THE EFFECT OF LIGHT ADAPTATION ON BRIGHTNESS ENHANCEMENT MEASURES

Thesis for the Degree of M. A.

MICHIGAN STATE UNIVERSITY

Charles Mark Bourassa

1960

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BY

CHARLES MARK BOURASSA

A THESIS

Submitted to the College of Science and Arts
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF ARTS

Department of Psychology

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ABSTRACT

The purpose of this study was to determine whether brightness enhancement matches are influenced by differential light adaptation.

Differential light adaptation could occur when any two targets which differ in luminous-flux-per-unit-time are matched for brightness. The target producing the greater amount of flux may produce more light adaptation than the other target. This would cause the target which emits the lesser amount of luminous flux to become relatively more effective.

In brightness enhancement studies the relative effectiveness of the intermittent stimulus might be increased due to this differential light adaptation. Since low PCFs allow less luminous flux per unit time than high PCFs it was hypothesized that low PCFs would produce the least absolute amount of light adaptation and high PCFs the most, therefore the low PCFs would involve the most differential light adaptation when used as they are in targets compared with steady targets.

In order to test the hypothesis, conditions were set up using two targets of the same size. Target 1 was on for 13 seconds producing a steady stimulus which served as a standard. Target 2 had two phases. The

second phase was a one-second long steady stimulus which came on after target 1 had been on for 12 seconds. This served as the comparison stimulus which the observers adjusted to match the standard stimulus. The first phase of Target 2 was called the 'fill' period. Various fill stimuli could be inserted and their effect on the final matches observed. When the fill stimulus was steady and equal in intensity to the standard stimulus both areas of the retina on which the targets were imaged would be equally adapted and the observers ability to make photometric matches could be tested (Condition C). With the fill stimuli reduced to zero it could be determined whether the standard stimulus produced light adaptation (Condition A). When intermittent stimuli were used in the fill period their effect on the final matching could be evaluated in line with the hypothesis stated above (Condition B). PCFs of .3, .5, and .7 were used. All observers used the right eye. The experiment was done in two parts which were similar in all details except that in Part One the standard was set at 50 c/ft^2 and in Part Two at 25 c/ft^2. The degree of brightness enhancement produced by the three PCFs was also measured.

The results from Condition C showed that of the three Observers (C, N, V) used, Observer V was not able to make photometric matches. However, this observer was fairly consistent in his judgements.

The data from Condition C show that the standard stimulus was capable of producing light adaptation in all observers.

The data from Condition B for Observers C and N indicated that PCFs of .5 and .3 have little or no influence on the final matches. In three of the four matches using a PCF of .7 a slight effect occured similar to what would be expected for differential light adaptation. No explanation could be offered for this.

It was felt that since Observer V had a great deal of experience with brightness enhancement observations his data with respect to brightness enhancement could be utilized. Observer N did not get brightness enhancement in Part One with a PCF of .7. In all other cases the degree of brightness enhancement was as expected, i.e., the PCF of .3 producing the most, the PCF of .7 the least.

APPROVED: S. Howard Bartley.

DATE: March 1 1960.

ACKNOWLEDGMENT

I deeply appreciate the continuous help, critizism, and patience of Dr. S. Howard Bartley during the formulation and execution of this study.

I wish also to thank Dr. Charles Hanley and Dr. Paul Bakan for their many useful suggestions regarding the preparation of the manuscript.

I also wish to gratefully acknowledge the many hours of her time that my wife donated to this study both as subject and typist.

C.M.B.

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INTRODUCTION

Although the facts concerning light adaptation have long been known it is only recently that attention has been called to certain possible interrelationships with other phenomena (10, 12, 32, 33). In general, if any two targets which differ in intensity (luminous flux per unit time) or duration are to be compared (matched), it is possible that light adaptation may play a part in determining the final match.

In studying brightness enhancement one of the two targets compared for brightness is a continuous (steady) field, and the other, is an intermittent one. One of the salient variables in intermittent stimulation is the pulse-to-cycle fraction (PCF), which represents the portion of the intermittent cycle occupied by the photic pulse. For example, a PCF of .7 indicates that the photic pulse occupies seven-tenths of the cycle. When PCF is made low we are provided with an example of this great discrepancy between the flux of two targets. Thus each target in the pair used may produce a different degree of light adaptation and thereby affect the matching. In other words, when both stimuli, the steady and the intermittent are presented simultaneously and viewed for some seconds, as is the case in brightness enhancement experiments, the steady reference target may possibly produce much more light adaptation on the part of the retina on which it falls, than the intermittent one will produce on the retinal area on which it is imaged. It may be however, that enough light adaptation occurs in the initial few seconds when the two targets are presented so that both areas of the retina become equally, or so nearly equally, adapted that the matching would not be affected. If this latter conjecture is true, then the two targets may turn out to be equally effective regardless of PCF and length of viewing time.

In general then, the problem dealt with in this study is whether, under experimental conditions very similar to those used in brightness enhancement studies, differential light adaptation occurs to an extent great enough to affect brightness matchs.

Before discussing the problem in more detail it may be wise to review the facts and theories concerning light adaptation and brightness enhancement. The review will be brief because this study is not primarily designed to shed any light on the mechanisms of light adaptation or brightness enhancement, but rather to determine whether or not a certain effect occurs.

Brightness enhancement is produced when an intermittent target provides an experience of greater brightness than a continuous, steady target of the same physical intensity.

Adaptation is generally considered to be a diminuation of a sensory end result during the duration of a uniform impingement.

Although sense-cell photochemistry is believed by many to be the sole basis of adaptation (17, 20) many other types of explanations have been offered. Crozier (15), for instance, has put forward the view that adaptation is related to the properties of populations of neural units. Also some special phenomena labelled as cases of adaptation have been attributed to other kinds of mechanisms (1, 2, 14, 18, 28). Many studies (1, 2, 14, 27, 28, 30, 31) indicate that traditional photochemical explanations are inadequate. Russian work, as reviewed by London (23), has indicated that the autonomic and central nervous systems may affect adaptation, more or less, directly.

Not much is known about light adaptation. Most texts on physiology or vision give it only a brief mention. The most common observation is that it proceeds rapidly; the greatest effect being in the first few seconds and completed in 5 to 10 minutes (5, 12, 13, 17, 19, 21, 24, 29). This fact makes light adaptation difficult to observe directly and hence most work has been done with dark adaptation which proceeds slowly enough to allow the experimenter to make a number of observations during its course. For this reason, many studies reported as dealing with light adaptation are actually concerned with the effect of various periods, intensities, and types of light adaptating stimuli on the course of dark adaptation and therefore bare only indirectly on the process of light adaptation (21, 25, 26). We do not need to deal with all problems of adaptation here. The present study, is designed so as to indicate whether measurable amounts of light adaptation occur in the reference target under the conditions by which light adaptation is studied.

As already mentioned, brightness enhancement is generally studied by using two targets side by side. The observer is asked to match the brightness of the steadily illuminated target to the brightness of the intermittent target. When, under certain conditions, the intermittent target is seen as brighter than the steady target, we say brightness enhancement has occured. There are several variables which affect the degree of brightness enhancement. One of these factors is PCF. In general as PCF decreases brightness enhancement increases (4, 9). This is true for PCF's ranging from .3 to .9. Another factor is target intensity; as intensity increases so does the degree of brightness enhancement. The lower limit depends on the type of targets used; but, at least in some cases, an intensity of .3 c/ft^2 will produce mild enhancement (7). Targets imaged separately, i.e., one on each eye, are more effective than targets which jointly cast illumination into the eye or eyes of the observer (8). In general, stimulus conditions which cut down entoptic stray light are more effective than conditions which allow a greater amount of it to be present. The last major variable is the rate at which the photic pulse is delivered to the eyes. It has been demonstrated that the optimum rate is about ten pulses per second (4).

Currently three explanations of brightness enhancement have been offered. One is photo-chemical and confined to the sense cells (22). However there is nowhere in the literature a complete account of this position. Another type of explanation has been offered by Grusser and Creutzfeldt (16). In a neurophysiological investigation they concluded that brightness enhancement was produced when the stimulus conditions created the highest frequency of receptor discharge. The third theory, the alternation of response theory, has been put forward by Bartley (3, 6, 11). This theory maintains that the optic pathway can be viewed as containing a certain fixed number of parallel circuits. These parallel circuits can be stimulated simultaneously (using a very intense stimulus), or when weaker stimulus conditions are used, fewer circuits will be activated concurrently. The amplitude of the cortical response, which this theory takes as indicitive of the sensory end result, is a function of the number of circuits which are concurrently and successively activated, and the state of responsiveness of the optic pathway. Thus, according to this theory, brightness enhancement occurs when the stimulus conditions can repeatedly evoke a maximal retinal response which is also timed so as to correspond with the rythmic activity (alpha rythmn) of the cortex.

The theoretical views have been mentioned only briefly because this experiment is not directly concerned with theory but rather with the possible existence of certain biases in the observation and measurement of brightness enhancement.

To return to the problem in this study, it can be seen that a target with a low PCF might be expected to produce less light adaptation than a steady target. Thus brightness enhancement might be interpreted as existing when it does not actually occur, or to be greater than it is when it does occur. The problem then, is to determine whether conditions which involve comparing intermittent targets with steady targets of the same intensity, will produce enough differential light adaptation to affect the final match.

There has been no previous work which deals directly with the influence of intermittent radiation on light adaptation. Earlier studies (12, 31, 33) dealt with the effect of steady targets which differed in intensity or duration. While the apparatus and procedures differed somewhat from one experiment to another the basic technique is the same in all experiments. One eye, for example the right, is exposed to illumination until adaptation has reached the desired stage. The left eye is, at the same time, brought into a fixed state of adaptation, constant through one series of readings, by exposure to darkness or to any illumination. The left eye is then exposed for one second to a variable illumination, which is adjusted in successive exposures until this illumination appears equal in brightness to the right eye field. A detailed consideration of the results of these experiments need not concern us. We should note that in all cases differential adaptation was found to affect the observer's perception of brightness. It was also found that the targets could be viewed for about one second in every ten seconds without affecting the state of adaptation to any noticeable extent (33).

It has been pointed out that our general area of interest is the relation between brightness enhancement and light adaptation. It was also indicated that the specific form in which this problem concerned us had to do with the possible affect of differential light adaptation in the measurement of brightness enhancement.

The hypotheses tested in this study are the following:

(1) Stimulation of an area of the retina by intermittent impingements will produce less light adaptation than stimulation by a continuous impingement of the same intensity.

(2) The differences in the amounts of light adaptation will be in keeping with the PCF's involved; low PCFs involving the least, and high PCFs the most light adaptation.

METHOD

In order to facilitate the description of the apparatus and procedure, the conditions used in this study will be described first.

CONDITIONS

Using two targets of the same size, the following conditions were employed. (A) One target was exposed for 13 seconds; the other for one second and terminated concurrently with the longer target (Condition A, Figure 1). (B) Again one target was exposed for 13 seconds. We shall call this the standard target since its intensity was uniform in time, and because the brightness of the other target was compared to it. The second target was intermittent for 12 seconds with three different PCFs. This 12 second period is called the fill period and the stimulus presented in this period is called the fill stimulus. The last second of illumination was steady (Condition B, Figure 1). (C) As a control, the same two targets were used but the intermittency of the second target was eliminated; i.e., both targets were steady (Condition C, Figure 1).

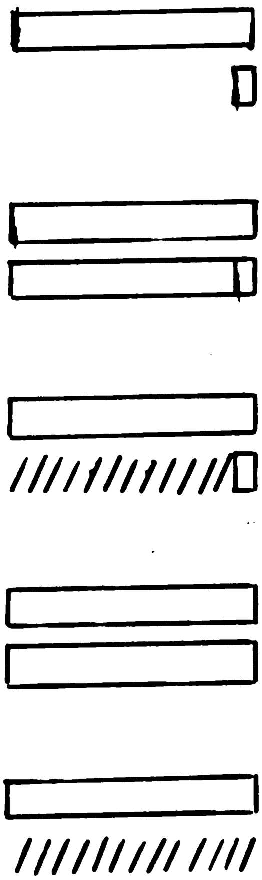
In all the cases just discussed the brightness comparisons were made during the last second of exposure. The stimulus occupying the last second of the steady target will be called the comparison stimulus.

The comparison in Conditions D and E had to do with the whole exposure time. It did not involve the one-second steady comparison exposure during the last second of the standard stimulus.

The first three conditions (A, B, and C, Figure 1) were used to assess the effects of differential light adaptation.

Conditions D and E were used to obtain measures of brightness enhancement.

Condition A was used to determine whether or not the standard stimulus was capable of producing noticable differential adaptation. In this condition, since the fill period was empty, that portion of the retina illuminated by the standard stimulus should have become relatively more light adapted than the portion of the retina not stimulated during the fill period. Hence, when the comparison stimulus falls on the relatively unadapted portion of the retina, its relative effectiveness should be increased causing the observer to make a match at a much lower level of intensity than if both areas were adapted to the same degree. Of course, if the stimulus conditions are not producing differential amounts of light adaptation, the match should be made at about the same level of intensity as in Condition C, that is, at photometric equality.



A
S 13 second continuous illumination.
C 12 second no illumination; 1 second comparison.

C
S 13 second continuous illumination.
C 12 second steady 'fill; 1 second comparison.

B
S 13 second continuous illumination.
C 12 second intermittent 'fill'; 1 second comparison.

D
S 13 second continuous illumination.
C 13 second continuous comparison (no separation of time into 'fill' or comparison periods).

E
S 13 second continuous illumination.
C 13 second intermittent standard (no separation of time into 'fill' or comparison periods).

Figure 1. See text for purposes of using each set of conditions.

Condition C was a simple matching task. The match that the observer made in this condition was one in which the portions of the retina that were illuminated by the two targets were adapted to the same degree. Hence the observer should set the variable stimulus nearly photometrically equal in brightness to the standard stimulus. It was a control to insure that the observers were utilizing criteria in their matching that led them to make reasonably accurate photometric matchings. The values obtained in this condition serve as a standard against which the effects of differential adaptation can be compared. This is important because the match is not only a difficult one to make but, due to the nature of the apparatus, there were some unavoidable color differences in the targets, and also, a difference in the texture of the targets was noticeable.

Condition B was the test condition. Various PCFs are presented during the fill period. Since different amounts of luminous flux per unit time are associated with different PCFs, it was hypothesized that the various kinds of fill stimuli would have differential effects on the amount of adaptation on that portion of the retina on which they are imaged and would produce a different amount of light adaptation than the standard stimulus. The differing amounts of adaptation were indicated by the observer's matching of the standard and comparison stimuli.

In Conditions D and E there was no one-second comparison stimulus. The 'fill stimuli' occupy a 13-second period. In obtaining measures of brightness enhancement (Condition E) the flickering stimulus became the standard and the 'steady' stimulus was adjusted by the observer to match the brightness of the flickering target. In Condition D the intermettency of the flickering target was eliminated. The value of the match in this condition was used to estimate the degree of brightness enhancement produced by Condition E.

In summary, the purpose of Condition A was to determine whether the target intensities will cause differential adaptation; Condition C was a control condition in which each target should have caused equal light adaptation, and Condition B contained the test conditions which allowed us to determine whether the various PCFs were producing differential adaptation. Condition D was used to establish a control value for the brightness enhancement matches which were obtained in Condition E.

APPARATUS

Photic Sources: The apparatus is presented schematically in Figure 2. There were three sources of photic radiation (Lamps) labelled 1, 2, 3. The radiation from Lamp 1 first passed through M_1 (a reduction screen) which also contained milk glass in order to evenly distribute the radiation. This was also true of Lamps 2 and 3, except that in the case of Lamp 3 there was an episcotister (E) between the lamp and the reduction screen. After passing through the first reduction screen the radiation from Lamp 1 continued through the second and third reduction screens (M_2 and M_3) where it reached the observer's eye.

Lamp 2 and 3 were never on at the same time. Lamp 2 produced the comparison stimulus and its radiation passed through M_1, the half silvered mirror (S), and then through M_2 and M_3 to fall on the observer's retina. Lamp 3 produced the fill stimulus. Its radiation passed through an Episcotister, through M_1 and was then reflected by the half silvered mirror through M_2 and M_3 where it was imaged on the same area of the observer's retina as the radiation from Lamp 2. The reduction screen concealed the mirror, the frame which held it, the milk glass, and the lamp housing. The half silvered mirror

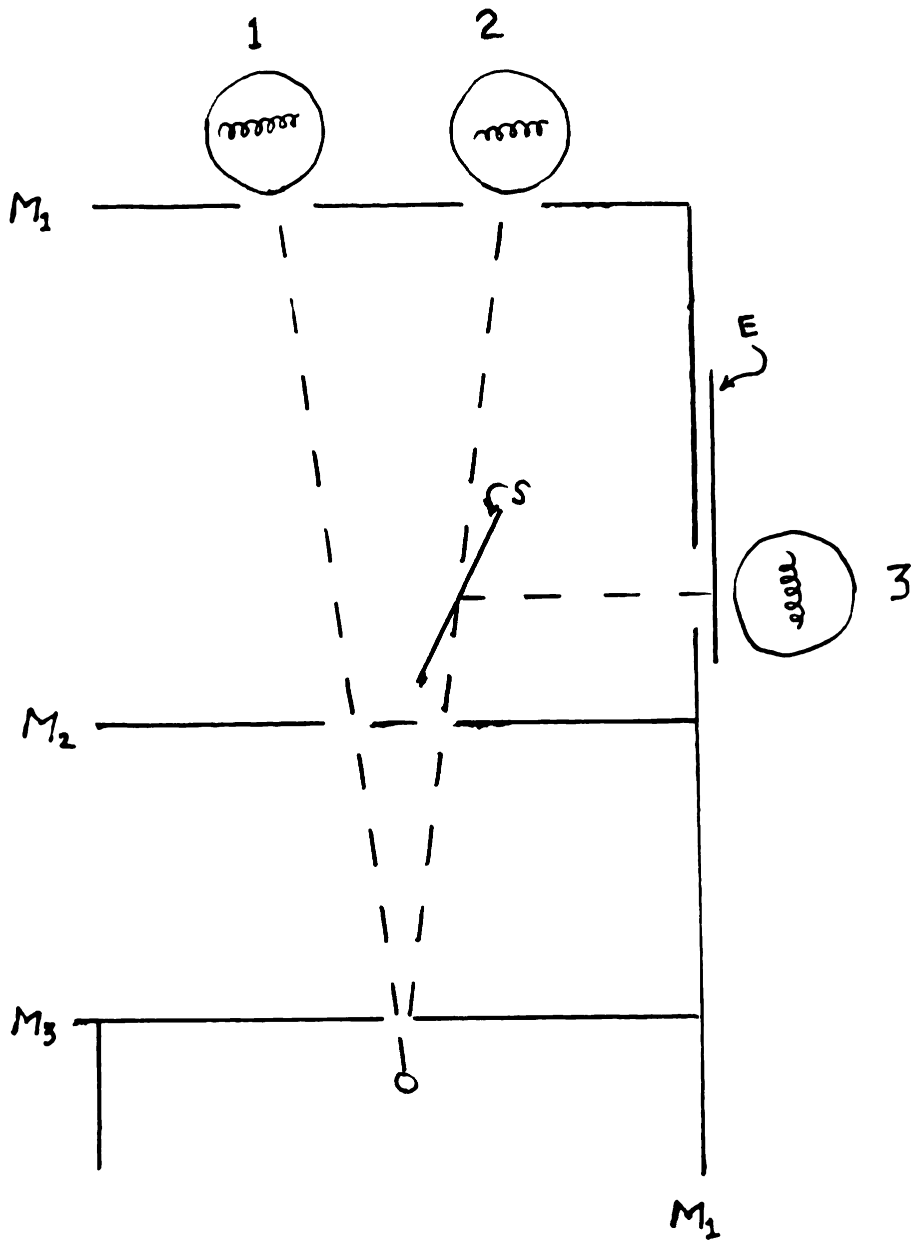


Figure 2. Schematic diagram of the apparatus. 1, 2, and 3 are the sources of photic radiation (Lamps). M_1, M_2, and M_3 are reduction screens. E is an Episcotister. S is a half silvered mirror. The dotted lines indicate the direction of the radiation emitted by the lamps. O is the position occupied by the observer.

allowed the source of radiation to be shifted instantly from Lamp 2 to Lamp 3 without changing its location on the observer's retina.

In summary, Lamp 1 provided the photic radiation which acted as the steady or standard stimulus. Lamp 2 emitted light which acted as the one-second comparison stimulus. Lamp 3 provided the fill stimuli, which was either intermittent, steady, or reduced to zero.

Temporal Relationship of the Photic Sources: The length of time the Lamps emitted radiation was controlled by the length and speed of cams on a revolving drum which activated microswitches. The speed of the drum was controlled by a Variac.

The time relationship of the Lamps (shown schematically in Figure 1) was the same throughout the experiment, except for Conditions D and E in which Lamp 3 was not used; in this case it was turned off. Lamp 1 was on for 13 seconds which it was felt was long enough to produce an effective amount of light adaptation and to represent the length of time used in brightness enhancement experiments to make a reading. Lamp 3 came on simultaneously with Lamp 1, but was on for only 12 seconds. Lamp 2 came on as Lamp 3 went off and lasted for one second. Thus 12 seconds after Lamp 1 came on, Lamp 2 came on. The period from the end of the comparison to the onset of the standard stimulus was 20 seconds. In other words, there was a 20-second period of darkness between the presentation of photic stimulation.

Episcotister: It has been pointed out that between Lamp 3 and M_1 there was an Episcotister. When the Episcotister was stationary, with its opening in front of Lamp 3, Lamp 3 would act as a source of steady photic radiation. However, when the Episcotister was rotated the photic radiation from Lamp 3 was interrupted and produced intermittent radiation (flicker).

Three Episcotisters, with PCFs of .7, .5, and .3 were used to vary the total amount of luminous flux per unit time, i.e., the PCF of .7 giving the greatest amount and the PCF of .3 the smallest. The Episcotister was driven by a variable speed motor. The speed of the motor, (measured by a tachometer unit), and hence the pulse rate, was controlled by a Variac. For the purposes of this experiment the pulse rate was kept constant throughout at ten per second.

Targets: It will be noted that the apertures in M_2 determined the size of the perceived targets. These apertures were squares 2.3 cm. on a side, separated by a distance of 3.3 cm. The apertures were 30 cms. from the observer's eye. Each target subtended a visual angle of about 4.39 degrees. The visual angle between targets was about 6.3 degrees. The overall visual angle, from the most lateral edge of one target to the most lateral edge of the other targets, was about 15 degrees.

The intensity of the targets was measured by a Macbeth Illuminometer placed in the position which was later to be occupied by the observer's eye. Curves were drawn which related the intensity of each of the Lamps in candles-per-square-foot to Variac settings.

The experiment was divided into two parts. In Part One, Lamps 1 and 3 were set to produce target intensities of 50 c/ft^2 and in Part Two they were set to produce intensities of 25 c/ft^2. It was hypothesized that the differences in intensity would produce differences in the amount of adaptation.

This section may be summarized by a discussion which relates the apparatus to the conditions it produced. The apparatus was designed so as to present the observer with two Targets, 1 and 2. For Conditions A, B, and C, Target 1 gave 13 seconds of continuous radiation at a constant intensity level which served as a standard stimulus. Target 2 had two phases. The second phase, produced by Lamp 2, was one-second long and ended concurrently with the standard stimulus. This was the comparison stimulus. The first phase of Target 2 was the fill period, which was 12 seconds long and contained photic radiation which was either steady, intermittent or reduced to zero.

When the photic radiation was not reduced to zero, its intensity was set photometrically equal to the intensity of Target 1. The observer, of course, perceived the illumination from both Lamp 2 and Lamp 3 as at Target 2. Thus both the fill stimulus which it was hypothesized would produce a change in adaptation, in that portion of the retina on which it fell, and the variable stimulus, which was used to measure the effect of the hypothesized adaptation, would fall upon the same portion of the observer's retina.

In Conditions D and E Lamp 2 was turned off, and the radiation for Target 2 was provided solely by Lamp 3. This radiation was either steady or intermittent. In any case, Target 2 served as the standard and Target 1 as the comparison stimulus.

OBSERVERS

Three observers were used; C, N, and V. C is the author, N his wife, and V a graduate student who obtained his Masters Degree in psychology. N and V were both naive as to the purpose of the experiment.

PROCEDURE

The observers were brought into the experimental room and seated at O (in Figure 2) in a chair with an attached chin rest. The chin rest was adjusted so as to bring the observer's eye in line with the holes in the reduction screens. When the Lamps were on, the observer saw two targets which were localized somewhere in the region of M_2.

The experimenter showed the observers where to fixate and where the Variac was located which they were to adjust. The room lights were turned out, the only illumination coming from a small red bulb used by the experimenter to record data. The observer was dark adapted for 10 minutes while the experimenter turned on the apparatus and adjusted it.

The order of presentation of conditions was the same for all observers in both parts of the experiment, Condition D was presented first, followed by Conditions C, A, B, and E. Part One was completed before beginning Part Two.

In Conditions A, B, and C, the observer was instructed to fixate between the two targets and to adjust the brightness of the last second of the right target to match the brightness of the left target during the same period. The observer was also instructed to make the match by finding a brightness of the comparison stimulus which was just dimmer and another just brighter than the standard stimulus and to halve this zone to arrive at the final match. Due to the short period of time the comparison stimulus could be observed, the observer had to first observe the relative brightnesses of the standard and comparison stimuli and then, after the comparison stimulus was off, make an appropriate adjustment of the Variac. This was repeated until the observer was satisfied with the match. Thus one matching took anywhere from three to ten minutes. When the observer reported that the variable and standard stimuli were equal in brightness, the experimenter recorded the Variac reading and spun the Variac to a new setting. The clicking of the microswitches signaled the occurence of the various stimuli to the observer.

When Conditions D and E were presented the observers were told that the right target now served as the standard and that they were to adjust the brightness of the left target to match that of the right target. They were again instructed to fixate between the targets and to make their match by halving the zone between the just noticably brighter and just noticably dimmer points. The observers were informed that the match concerned the entire period of stimulus presentation. The observer was allowed to use as many 13-second periods of stimulation as were necessary to make the final match. When the observer was satisfied with the match the experimenter recorded the Variac setting. In all conditions the observer would make five matches; then the experimenter and observer would exchange places and five more matches were made, until 20 matches for each observer were made under that condition. Ten matches per observer were made in the morning and ten in the afternoon. No observer was allowed to examine the data collected from him until he had completed the condition under which the data had been collected. The observer could not see the variac which he was adjusting. All observers used the right eye.

RESULTS AND DISCUSSION

The results are summarized in Table 1. Each number is the mean of 20 readings. The values are given in candles- per-square-foot, and represent the intensity level at which each of the observers judged the comparison and standard stimuli to be equal in brightness. A complete tabulation of the data in terms of Variac settings is reported in appendix A.

CONDITIONS C AND D

Conditions C and D result in equal adaptation to both portions of the retina on which the targets are imaged. They are more or less traditional matching tasks which indicate whether or not the observers are able to make reasonably accurate photometric matches.

Table 1 shows that Observer V is extremely inaccurate. In three out of four cases he deviates by roughly 50 percent from photometric equality. In the fourth case, i.e., Condition C Part One, he is 15 c/ft^2 below the standard.

Observer V, under these circumstances, was not able to make brightness matches based on photometric qualities. The matches made under Conditions C and D serve as the standard or control against which the other conditions have to be compared. Because Observer

PART	ONE			TWO		
OBSERVER	C	N	V	C	N	V
CONDITION						
D	46.0	51.0	25.5	22.5	23.0	15.0
C	54.0	49.0	35.0	27.5	26.0	13.0
A	32.0	42.0	16.5	17.0	17.5	10.9
B PCF .7	44.0	51.0	32.0	23.0	19.0	11.6
PCF .5	54.0	50.0	27.0	25.0	23.0	13.0
PCF .3	49.0	47.0	30.5	26.0	25.5	14.0

Table 1. The mean luminosity values in c/ft^2 at which each observer judged the comparison stimulus to be equal in brightness to the standard stimulus. In Part One the standard was set at 50 c/ft^2 and in Part Two at 25 c/ft^2. Each mean is based on 20 readings.

V could not make the matches against which his other results can be compared it is extremely difficult to analyze his data. That is, since we do not know what criteria Observer V used in making his matches we do not know how this criteria might be effected either by light adaptation or by intermittent radiation. Therefore Observer V's data must be treated with extreme caution when it is used to infer anything about brightness matching.

Observers C and N in all cases are reasonably close to photometric equality. We can thus take these observer's values in Condition D as adequate controls for the brightness enhancement matches in Condition E and the values in condition C as standards against which the effects of differential light adaptation can be compared.

CONDITION A

Condition A indicates whether or not the intensity of the standard stimulus is great enough to produce light adaptation. The lower values which all the observers give under these conditions in both Parts One and Two show that the standard stimulus has decreased in effectiveness (has produced adaptation) during the time it is on. In other words, with no fill stimulation the intensity levels used for the standard stimuli are capable of producing differential amounts of light adaptation in the observers, thereby increasing the relative effectiveness of the variable stimulus.

CONDITION B

Condition B involves variations in the PCF used in the fill period. These are the test conditions. According to hypothesis, the intermittent stimulation during the fill period should cause some amount of light adaptation to occur on that portion of the retina which it strikes. Since the photic radiation is interrupted, less radiation-per-unit-time is actually falling on the retina from the fill stimulus than from the standard stimulus. More adaptation may occur to the standard stimulus than to the fill stimulus, thus increasing the relative effectiveness of the comparison stimulus. Thus it would be expected that the matchings in Condition B would be made at an intensity somewhere between the intensities of the matches made under Conditions A and C. Also it might be expected that the amount of light adaptation produced by the fill stimulation would be directly related to the amount of radiation-per-unit-time which fell on the retina. Hence the PCF of .7 should produce matches closest to the match made under Condition C, with the PCF of .3 producing matches more nearly similar to those made under Condition A.

In contrast to these expectations is the possibility that, due to the speed of light adaptation, the intermittent target is able to produce an amount of adaptation equivalent to the steady target.

Table 2 show the deviations of the matches made by Observers C and N in Condition B both from their own control values (Condition C) and from photometric equality. Since Observer V was not matching on the basis of photometric qualities his deviations from photometric equality would be meaningless and therefore are not given.

With a PCF of .3, matches of Observers N and C are somewhat lower than their respective control values but are very close to photometric equality. With a PCF of .5 the values of the observer's matches are close both to the values obtained in the control matches and to photometrically determined levels of equality. With a PCF of .7 Observer C gives his lowest values in both parts of the experiment. Observer N is close to both her own control value and photometric equality in Part One but shows large drops in the matches in Part Two.

It has been indicated that Observer V was not able to make matches on the basis of photometric intensity. It was also pointed out that whatever

	OBSERVER	C			N			V		
	PCF	.7	.5	.3	.7	.5	.3	.7	.5	.3
1 PHOTOMETRIC EQUALITY	PART ONE	-6.0	+4.0	-1.0	+1.0	0	-3.0			
	PART TWO	-2.0	0	+1.0	-6.0	-2.0	+0.5			
2 CONTROL VALUE	PART ONE	-10.0	0	-5.0	+2.0	+1.0	-2.0	-3.0	-8.0	-4.5
	PART TWO	-4.5	-2.5	-1.5	-7.0	-3.0	-0.5	-1.4	0	+1.0

Table 2. Segment 1 shows the deviations of each observer's matches in Condition B, where the three PCFs were used as fill stimuli, from photometric equality. Segment 2 shows the deviations as departures from each observer's control value.

criterion Observer V used appears to have been affected by differential adaptation. Examination of Observer V's data in appendix A will show that he is fairly consistent in his judgements. Assuming that Observer V maintained the same criterion throughout the study, we may compare his results with the results obtained from Observers N and C.

In Part One Observer V's match involving a PCF of .5 is extremely low, unlike either of the other two observers. In Part Two, the match involving a PCF of .7, is his lowest value. In this he agrees with Observers N and C.

It must be emphasized that the importance of Observer V's data in regard to brightness matching is extremely dubious. Therefore the rest of the discussion will be largely concerned with the data obtained from Observers N and C.

Tables 3 and 4 are frequency distributions of each observer's matches in the control and test conditions. This graphical presentation makes the relations pointed out above somewhat clearer. It can be observed that in three out of four cases the median of the matches made using the PCF of .7 are considerably lower than the control median. Observer N's median score with a PCF of .3 is slightly lower

	OBSERVER C				OBSERVER N			
PCF	CONT.	.3	.5	.7	CONT.	.3	.5	.7
73-75								
70-72			/					
67-69								
64-66	//		///	/	/			
61-63	//	//	/	//			/	
58-60	////	/	/	/	/		/	///
55-57	/	//	///			/	//	///
52-54	卌 ←	//	/// ←	/	卌 /	/	卌	卌 / ←
49-51	////	//// ←	卌	/	卌 ←	////	/// ←	///
46-48	//	///	/	/	////	卌 / ←	////	////
43-45		////		/// ←		卌 ///	////	/
40-42		//		///	//			
37-39			//	//				
34-36				///				
31-33				/				
28-30				/	/			
25-27								

Table 3. A frequency distribution showing the individual readings in c/ft^2 for Observers N and C in Condition C (equal adaptation) and the three PCFs of Condition B. The readings are the point at which the observer judged the comparison and standard stimuli to be equal in brightness. The standard was set at 50 c/ft^2. The arrows indicate the median point of each distribution.

	OBSERVER C				OBSERVER N			
PCF	CONT.	.3	.5	.7	CONT.	.3	.5	.7
47-49								
45-47								
42-44								
39-41								
36-38	///			/				
33-35	//	/		//	////	/		
30-32	/	//	/		/	/		
27-29	卌 ←	卌/	卌//// ←	//	卌/ ←	卌	卌	//
24-26	卌/	卌//// ←	卌	//	////	卌/// ←	卌// ←	
21-23	//		/	//// ←	////	卌	///	卌
18-20	/	//	////	卌///	/		////	卌/// ←
15-17				/			/	////
12-14								/
9-11								

Table 4. A frequency distribution showing the individual readings in c/ft^2 for Observers N and C in Condition C (equal adaptation) and the three PCFs of Condition B. The readings are the point at which the observer judged the comparison and standard stimuli to be equal in brightness. The standard was set at 25 c/ft^2. The arrows indicate the median point of each distribution.

than her median score in the control condition. In both parts of the experiment the distribution of the matches made involving a PCF of .5 are similar to the distribution of the control matches although they are skewed toward the lower end of the scale in Part Two.

The data show that the values of the matches obtained with PCFs of .5 and .3 are similar. It is also found that if these PCFs produce less adaptation than a steady source of the same intensity the effect is small. With these two PCFs the greatest deviations from photometric equality are, for the standards of 25 and 50 c/ft^2 respectively, two and four c/ft^2. The greatest deviations from the observers own control value are three and five c/ft^2.

There is an indication that the PCF of .7 produces an effect which is similar to that which one would expect if differential adaptation were actually occuring. The data were rather ambiguous on this point since in Part One Observer C showed an effect similar to differential light adaptation whereas in Part Two both Observers N and C showed this effect. It may be added that Observer V's data also indicates the existence of this effect in Part Two of the experiment. In other words, all observers show this effect in Part Two, while only Observer C shows it in Part One.

This PCF allows more radiation to fall on the observers retina per unit time than either of the other PCFs and should cause less differential adaptation than the PCFs of .3 and .5. The fact that some effect of differential adaptation should occur with a PCF of .7, but not with PCFs of .5 and .3, is entirely contrary to expectation and hence difficult to evaluate. It may be that the drop in matching values only indicated a shift in the observers' criterion rather than an effect resulting from differential adaptation. The fact that three out of the four observations involving a PCF of .7 were low values casts doubt on such an interpretation. Further experimentation is needed to confirm the existence of the effect, but if the effect actually exists, it seems likely that it is not due directly to differential light adaptation since this would involve more light producing an effect like less light. It is possible that the explanation will be found in the neural properties of the visual apparatus.

BRIGHTNESS ENHANCEMENT

Observer V has had a great deal of experience with brightness enhancement so his data with respect to brightness enhancement can probably be utilized. The data are summarized in Table 5. The degree of brightness enhancement is as expected, i.e., the PCF

PART	ONE			TWO		
OBSERVER	C	N	V	C	N	V
PCF .7	90.0	44.0	100.5	39.5	39.0	46.0
PCF .5	105.9	99.0	128.0	66.0	57.0	77.0
PCF .3	204.0	101.9	140.0	102.9	62.0	89.9

Table 5. The mean values in c/ft^2 of the intensity at which a steady target was judged to be equal in brightness to an intermittent target which served as a standard (Condition E). Intermittency was produced by Episcotister and involved PCFs of .3, .5, and .7. Each value is the mean of 20 readings.

PART	ONE		TWO	
OBSERVER	C	N	C	N
PCF .7	1.96	0.86	1.77	1.54
PCF .5	2.30	1.94	2.40	2.48
PCF .3	4.43	2.00	1.77	2.70

Table 6. The values indicate the relative effectiveness of the intermittent source when compared to a steady source of illumination. The figures were obtained by dividing the brightness enhancement values, given in Table 4, by the control value established for each subject in Condition D.

of .3 producing the most, .7 the least and .5 in between, with the single exception that Observer N gets no brightness enhancement in Part One with a PCF of .7.

Table 6 indicates the relative degree of effectiveness of the intermittent stimulus. The values in Table 6 were obtained by dividing the values obtained by each observer when matching the intermittent and steady targets in Condition E, by that observer's control value obtained in Condition D. It is, of course, impossible to do this with Observer V's data since he was unable to establish an accurate control value. It can be seen that although Observer N in Part One with a PCF of .7 did not get brightness enhancement her match is above the Talbot level. Observer N evidently used some criteria of matching other than brightness.

The relative increase in effectiveness of the comparison stimulus during the adaptation condition (Condition B) can be estimated if the value of the control match (Condition C) is divided by the value of the match in Condition B. For Observer C in Parts One and Two respectively, the increase in effectiveness of the comparison stimulus is 1.69 and 1.62 times. For Observer N the increase in effectiveness is 1.17 and 1.48 times. In other words, over the time period used in this study, a stimulus falling on an unadapted portion of the observers retina was, roughly, 1.5 times as effective as the same stimulus falling on an adapted portion of the retina.

Table 6 shows that in measuring brightness enhancement the relative effectiveness of the intermittent stimulus was, with PCFs of .3 and .5, at least twice as great as the effectiveness of the standard stimulus. Clearly, even if differential light adaptation were producing a maximum effect, it would still not account for the increase in effectiveness found in brightness enhancement. It is interesting that the PCF of .7, which produces the least brightness enhancement is the only PCF which shows an effect similar to differential light adaptation.

It is worth noting that there may be a strong set effect involved in making these types of observations. It was hoped that since the order of conditions was not randomized, any effect due to set could be reduced by making half of the observations in the morning and half in the evening and also by the observer and experimenter changing roles after each had made five observations. The writer became aware in his role as observer, and from the behavior and comments made by the other observers, of two things that made him feel there was a strong set effect.

One thing was that each observer made progressively more rapid matches under each condition. When the conditions were changed, the observer became very slow in making the matches. The second thing is related to this. The observer reported a feeling of 'confusion' when conditions were changed. It must be remembered that the task of the observer is the same under every condition except D and E. Changing the conditions does not require the observer to alter his stance toward the task. Therefore, if learning is involved in performing the task, it would not cause the initial confusion and the gradual acceleration of performance in each condition. It seems likely that the observers establish some criteria of matching which they use while the stimulus conditions remain constant. When the conditions are changed the observers re-evaluate their criteria. As mentioned earlier, the task is difficult due to slight differences between the targets and presumably when the observers re-evaluate their criteria some slight change takes place. This would, of course, result in an exageration of any differences between the various conditions.

The conclusions reached through this analysis are extremely tentative. A great deal of research will be required before these conclusions are confirmed or altered.

As a preliminary test of the affect of light adaptation on brightness enhancement this study seems to have served its purpose. It is unlikely that increasing levels of intensity would reveal any further effects since under conditions of monocular viewing an increase in the amount of entoptic stray radiation would tend to produce uniform illumination of the retina.

With PCFs of .3 and .5 it would seem doubtful that the light adaptation involved in any of the targets is such that the standard steady target used in a brightness enhancement experiment becomes differentially effective as a function of observation time and thus distorts readings and conclusions in a brightness enhancement experiment. It would seem that it is safe to conclude that most of the light adaptation that does occur in any of the targets used in this experiment occurs so quickly that the later differences are negligible. The data were somewhat ambiguous with regard to a PCF of .7, but it is possible that some other effect similar to differential light adaptation may have aided in causing the intermittent target to become some what more effective than the steady target.

The present measures of brightness enhancement tended to confirm previous studies.

SUMMARY

In measuring brightness enhancement differential light adaptation might act to increase the relative effectiveness of the intermittent target. It was hypothesized that low PCFs would produce the most differential light adaptation and high PCFs the least.

In order to test the hypothesis, conditions were set up using two targets of the same size. Target 1 was on for 13 seconds producing a steady stimulus which served as a standard. Target 2 had two phases. The second phase was a one-second long steady stimulus which came on after target 1 had been on for 12 seconds. This served as the comparison stimulus which the observers adjusted to match the standard stimulus. The first phase of Target 2 was called the 'fill' period. Various fill stimuli could be inserted and their effect on the final matches observed. When the fill stimulus was steady and equal in intensity to the standard stimulus both areas of the retina on which the targets were imaged would be equally adapted and the observers ability to make photometric matches could be tested (Condition C). With the fill stimuli reduced to zero it could be determined whether the standard stimulus produced light adaptation (Condition A). When intermittent stimuli were used in the fill period

their effect on the final matching could be evaluated in line with the hypothesis stated above (Condition B). PCFs of .3, .5, and .7 were used. All observers used the right eye. The experiment was done in two parts which were similar in all details except that in Part One the standard was set at 50 c/ft^2 and in Part Two at 25 c/ft^2. The degree of brightness enhancement produced by the three PCFs was also measured.

The data indicate the PCFs of .3 and .5 produce little or no differential light adaptation. The PCF of .7 may show an effect similar to that of differential light adaptation.

The measures of brightness enhancement were as expected, i.e., the PCF of .3 producing the most and the PCF of .7 the least.

APPENDIX

C	A	B .7	B .5	B .3	D	E .7	E .5	E .3	
116	93	95	126	106	89	84	98	120	
120	95	103	118	107	110	100	115	122	
120	93	99	118	106	113	94	102	113	
111	88	99	107	113	104	90	112	116	
114	97	102	119	108	105	96	110	114	
112	89	98	116	113	109	92	106	124	
114	98	97	110	102	119	95	104	113	
111	103	100	113	102	111	95	108	123	
110	97	102	112	116	104	95	113	122	
111	93	104	113	110	102	100	111	120	
108	97	100	101	109	100	103	117	120	
110	93	116	101	106	100	95	104	123	
114	110	110	110	104	111	90	109	120	
114	97	104	109	111	107	98	114	125	
113	93	112	112	111	112	94	109	122	
110	94	118	110	116	116	84	108	123	
116	93	104	113	109	108	96	113	126	
108	95	108	109	110	107	94	104	117	
110	108	114	114	114	106	90	116	123	
110	96	117	112	107	102	97	118	124	
2252	1922	2102	2243	2180	2135	1182	2191	2410	TOTAL
112.60	86.10	105.10	112.5	109.0	106.75	94.1	109.55	120.5	MEAN
3.35	5.34	6.92	5.64	4.02	6.43	4.73	5.05	3.84	S.D.

Table 7. Raw data in Variac readings with totals, means, and standard deviations for Observer C in Part One.

C	A	B .7	B .5	B .3	D	E .7	E .5	E .3	
94	108	110	110	109	112	75	94	98	
102	100	104	111	113	115	76	88	87	
110	104	108	104	104	116	74	91	90	
110	108	110	106	106	112	80	99	94	
102	108	111	110	107	110	80	95	109	
109	109	112	115	109	110	78	99	102	
108	100	108	111	106	111	83	94	110	
112	94	113	113	106	106	86	94	103	
111	108	114	112	104	104	82	90	109	
108	99	112	116	104	104	88	98	88	
114	104	108	106	111	93	80	100	97	
112	104	108	108	108	102	81	100	100	
110	104	109	108	108	111	78	93	105	
118	104	113	107	110	116	76	95	104	
108	104	114	105	109	111	72	98	108	
110	104	112	109	108	116	74	94	105	
112	105	113	113	106	109	70	98	106	
112	102	114	108	106	110	82	100	109	
112	103	111	112	107	115	86	100	100	
107	100	112	112	107	110	90	100	94	
2181	2072	2216	2196	2148	2193	1591	1920	2018	TOTAL
109.05	103.6	110.8	104.8	107.4	108.65	795.5	96.0	100.9	MEAN
4.93	3.45	2.58	3.22	2.29	5.52	5.25	3.62	6.91	S.D.

Table 8. Raw data in Variac readings with totals, means, and standard deviations for Observer N in Part One.

C	A	B			D	E			
		.7	.5	.3		.7	.5	.3	
95	91	93	90	92	89	100	105	108	
96	85	95	90	88	91	94	113	120	
91	86	90	96	98	88	92	108	112	
106	83	96	102	96	91	99	104	111	
97	86	90	86	88	89	100	102	108	
109	78	98	83	90	90	103	112	102	
93	76	93	96	92	92	99	104	106	
96	74	106	97	89	100	95	101	115	
101	79	97	94	93	90	102	98	106	
98	86	95	90	96	91	95	99	108	
104	76	102	106	91	93	99	99	102	
94	82	106	89	92	94	94	99	98	
99	73	102	94	88	92	94	95	104	
106	89	94	85	89	94	98	103	106	
94	83	95	90	104	92	99	102	102	
104	82	99	90	106	90	100	101	112	
106	80	94	94	100	92	94	112	98	
98	86	90	91	102	94	98	104	105	
103	84	94	97	98	91	102	108	104	
98	79	104	86	111	91	94	104	104	
1988	1638	1933	1846	1903	1834	1951	2073	2131	TOTAL
99.4	81.90	86.65	92.30	85.15	91.7	97.55	103.65	106.55	MEAN
5.02	4.82	4.91	5.57	6.49	2.51	3.19	4.78	5.33	S.D.

Table 9. Raw data in Variac readings with totals, means, and standard deviations for Observer V in Part One.

C	A	B			D	E			
		.7	.5	.3		.7	.5	.3	
97	78	89	92	92	86	68	82	79	
91	79	86	90	89	89	74	90	82	
93	82	85	84	91	88	73	101	94	
92	78	94	94	96	81	73	83	106	
101	82	99	90	92	83	72	85	113	
90	83	86	86	92	89	71	85	108	
90	91	87	94	86	85	77	83	116	
90	83	85	90	90	89	76	84	120	
95	87	84	93	95	89	81	85	90	
93	80	87	92	89	80	74	92	98	
85	81	100	86	89	101	80	87	107	
90	81	90	84	89	84	80	89	110	
89	81	88	89	85	89	81	89	100	
100	81	97	93	92	90	81	90	104	
100	81	93	93	91	90	80	88	120	
88	82	79	93	90	84	82	85	103	
88	80	86	87	97	85	84	92	110	
98	86	85	95	94	94	76	90	100	
92	87	85	90	94	94	77	85	100	
93	81	88	94	90	96	75	84	108	
1855	1644	1773	1809	1823	1766	1535	1749	2068	TOTAL
92.75	82.2	88.65	90.45	91.15	88.3	76.75	87.405	103.4	MEAN
4.35	3.19	5.24	3.25	3.0	5.07	4.16	4.32	10.81	S.D.

Table 10. Raw data in Variac readings with totals, means, and standard deviations for Observer C in Part Two.

C	A	B			D	E		
		.7	.5	.3		.7	.5	.3
97	89	84	80	88	87	78	78	86
87	96	82	90	91	93	81	80	84
98	86	79	89	94	86	71	84	84
92	87	88	93	89	86	80	78	88
91	84	88	94	89	92	71	81	89
89	72	86	87	89	88	83	82	91
94	84	88	90	90	95	76	88	84
89	82	93	94	87	84	78	87	90
92	78	86	91	95	90	72	82	85
93	88	80	85	93	94	72	80	86
92	84	86	84	94	79	79	90	63
97	85	85	84	94	80	78	80	74
96	79	88	87	92	90	69	82	78
98	84	83	90	90	88	74	91	90
90	72	86	88	97	88	72	83	87
88	79	84	92	88	93	78	89	90
84	84	88	89	88	92	78	87	98
93	82	81	92	90	94	80	91	89
88	77	94	90	90	88	80	90	81
88	84	84	85	88	86	75	87	85
1836	1656	1713	1774	1816	1773	1525	1690	1702
91.8	82.8	80.65	88.7	90.8	88.65	76.25	84.5	85.1
3.89	5.48	3.73	3.62	2.67	4.30	3.87	4.36	7.07

Table 11. Raw data in Variac readings with totals, means, and standard deviations for Observer N in Part Two.

C	A	B			D	E		
		.7	.5	.3		.7	.5	.3
78	74	75	80	78	76	78	92	94
74	73	70	74	80	83	84	94	94
83	74	60	78	81	79	86	88	82
89	76	73	81	78	79	72	92	101
86	74	81	80	76	77	78	100	88
84	73	82	76	85	76	76	81	95
81	69	73	73	82	77	84	91	94
77	73	80	80	73	79	81	94	88
71	76	72	72	81	80	78	88	95
80	84	79	76	82	80	78	90	97
78	75	76	79	79	76	74	90	97
77	70	77	82	78	77	86	81	94
74	68	80	70	78	82	82	86	100
72	77	75	85	72	80	73	90	97
77	74	71	80	80	85	85	88	96
75	72	74	86	83	86	79	94	96
74	76	75	75	76	81	73	89	88
76	71	77	67	72	77	81	91	92
76	78	78	76	78	80	74	97	89
68	71	76	70	78	74	80	92	102
1550	1478	1504	1540	1570	1584	1582	1808	1879
77.5	73.9	75.2	77.0	78.5	79.2	79.1	90.4	93.95
4.51	3.60	4.76	4.90	3.55	3.04	4.28	4.47	4.83

Table 12. Raw data in Variac readings with totals, means, and standard deviations for Observer IV in Part Two.

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