to those of the higher thresholds. The distinction between dark flash observed at these PCFs, and coarse flicker is indeed a fine one. The method of single stimuli provides a test of this suggestion.

One might think the categories derived here to be arbitrary distinctions. Perhaps they are. But the evidence does not support such a position. Observers were able to repeat observations quite reliably. And observers agreed at about what point a given threshold existed when they made direct comparisons with each others' observations. Finally, similar distinctions under a variety of labels, have been reported in the literature far too frequently not to be real.

It may be possible to pinpoint the thresholds in another way by using a modulated intensity. Pulse rate could be maintained at a slow rate and intensity varied between some high value and a lower intensity. Because the sensation at higher pulse rates is one of dimming and brightening, it may be possible to match an intermittent stimulus with a null period and variable rate to an intermittent stimulus alternating between two intensities, with constant pulse rate. In this way the experience of coarse flicker, for example, may be found to be produced by a modulation of, say, 85 per cent.

SUMMARY

Previous work has shown that subfusional photic intermittencies are effective in producing phenomena such as brightness enhancement, color changes, subjective figures, etc. And many researchers have reported incidental observations of changes in the appearance of intermittentness. In this research six classes of intermittentness were defined, flash, coarse flicker, fine flicker, ripple, flutter, and fusion, and the thresholds determined by the method of limits under four intensities ranging from 3630 c/ft^2 to 36.3 c/ft^2 and five pulse-to-cycle fractions (PCF), 1/8 to 7/8. Three observers determined thresholds under each combination of PCF and intensity for observations of the target, and of the surrounding field.

Analysis of variance showed that PCF, intensity, threshold, and observer were all significant variables. However, shapes of curves for the three observers were very similar, and when one of the observers adjusted the setting of another for any given threshold, only one or two pulses per second difference was found. Results of observations made on the target or surround differed with intensity. At low intensities flicker persisted longer in the target, at high intensities, in the field. This also depended upon the PCF, greater differences being observed with higher PCFs.

It was shown that the existence of the several thresholds could not be attributed to the effects of rise time (onset) of the stimulus, since rise and fall time were too brief to be effective. From the alternation of response theory as presently stated, one would not predict discrete stages in the appearance of flicker as pulse rate is

increased, but only a gradual change in appearance. It is only necessary to assume that all channels in the optic pathway may not be equivalent, in order to account for the phenomena. Differences in latencies and discharge rates of on and off responses, and the relations between on and off responses were suggested as providing a mechanism for the experience of several thresholds. That is, on or off responses may drop out at one pulse rate as pulse rate is increased, producing one threshold. As pulse rate is further increased, the remaining response occurs with each stimulus up to the point where it no longer responds to every pulse, producing another threshold. Finally a point is reached where no response occurs to any pulse, the fusion threshold.

Suggestions were made for further research.

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APPENDIX

Means and Standard Deviations for Ten Observations on Each Threshold Under Each PCF-I Condition for J. R., Observing the Target

PCF	c/ft^2	flash-coarse flicker $\bar{X}$	S	coarse-fine flicker $\bar{X}$	S	fine flicker-ripple $\bar{X}$	S	ripple-flutter $\bar{X}$	S	flutter-fusion $\bar{X}$	S
1/8	3630	4.1	1.6	8.5	2.9	15.4	5.6	32.2	4.9	41.3	2.3
	1143	3.8	1.6	7.6	3.2	13.7	6.7	35.3	2.6	41.2	2.0
	363	3.8	1.2	7.2	2.6	13.1	5.4	35.4	2.5	42.1	1.5
	36.3	2.5	.9	6.0	2.7	12.5	6.0	31.9	2.8	39.5	2.5
1/4	3630	4.2	.8	9.3	2.7	16.6	5.8	32.6	3.0	40.3	3.5
	1143	4.1	2.0	8.4	3.6	15.6	6.5	34.1	3.6	42.5	2.0
	363	3.7	1.3	7.0	1.7	13.1	3.9	33.9	3.6	41.4	1.8
	36.3	3.8	1.5	7.6	2.6	12.7	4.2	33.6	4.3	39.6	2.0
1/2	3630	5.0	1.1	8.4	1.8	14.0	3.0	29.4	4.0	39.5	1.7
	1143	4.2	1.4	9.6	3.5	15.4	5.2	31.8	3.6	39.4	2.2
	363	4.9	1.1	8.6	1.8	14.8	3.7	33.1	2.7	39.4	1.6
	36.3	3.5	1.6	6.9	2.2	13.2	3.4	33.9	3.0	39.9	2.0
3/4	3630	4.4	1.8			10.6	2.3	26.8	3.5	36.5	3.2
	1143	3.4	1.6	6.9	1.7	11.1	2.8	27.4	6.2	37.3	1.4
	363	3.2	1.5	7.1	2.0	12.0	3.4	31.0	3.4	37.0	2.2
	36.3	3.1	1.7	6.8	2.6	13.1	5.0	32.0	2.7	37.2	1.4
7/8	3630	3.1	1.2			8.2	2.4	20.9	4.5	32.5	2.2
	1143	2.8	1.2			7.7	2.4	20.4	5.7	29.2	5.2
	363	3.6	1.8			9.0	2.3	25.7	4.5	33.4	3.4
	36.3	2.5	1.3			8.8	2.4	27.8	1.9	32.8	1.5

Means and Standard Deviations for Ten Observations on Each Threshold Under Each PCF-I Condition for J. R., Observing the Surrounding Field

PCF	c/ft^2	flash-coarse flicker $\bar{X}$	S	coarse-fine flicker $\bar{X}$	S	fine flicker-ripple $\bar{X}$	S	ripple-flutter $\bar{X}$	S	flutter-fusion $\bar{X}$	S
1/8	3630	4.9	1.3	8.5	2.6	15.3	4.2	33.3	2.4	39.2	2.2
	1143	3.9	1.0	7.7	1.6	13.1	3.5	27.0	3.9	33.6	4.3
	363	4.0	.6	7.0	1.0	11.1	1.2	27.8	4.1	34.1	3.6
	36.3	3.0	.7	5.5	.9	8.8	1.5	20.2	3.4	28.1	3.9
1/4	3630	4.6	1.0	8.9	3.0	16.1	5.1	35.4	3.7	41.1	3.4
	1143	4.1	1.6	7.6	3.4	14.0	4.2	30.2	2.1	37.7	1.5
	363	3.4	1.0	6.7	1.5	12.4	3.6	26.0	4.6	34.1	3.5
	36.3	2.9	.6	5.6	.8	9.7	1.8	21.5	3.8	28.2	2.6
1/2	3630	5.0	1.0	9.5	3.0	18.4	3.8	36.7	2.2	43.0	2.2
	1143	4.0	1.1	7.9	2.2	13.3	3.6	29.9	3.3	36.4	1.7
	363	4.8	1.4	8.1	1.2	12.2	3.1	24.9	4.5	31.2	2.6
	36.3	2.8	.6	5.5	.8	9.5	1.4	18.9	3.0	26.0	2.8
3/4	3630	4.0	1.6	8.0	1.6	15.9	5.3	35.7	1.6	40.8	1.0
	1143	3.4	1.3	6.2	1.7	12.6	2.9	30.0	1.7	35.2	1.9
	363	3.8	1.3	7.2	1.0	11.4	2.1	27.0	2.4	32.9	1.1
	36.3	2.1	.8	4.1	1.0	7.5	1.2	15.5	2.8	21.9	4.0
7/8	3630	3.1	1.3	6.5	1.6	13.0	4.7	33.0	1.8	37.8	2.0
	1143	3.2	1.6	6.7	2.4	10.5	2.9	27.5	1.1	31.0	.8
	363	2.6	1.0	5.6	1.8	10.6	4.0	24.4	2.8	29.4	2.7
	36.3	2.4	.9			6.7	1.2	13.3	2.9	21.1	4.2

Means and Standard Deviations for Four Observations on Each Threshold Under Each PCF-I Condition for R. B., Observing the Target

PCF	c/ft^2	flash-coarse flicker $\bar{X}$	S	coarse-fine flicker $\bar{X}$	S	fine flicker-ripple $\bar{X}$	S	ripple-flutter $\bar{X}$	S	flutter-fusion $\bar{X}$	S
1/8	3630	6.1	3.3	11.5	3.9	19.3	4.8	28.4	4.2	34.9	3.3
	1143	8.0	4.7	12.7	3.8	18.4	4.5	27.9	3.3	36.7	2.4
	363	9.2	3.5	14.8	6.6	21.0	7.0	28.2	4.6	36.9	1.9
	36.3	7.1	2.2	13.9	3.4	22.0	5.2	28.8	5.5	35.7	3.7
1/4	3630	8.7	3.8	14.0	5.5	21.6	6.6	29.6	5.2	37.6	3.0
	1143	8.5	5.3	13.5	6.3	20.8	6.9	25.2	6.3	35.3	.8
	363	6.2	3.6	11.7	3.5	20.6	2.7	32.6	4.0	38.5	3.2
	36.3	7.0	4.6	11.5	3.8	16.0	3.5	25.0	4.4	32.6	3.2
1/2	3630	5.4	2.2	10.2	1.8	18.2	3.0	26.8	1.5	33.6	.9
	1143	7.2	3.4	13.2	6.2	20.5	5.4	26.2	4.5	35.0	1.2
	363	5.9	1.3	14.4	1.0	23.8	1.0	30.1	1.6	36.6	3.0
	36.3	8.2	2.3	12.7	3.8	19.6	3.2	28.5	.9	35.0	1.1
3/4	3630	7.0	3.4			12.0	4.9	18.8	5.0	26.6	5.0
	1143	9.2	2.5	13.7	3.8	18.7	4.8	23.6	5.3	27.1	4.9
	363	6.4	.5	11.6	3.0	22.6	2.2	29.6	1.7	34.1	1.1
	36.3	7.6	3.6	12.9	4.7	20.9	2.6	28.5	1.3	34.8	1.8
7/8	3630	4.7	1.8			10.8	2.0	17.8	4.4	24.8	5.9
	1143	7.4	2.6			11.5	2.6	18.0	3.8	27.2	5.4
	363	6.5	.8	11.6	2.0	19.2	2.5	24.4	3.4	31.2	.8
	36.3	5.5	.6	11.3	3.8	17.0	3.5	25.8	1.8	30.0	1.5

Means and Standard Deviations for Four Observations on Each Threshold Under Each PCF-I Condition for R. B., Observing the Surrounding Field

		flash-coarse flicker		coarse-fine flicker		fine flicker-ripple		ripple-flutter		flutter-fusion	
PCF	c/ft^2	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
1/8	3630	5.3	2.2	11.8	5.8	18.4	5.9	27.0	3.9	34.6	.6
	1143	6.6	2.4	11.8	4.0	18.4	3.7	26.5	3.6	35.6	1.4
	363	8.7	2.9	12.8	5.6	18.6	4.6	26.4	1.7	34.8	1.1
	36.3	4.3	1.4	8.2	2.6	12.1	4.1	18.6	5.6	29.4	.7
1/4	3630	7.6	5.9	15.5	5.8	24.6	3.9	34.4	1.4	39.7	2.9
	1143	8.4	3.5	15.4	4.2	20.8	4.4	28.0	3.5	35.5	1.0
	363	7.1	1.5	12.6	3.3	18.7	4.7	27.4	4.9	35.7	2.4
	36.3	5.2	.6	9.2	3.1	12.9	3.5	20.7	3.7	30.0	2.2
1/2	3630	8.2	3.1	14.1	5.0	20.7	6.6	30.4	4.3	38.1	2.0
	1143	7.3	4.8	12.1	6.3	18.2	6.1	26.3	5.0	34.7	.7
	363	6.6	1.6	13.8	4.2	20.9	4.8	29.9	4.8	35.3	4.1
	36.3	4.8	1.2	8.4	2.2	12.7	1.7	20.0	2.3	27.4	2.3
3/4	3630	5.8	.5	12.6	2.8	20.9	2.4	32.3	1.7	39.9	3.6
	1143	7.8	3.4	15.2	5.3	22.2	5.0	29.5	3.5	36.1	2.0
	363	7.8	3.1	14.6	6.9	21.0	6.0	26.9	2.8	35.3	2.0
	36.3	5.4	1.6	9.6	2.8	15.6	3.2	22.0	3.3	31.1	2.7
7/8	3630	8.6	3.1	14.0	4.3	21.6	4.6	28.6	4.4	37.4	2.2
	1143	7.3	1.3	13.4	2.9	18.7	1.8	25.6	.8	29.8	1.3
	363	7.4	3.2	13.8	5.2	19.1	4.0	26.2	1.4	33.1	4.6
	36.3	5.9	1.6			11.9	3.1	16.6	3.2	27.1	1.4

Means and Standard Deviations for Four Observations on Each Threshold Under Each PCF-I Condition for L. K., Observing the Target

PCF	c/ft²	flash-coarse flicker $\bar{X}$	flash-coarse flicker S	coarse-fine flicker $\bar{X}$	coarse-fine flicker S	fine flicker-ripple $\bar{X}$	fine flicker-ripple S	ripple-flutter $\bar{X}$	ripple-flutter S	flutter-fusion $\bar{X}$	flutter-fusion S
1/8	3630	6.9	2.9	14.4	4.9	20.3	5.2	27.3	6.1	37.3	.7
	1143	6.8	3.7	13.3	6.9	19.2	7.6	27.4	7.8	38.8	1.5
	363	4.9	1.4	12.2	4.1	19.2	5.0	28.7	4.0	40.6	2.3
	36.3	4.8	2.3	10.8	5.2	15.0	5.4	20.2	5.7	34.9	4.9
1/4	3630	7.4	2.9	15.7	5.5	22.4	5.8	29.8	2.8	41.4	2.1
	1143	5.5	2.2	13.3	3.9	19.4	5.4	27.7	4.2	35.2	2.7
	363	6.6	4.0	10.7	4.1	16.8	7.6	24.4	7.9	38.8	3.9
	36.3	5.3	3.2	12.0	4.6	20.2	6.3	24.8	6.7	35.3	4.8
1/2	3630	5.7	3.6	11.3	3.1	22.2	8.0	28.9	8.7	41.0	2.2
	1143	5.9	2.0	13.3	3.2	20.7	2.4	27.8	1.4	36.5	.6
	363	4.8	.8	11.3	3.3	17.0	5.4	25.2	3.6	36.4	.7
	36.3	5.7	3.5	11.7	9.1	20.2	7.1	28.3	5.1	37.8	3.0
3/4	3630	5.8	1.0			19.4	4.6	26.6	5.3	33.7	4.8
	1143	5.3	1.3	12.2	3.9	19.9	7.2	24.8	5.2	34.6	.9
	363	4.4	.6	9.6	2.7	15.4	5.1	21.2	6.0	31.9	2.0
	36.3	5.6	1.4	10.8	2.3	16.6	2.5	24.4	2.7	34.0	2.6
7/8	3630	3.5	1.0			12.2	3.7	19.3	5.1	29.3	4.7
	1143	4.8	1.5	9.0	2.4	11.4	2.3	19.2	4.1	27.9	3.9
	363	3.7	1.3	7.9*	.7*	11.8	1.9	18.8	2.4	29.2	3.2
	36.3	3.8	1.4	10.4	3.7	16.1	4.5	22.7	4.8	31.0	2.8

* Two observations.

Means and Standard Deviations for Four Observations on Each Threshold Under Each PCF-I Condition for L. K., Observing the Surrounding Field

PCF	c/ft²	flash-coarse flicker $\bar{X}$	S	coarse-fine flicker $\bar{X}$	S	fine flicker-ripple $\bar{X}$	S	ripple-flutter $\bar{X}$	S	flutter-fusion $\bar{X}$	S
1/8	3630	9.0	5.5	17.9	9.5	22.9	7.9	28.2	5.3	36.2	1.6
	1143	7.9	4.6	14.1	8.4	20.1	9.6	24.9	8.7	33.8	3.2
	363	8.3	3.4	15.3	6.0	20.6	6.8	25.4	6.9	31.5	7.7
	36.3	7.5	7.4	18.4*	131.4	17.2	9.5	21.0	9.4	24.5	10.8
1/4	3630	8.3	5.7	14.5	7.6	20.7	7.3	27.1	5.9	38.4	5.6
	1143	6.8	2.7	13.4	5.3	19.1	7.2	23.2	8.6	27.9	9.0
	363	5.9	4.1	11.1	5.7	16.9	4.7	23.0	6.2	31.4	7.9
	36.3	6.2	3.3	11.4	5.2	16.6	5.8	22.8	7.2	29.8	5.1
1/2	3630	8.3	3.4	17.8	6.9	23.4	6.3	30.3	5.0	37.4	4.4
	1143	7.2	3.1	15.4	7.2	20.5	6.2	25.4	4.3	32.5	2.4
	363	6.2	2.7	11.8	5.8	16.3	7.5	23.2	6.1	33.0	2.0
	36.3	6.1	3.6	14.4	9.0	19.0	8.6	25.7	7.2	34.6	7.3
3/4	3630	9.6	4.8	18.0	11.6	22.6	11.1	27.4	10.0	36.6	2.8
	1143	6.4	2.2	14.4	6.4	20.6	6.4	27.4	4.3	33.5	1.3
	363	5.3	1.3	9.9*	19.2*	14.0	3.5	20.2	3.9	28.3	4.6
	36.3	4.2	1.5	6.8*	.6*	11.8	1.5	15.3	2.5	21.0	4.4
7/8	3630	6.0	2.2	12.5	3.9	19.6	5.4	25.6	4.3	32.6	2.0
	1143	5.2	1.8	9.5	3.7	13.6	3.6	20.2	1.4	26.8	1.5
	363	5.0	1.7			12.5	7.2	16.9	4.8	26.4	3.2
	36.3	3.7	.5			7.1	1.7	11.0	2.1	17.7	3.2

* Two observations.