AN INVESTIGATION OF THE INFLUENCE OF THE INTERRELATIONSHIP AMONG CERTAIN VARIABLES AND OBSERVER CRITERION ON APPARENT BRIGHTNESS UNDER CONDITIONS OF INTERMITTENT STIMULATION

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY

Carl William Schneider

1965

This is to certify that the

thesis entitled

AN INVESTIGATION OF THE INFLUENCE OF THE INTERRELATIONSHIP AMONG CERTAIN VARIABLES AND OBSERVER CRITERION ON APPARENT BRIGHTNESS UNDER CONDITIONS OF INTERMITTENT STIMULATION

presented by

Carl William Schneider

has been accepted towards fulfillment of the requirements for

Ph.D. degree in Psychology

Major professor

Date December 15, 1965

O-169

ABSTRACT

AN INVESTIGATION OF THE INFLUENCE OF THE INTERRELATIONSHIP AMONG CERTAIN VARIABLES AND OBSERVER CRITERION ON APPARENT BRIGHTNESS UNDER CONDITIONS OF INTERMITTENT STIMULATION

by Carl William Schneider

In the first part of this investigation four variables were systematically manipulated in an attempt to understand the way in which they interact to produce varying levels of brightness. The second part of the investigation deals with the problem of observer criterion under difficult conditions in which phenomenal changes occur.

Part 1. Two observers made 7000 observations each under conditions in which four variables were combined and systematically manipulated. Seven pulse-to-cycle fractions (PCF) ranging from 0.9 to 0.1, three frequencies of 20, 10 and 5 pps, four intensity levels of 70, 130, 280 and 440 c/ft^2 and two target sizes of 3.5° and 1.75° when combined formed a total of 168 conditions. The photic sources were Sylvania modulator tubes which were driven electronically. Brightness matches were made by manipulation of a neutral density wedge which traveled on a rack and pinion in front of the steady source. The data were analyzed graphically on a ratio of effectiveness scale in which the expected

level was derived by extrapolation from the data according to Talbot's law. The standard deviation (SD) of 40 observations made under each condition are also presented graphically.

The following results were obtained. The smaller target tended to reduce effectiveness to a greater degree for the shorter PCF's than the longer ones. Smaller PCF's at the most effective rates yielded the maximal effectiveness levels. Frequencies of 5 and 10 pps produced effectiveness levels above the expected level with the large target, but the ratios obtained with the small target at 10 pps dropped below the expected level. At 20 pps all ratios were on or below the expected level. One of the conclusions drawn was that the greater the effectiveness of a particular frequency, the greater will be the effect on the ratio by manipulations of PCF, intensity and target size. The standard deviations obtained with the 5 pps frequency were larger than those obtained at higher frequencies. This finding plus the fact that the raw scores tended to form a bimodal distribution suggested that the observer was shifting his criterion.

Part 2. In the second part of the experiment this problem was investigated by having the observer make brightness matches at frequencies between 20 and 1 pps with a constant pulse length of 20 milliseconds. Under these conditions the ratio of effectiveness increased as frequency decreased until 6 pps was reached. It leveled off between 6 and 3 pps and then increased sharply at 2 and 1 pps. The SD increased as frequency decreased until 5 pps was reached and then decreased. The SD's were higher for 2 and 1 pps than those for 20 and 10 pps but lower than those for 6, 5, 4 and 3 pps. The frequencies of 6, 5, 4 and 3 were characterized by a bimodal distribution.

It was concluded that the observer shifts his criterion at the lower frequencies and makes brightness matches to single flashes rather than to an average between the light and dark period, which is what he must do at the higher frequencies. It was suggested that the brightness levels obtained with the lower frequencies are related to single pulse phenomena, and that the brightness enhancement phenomenon described by Bartley must be limited to those frequencies above at least 8 pps.

Approved: S Howard Bartley

Date: Dec 15, 1965

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By

Carl William Schneider

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Psychology

1965

ACKNOWLEDGMENTS

No thesis is complete without recognition of those individuals whose assistance made the completion of this problem possible.

I wish first to thank Dr. S. H. Bartley who as my graduate advisor and committee chairman gave continuous help and criticism in the formulation of this problem. His tireless devotion to the development of psychology as a science will serve as a lasting inspiration.

I wish to thank those members of my committee: Dr. W. D. Collings, Dr. D. M. Johnson, and Dr. S. C. Ratner for their reading and criticism of the thesis. A special thanks must go to Dr. S. C. Ratner whose particular interest in this student's future will long be remembered.

Dr. R. J. Ball contributed a great deal to my understanding of the complexities involved in the formulation of this problem. To John Kazsuk, whose contribution of time and energy as an experimenter and observer matched my own, I am particularly grateful. Jere N. Beauchamp provided a valuable service by designing and constructing a piece of apparatus that made this investigation possible.

To my wife I am especially grateful for her enduring patience and encouragement throughout the graduate program.

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INTRODUCTION

According to Plateau (32) the first investigation into the temporal aspect of vision was a doctoral dissertation by Segner, De raritate luminus in 1740. Since that time there have been a great many articles and books published which have dealt, directly or indirectly, with the problem of the relationship between simple and complex temporal inputs and the resultant sensory phenomena. While some aspects of time related visual phenomena, such as flicker-fusion, have been investigated rather thoroughly there are other aspects of the problem that have been for the most part neglected. This investigation represents an attempt to examine one of those aspects of the problem, namely, the brightness phenomena related to varied conditions of intermittent photic stimulation.

The apparent brightness associated with sub-fusional rates of intermittent photic stimulation has been investigated most extensively by Bartley and co-workers (8,9,10,11, 12,13,20,35,36,40,41). Much of this work has dealt with the variables which may influence apparent brightness. Included among the variables which have been investigated are the frequency of the intermittent photic stimulation, varied intensity levels, target size, pulse-to-cycle fraction, monocular versus binocular viewing, varied pulse trains and finally wavelength.

As we shall see in the following review all of these variables have been studied individually or occasionally in combination with one other. However, no attempt has been made to systematically examine the way in which a particular combination of variables interact to produce the sensory end result. While it has been traditional to specify the change in the sensory end result associated with the manipulation of a single variable, one must recognize the fact that there are other controllable and effective variables in the field, all of which are interrelated. This interrelationship is no doubt very complex, and consideration must be given to the possibility that manipulations of a particular variable under a certain set of conditions may yield a sensory end result quite unlike that obtained when the same manipulations are made under a different set of conditions. This point will become more clear to the reader as we consider the findings related to the variables to be investigated in this study.

The second part of the investigation will involve a systematic analysis of the variation obtained under the experimental conditions in an attempt to determine what effect, if any, observer criterion may have on the results.

In this investigation a full spectrum photic source will be employed, and the following variables will be systematically manipulated.

1. Pulse-to-cycle fraction (PCF). This is defined as the fraction of the total cycle occupied by photic input during intermittent photic stimulation.

2. Frequency of intermittent photic stimulation. This is usually defined by the number of pulses occurring per second.

3. Target size or size of the retinal area stimulated. This is defined by the visual angle subtending the eye.

4. Intensity of the photic source. This is the amount of radiant energy which actually reaches the eye. It is determined by photometry at the position of the eye rather than at the target.

It has been traditional to determine the apparent brightness of an intermittent source by referring to the intensity level of a steady matching source. If the intensity required for a match is twice as high as the intensity of the intermittent source the tacit assumption has been that the target appeared twice as bright. This implies that there is a one-to-one relationship between intensity and brightness. Since we have matched the apparent brightness of one source to the apparent brightness of another source we have only an indirect measure of brightness, and therefore have no basis for assuming that there is a linear relationship between brightness and intensity. Since we do not have a scale for brightness, such as Steven's (39) sone scale for loudness, I have chosen to refer only to the effectiveness of a target as determined by the relationship of obtained values to expected values which can be calculated by extrapolation from Talbot's law. If a target is found to be more effective under certain conditions it may be assumed that it is brighter, but no conclusion is drawn as to how much brighter. What we are dealing with is essentially only an ordinal relationship.

Historical Review

The fact that intermittent photic stimulation may be more effective in producing brightness than steady stimulation was first mentioned by Brewster (23) in 1834. However, it was Brücke (24) in 1864 who first studied the phenomenon in a systematic way. Evidently the phenomenon was forgotten for it was not mentioned again until Bartley (8) investigated it in 1938. The phenomenon has been referred to as "brightness enhancement" (8), the "Bartley effect" (29), the "Brucke effect" (8) or the "Brucke-Bartley effect" (35) by various investigators. At times these terms have been used separately or interchangeably in the same article. However, Bartley (15) has shown in a somewhat recent paper that we are actually dealing with two separate phenomena, and it is the sense in which Bartley has dealt with brightness that is of particular interest in this investigation.

On the basis of early findings with animals Bartley and Bishop (5,6), Bartley (7,9) and Bishop (19) and later work with humans (8) Bartley formulated the Alternation of Response theory (14,15,16) to account for diverse brightness phenomena. While it is not necessary to review the theory here it has certain implications which are relevant to this investigation and worth mentioning.

In the theory, Bartley attempts to describe the neurophysiological processes underlying certain sensory end results. It is suggested that those conditions of photic input which can induce a maximum response in the optic cortex will also produce a maximal brightness effect. It is also suggested that this can be accomplished by utilizing conditions of intermittent stimulation which will fire a maximum number of channels in the optic pathway (optic nerve, lateral geniculate and radiation fibers to the cortex) which will in turn give rise to a maximal cortical response if the input is properly tuned to the intrinsic periodicity of the cortex.

The theory has generated a number of hypotheses concerning those variables which will produce maximum brightness. These variables have been investigated rather extensively, and it is with the findings on four of these variables to which we will not turn our attention.

1. <u>Rate of intermittency at which maximum brightness is obtained.</u>[1]

In his original investigation Bartley (8) achieved maximum brightness at a rate of 8-10 pps with a PCF of 0.50 when the standard source was at approximately 95 c/ft^2.

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[1]In many of the studies reported here it is not always clear if the brightness levels obtained are enhancement levels as defined by Bartley or levels based on some other criterion. Therefore, I have chosen to refer to the maximum brightness levels obtained without attempting to decide whether or not they are enhancement levels or something else.

Halstead (29) using 4.2-40 pps at an intensity level of 7 c/ft^2 and a PCF of 0.50 obtained similar results from normals and patients with cerebral lesions. Bartley, Paczewitz and Valsi (13) found 10.6 pps to be more effective than 32 pps at intensity levels of 60, 100 and 150 c/ft^2 with a PCF of 0.30. In these studies more than one rate was used and 10 pps or very close to it was found to be the most effective rate.

There are many other studies where intermittency rates below 10 pps were found to be more effective. Lindsley (33) has reported obtaining maximum brightness at rates from 10 pps down to 5 pps, and for some subjects it was obtained at 2 or 3 pps. Alpern and Sugiyama (1) varied rate from 2-30 pps with a PCF of 0.50 and an intensity level of 12 foot-Lamberts and obtained maximum brightness at 2.5 pps. Battig, Voss and Brogden (18) varied frequency from 4 to 20 pps and found maximum brightness at 4 pps for both high and low luminance levels. The luminance levels used were not reported. In one investigation Bartley (10) examined the effectiveness of rates between 3.6 and 20 pps at a very low intensity level (0.007 c/ft^2) and PCF of 0.50 and maximum brightness was obtained at 3.6 pps with three out of four observers. Gulick (28) varied rate from CFF to 1 pps with pulses that were 20 microseconds long and obtained maximum brightness at 2 pps. Ball (2,3) studying chromatic brightness enhancement tendencies found 9.8 pps to be more effective than higher rates, but he also found 6.5 pps and 7.8 pps to be almost as effective as 9.8 pps. Bartley, Nelson and Soules (17) used intermittency rates of 4, 10, 24 and 48 pps and found 4 pps to be most effective at an intensity level of 173.55 c/ft^2 with a PCF of 0.25.

There are a number of investigations where 5 pps was found to be the most effective frequency even though some slower rates were employed. Colgan (25) explored the effectiveness of rates from 3 to 32 pps with a PCF of 0.50 at 5.1 foot-Lamberts and found maximum brightness at 5 pps for a group instructed to match only to the "on" of the pulse. Reidmeister and Grusser (38) studied the effect of frequency on brightness and obtained a maximum at 5 pps with a PCF of 0.50. Nelson, Bartley and Ford (36) using part-spectrum targets at an intensity level of approximately 48 c/ft^2 and rates of 20, 10 and 5 pps obtained maximum brightness at 5 pps with a 0.25 PCF for five different wavelengths ranging from 490 to 700 millimicrons. In a very recent study Bourassa and Bartley (22) used rates of 5, 10, 15 and 20 pps with three different intensity levels (0.75, 10 and 20 c/ft^2) at PCF's of 0.25 and 0.75 and obtained maximum brightness at 5 pps for the 10 and 20 c/ft^2 levels at 0.25 PCF.

2. Intensity level at which maximum brightness is achieved.

Naturally most of the efforts in this area have been devoted to investigations of intermittency rates, and many experimenters have used only one intensity level. However a few investigators have used various intensity levels within a single study, and it is these that will be considered here.

The earliest study in which different intensity levels were used was carried out by Bartley (10). Fifteen increments in intensity ranging from 0.11 c/ft^2 to 730.0 c/ft^2 were employed with an intermittency rate of 10 pps. The brightness levels obtained appeared to be in line with the intensity levels, i.e., the highest intensities produce the greatest brightness and the lower intensities the least. In another study Bartley, Paczewitz and Valsi (13) included four intensity levels in an investigation concerned primarily with PCF. The levels used were 13 c/ft^2, 60 c/ft^2, 100 c/ft^2 and 150 c/ft^2, and maximum brightness was obtained at 60 and 100 c/ft^2 at 10.6 pps with a PCF of 0.30.

Valsi (40) in a rather complicated investigation employed intensity levels of 22, 40, 95, 175 and 310 c/ft^2 with an intermittency rate of 10 pps, PCFs of 0.04, 0.30 and 0.50, two target sizes and two viewing conditions (monocular or binocular). The brightness levels obtained seemed to depend on the particular combination of variables being used at any instant plus the observer viewing them, and consequently no particular intensity level appeared to be consistently more effective.

In a recent investigation Bourassa (21) obtained greater brightness for 10 and 20 c/ft^2 than for 0.75 c/ft^2 with a small target and 5 pps. With a large target at intensity levels of 4.0 and 0.30 c/ft^2 the former was more effective again at 5 pps.

As was reported earlier Battig, Voss and Brogden (18) claim to have obtained maximum brightness at both their high and low luminance levels, but they did not report the luminance levels employed in the investigation! Hudson (30) reported that maximum brightness was obtained with 4 out of 27 naive subjects at the highest luminance level used in the investigation which was 440 foot-Lamberts. In an investigation of chromatic enhancement tendencies Ball (3) concluded that the higher intensity employed was more effective in producing brightness. His highest intensity level was 150 c/ft^2.

3. <u>The pulse-to-cycle fraction (PCF) at which maximal brightness is achieved</u>.

By comparison the PCF has received a great deal less attention than either frequency or intensity level. The PCF defines two important components of the visual presentation, i.e., the length of the pulse and the length of time between pulses or the null period. It was not until quite recently that the latter component has received the attention it deserves (35).

Bartley (8) in the first investigation of brighthess under conditions of intermittent stimulation employed PCFs of 0.88, 0.77 and 0.50 and found 0.50 to be quite a bit more effective than the other two. This was at an intermittency rate of 10 pps so the pulse length would be 50 milliseconds and the null period would also be 50 milliseconds.

Later Bartley, Paczewitz and Valsi (13) carried out a systematic investigation of PCF with values of 0.9, 0.7, 0.5, 0.3 and 0.2 at four different intensity levels and two different rates. Maximum brightness was obtained at a PCF of 0.3 at 10 pps, which would be a 30 millisecond pulse followed by a 70 millisecond null period. In a follow up study Valsi (40) employed PCFs of 0.50, 0.30 and 0.04 at five intensity levels with a rate of 10 pps. Under some conditions 0.50 was most effective and under other conditions 0.30 proved to be the most effective. Under a few conditions the effect of both PCFs was equivalent and 0.04 was always the least effective.

Nelson, Bartley and Ford (36) investigating the brightness of part-spectrum targets employed PCFs of 0.75, 0.50 and 0.25 at rates of 20, 10 and 5 pps, and the results were varied. At 5 pps a PCF of 0.25 produced maximum brightness. At 10 pps all PCFs tended to produce equivalent brightness, and at 20 pps a PCF of 0.75 was most effective.

Reidmeister and Grüsser (38) found a PCF of 0.50 to be more effective than 0.33 and 0.143 at 5 pps.

4. <u>The target size with which maximum brightness is obtained</u>.

Target size has been the least studied of all of the variables mentioned. Target size is usually defined by the visual angle which is the angle of the target subtended at the eye. The target may be foveal, which is less than 2°, or parafoveal which is greater than 2°.

Valsi (40) utilized two different arrangements where he compared rectangular targets 1.50 x 1.75 inches with 0.50 inch square targets viewed at a distance of 20.25 inches. He found the large target to be more effective for one observer and the small target to be more effective for the other. However, these results must be accepted with caution because he has confounded shape with size.

Ball (2) has utilized a 4° and a 1.25° bipartite target and found the large target to be more effective for one observer while the small target was more effective for two other observers. Katz (31) in an investigation of "brief flash brightness" employed 5°, 2.5° and 0.5° targets and found no difference in the effect of target size except for an increase in observer variability for smaller targets.

Comment

The results of the previous investigations are quite varied to say the least. As we have seen, the bulk of the investigations have been concerned with frequency and quite naturally so since it is primarily the effects of intermittent stimulation in which we are interested. However, it does seem a bit absurd that some investigators failed to report the intensity level(s) employed, some failed to report the target size, and in one instance the intermittency rate was not reported! It should be obvious after reviewing the literature that these variables are important and will no doubt have a profound effect on the results.

Bartley (8) implied that 10 pps was a critical rate for obtaining maximum brightness, but in a later paper (10) he demonstrated that different results might be obtained when other factors such as intensity, visual angle, PCF, etc., are varied. Taking this into consideration, it should not be too surprising that previous findings are so varied, since in no study was the same or even approximately the same intensity level used and the target sizes and target arrangements, although not reported in most cases, were without a doubt quite different.

In Valsi's thesis (40) gross differences in results were obtained by two trained subjects even though all of the conditions were identical for both. This investigation indicates that we have another variable rarely considered in this area, i.e., observer criterion. Hudson (30) criticized previous findings on the basis of his own results which were obtained from 27 naive subjects who made only a limited number of observations. Nelson, Bartley and DeHardt (34) have effectively shown this to be a rather poor procedure in vision studies where a reasonably high degree of precision is desired.

In general, it appears that the lowest frequency utilized in previous investigations has been the most effective. These findings do not agree with Bartley's suggestion that the most effective rate will be one which is synchronous with the instrinsic cortical periodicity of the organism. This rate would be somewhere between 8 and 12 pulses per second.

However, previous investigators have not considered the possibility that they may be dealing with a different phenomenon at very low rates. At those rates which Bartley defines as enhancement frequencies (around 10 pps) the target appears as a rapidly undulating light and dark period with no discrete separation between the two. At frequencies below this two separate entities emerge, i.e., a discrete light and dark period, and a phenomenal change becomes evident.

When a subject is making a match at a rapid rate he is matching to an average between the light and dark periods since it is not possible to separate the two. At lower rates it is extremely difficult to match to an average, and the result may be a change in criterion. This new criterion which emerges may be associated with a phenomenon which is different than that which Bartley describes as "brightness enhancement."

Findings on the relationship of intensity to apparent brightness are as varied as those dealing with frequency. Bartley (15) has suggested that at very high intensities stray illumination increases, and when one directs intermittent stimulation and steady stimulation into the same eye the stray illumination may tend to stimulate areas of the retina that should be resting during the null period. It is assumed that this would reduce the brightness effect, since it reduces the number of channels available to fire at any instant. While this may be true it is not known at the present time what the critical parameters are for those factors which may reduce brightness.

As we have seen some investigators have found their highest intensities to be most effective while others have found the middle range to be more effective. In any one of these investigations only a limited range of intensities has been used, and those investigators who found their highest intensities to be most effective were not using levels as high as those who found their middle range to be more effective. Obviously, any general statement about what levels of intensity are more or less effective would be quite premature, since only a very limited range of intensities have been investigated.

The findings on the effect of PCF on brightness tend to be split with about half in favor of 0.5 and the other half in favor of 0.3. It is also apparent that a PCF which is most effective in producing maximum brightness at one frequency will not necessarily be the most effective one at some other frequency. There is no doubt an important relationship which exists between PCF and intensity, but previous findings do not permit one to assume this to be the case.

One consistent finding in all of the previous research is that very large PCFs such as 0.9 and 0.7 are very ineffective regardless of the intermittency rate. This is not too surprising for even though there is more energy striking the eye per unit of time, the null period between pulses is extremely short and the visual mechanism is unable to recover completely between pulses.

It has also been found that extremely short PCFs such as 0.1 and 0.04 are very ineffective. If we consider the null period between pulses as being an important contributor to the brightness effect, we would expect the shorter PCFs to produce a greater effect since there is more time between pulses for the channels of the pathway to recover. However, this is not the case, and attempts have been made to explain this finding (13,40) but no satisfactory conclusion has been reached.

So little work has been done on the effect of target size on apparent brightness that little can be said. It has been suggested that any condition which increases the amount of stray illumination will reduce brightness (15). It has also been suggested that very small targets which activate only a small portion of the retina may be ineffective (15,16). The parameters for this relationship have yet to be determined.

The variety of results obtained by previous investigators are no doubt due to what were in many instances extreme differences in the conditions employed. A systematic manipulation of a number of variables utilized within a single investigation should demonstrate that there is a complex interaction among the elements involved, and this interaction may account for the large disparity in previous findings. For example, a particular PCF may be very effective at a certain frequency, but a change in frequency may be accompanied by a shift in maximal effectiveness to a different PCF. Bartley (10) recognized that some of these factors were interrelated, but no serious consideration of this possibility has appeared in the literature.

In the present investigation an attempt will be made to understand this interaction among variables and to demonstrate that it is not a haphazard affair. An attempt will also be made to determine the relationship of observer criterion to the results obtained at frequencies below 10 pps where a phenomenal change in the quality of stimulation becomes evident.

This investigator is well aware of the difficulty involved in such an undertaking and considers this endeavor as only the beginning of an attempt to reach a new level of sophistication in understanding the problem. This undertaking was stimulated by the belief that we have reached a stage of development where the isolation of single variables and formulations of ad hoc hypotheses concerning them, while sufficient and necessary in the course of time, are no longer sufficient if we are to have a complete picture of the processes in which we are interested.

Methodological Considerations

The following section, usually not included as part of a dissertation, is presented here for those who are interested in the further development and improvement of the procedures utilized in this area of research and at the same time avoiding the errors committed by previous investigators. Many students of vision enter the area somewhat overwhelmed by what appears to be a multitude of complexities, and it is hoped that the following suggestions will also serve as an aid to those who are, for the first time, faced with the problem of designing an effective experiment.

The traditional procedure employed in obtaining measures of apparent brightness has involved the "Method of Average Error" (27,42) in which the subject matches one photic source to another of known intensity, and both ascending and descending trials are used.

In some of the earlier studies concerned with the measurement of brightness of an intermittent photic source the observer was required to vary the intensity of the intermittent source to match a fixed steady source. This is admittedly a poor procedure since the intensity of the intermittent source can affect its apparent brightness to a large degree. The result is that two important variables have been confounded to the extent that the experimenter can not be sure if his results are due to the intermittency rate, varying intensity or a combination of both. In some more recent experiments the investigators have reversed the procedure so that the steady source is matched to the intermittent one. It is suggested here that this latter procedure be established as the safest method in future experiments.

Another problem closely related to this concerns the manner in which the intensity of the matching or comparison source is manipulated. The method most often used is one in which a lamp is connected to a Variac and the intensity of the lamp is raised or lowered by increasing or decreasing the current. The lamp is then photometered while the Variac is set at different positions (usually very low, middle and very high) and the remaining intensity levels are interpolated to fit all of the other dial settings.

Two serious problems arise from this procedure. When the current driving the lamp is varied there are accompanying hue shifts which can be quite disturbing and may affect the match. The other problem is related to the way in which the lamp and Variac change as the current is altered. Dial readings on Variacs change in a linear fashion, and presumably the current does likewise. However, most lamps do not change intensity in a linear fashion when the current driving them is altered. Therefore, we take the risk of committing gross quantitative errors by interpolating intensity levels to match dial settings on a Variac.

It is suggested that a much cleaner arrangement is one in which the intensity of the comparison source is raised or lowered by means of a calibrated neutral density wedge or a calibrated polaroid sheet device which changes the percentage of transmission as the axes of the two sheets are rotated toward or away from one another. With either one of these arrangements the experimenter can obtain the percentage of transmission required for a match when both targets are steady, and this can be used as a standard. This eliminates the necessity of having to measure the intensity of the comparison source at all, it reduces the possibility of error in measurement and it eliminates hue shift.

Previous investigators have also committed errors in their treatment of the order of presentation of conditions. There has been a tendency, when many conditions are being used not to randomize the order in which they are presented. For example, if PCF is the variable being investigated the experimenter presents them in an ascending or descending order. This procedure leaves the investigation open to two possible sources of error. Experimental bias may result since the observer in these investigations is usually highly trained and completely familiar with the hypotheses being tested.

Secondly, the order of presentation itself may yield results which are due to the particular order of conditions employed. Alpern and Sugiyama (1) have demonstrated quite clearly, in a very well controlled investigation, that the apparent brightness of a particular condition can be influenced a great deal by the condition preceding it.

Naturally this problem is more serious in those experiments where one is utilizing equipment which makes it possible to shift from one condition to the next rapidly. However, it is suggested that the experimenter adopt the policy of randomizing all conditions in the experiment except intensity level which introduces adaptation problems.

The preceding suggestions are based on the assumption that one of the merits of "good" research is determined by the degree of precision obtained by utilizing appropriate controls. It is hoped that future investigators will not only incorporate these ideas into their own research, but will also find ways in which the research procedures can be improved further.

Treatment of Data

There are various ways in which an investigator can treat the data obtained in brightness experiments. He may, as Bartley and co-workers have done, consider the brightness of intermittent stimulation in relation to steady stimulation. The results are usually expressed as a ratio which is obtained by dividing the mean intensity of the comparison by the fixed intensity of the intermittent source. A ratio of 1.00 indicates that the two sources are the same intensity and presumably equal in apparent brightness.

Some investigators have merely presented the luminance units required to match in graphical form. This sort of presentation may lead one to believe that there is a one-to-one relationship between the luminance level and brightness. It was suggested earlier that this is an unsafe assumption since we do not know what the relationship is between brightness and luminance.

Colgan (25) and Gulick (28) suggested that the data be examined in relation to the Talbot level. According to Talbot's law the brightness levels obtained at rapid rates of intermittency are dependent upon the pulse-to-cycle fraction. This principle can be applied to sub-fusional rates by extrapolation. For example, if the PCF is 0.1 we may expect the effectiveness to be 1/10 that of a PCF of 1.0 which is the theoretical point representing steady stimulation. This type of treatment takes into account the amount of energy emitted per unit of time, and it is the possible deviation from this that we are attempting to discover.

The expected values are obtained by first finding the amount of energy; or, as in this investigation, the percentage of transmission required to make a match when both targets are steady. Once this value has been obtained we simply multiply by the PCF. For example, if 40% transmission is required to make a match when both targets are steady, we would expect that it would take 4% transmission to make a match when the target is intermittent with a PCF of 0.1.

After the expected values have been ascertained the ratio of effectiveness can be computed by dividing the obtained value by the expected value.

This method of analysis is used in the present investigation since the indications are that it may be a more sensitive indicator of differences that exist than those methods used by previous investigators.

METHOD

Apparatus

The apparatus is shown diagrammatically in Figure 1.

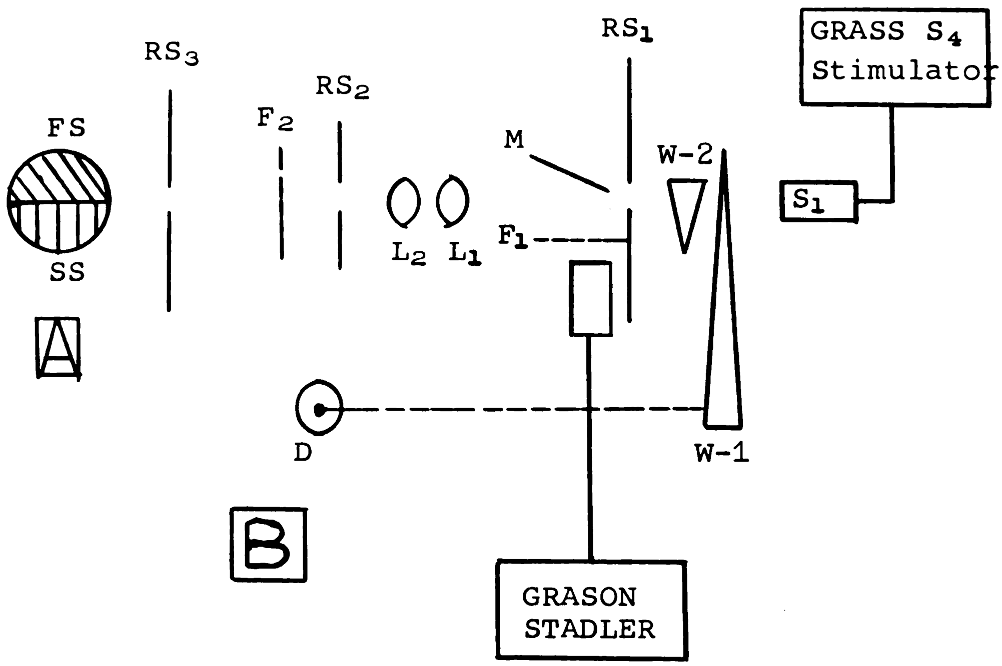


Fig. 1. Schematic diagram of the apparatus showing the arrangement of light sources S_1 and S_2, neutral density wedges W_1 and W_2, field stops, filter holders, control for the wedge and the appearance of the bipartite field.

The photic sources (S_1 and S_2) are Sylvania glow modulator tubes. S_1 is the steady source and is driven electronically by a modified Grass S-4 stimulator. S_2 is the intermittent source and is driven electronically by the Grason-Stadler flicker-fusion apparatus. W_1 is a neutral density wedge which could be moved to the right or left on a rack and pinion device by turning the dial (D). W_2 is a stationary balance wedge. The wedge was calibrated so that readings obtained as the observer raised or lowered the intensity could be converted into percentage of transmission required for a match. This device was accurate to within .1%. RS_1 is a reduction screen. M is a first surface mirror which cut S_1 in half and reflected half of S_2. F_1 holds a permanently fixed .6 neutral density filter which limited the intensity level to a high of 440 c/ft^2. L_1 and L_2 are collimating lenses which were movable in the line of regard, thus enabling the observer to bring the target into focus. RS_2 is a field stop which was used to control target size. F_2 held the neutral density filters which enabled the experimenter to shift intensity levels during the experiment. RS_3 is a field stop used to reduce stray illumination. Part B represents the appearance of the bipartite field in which FS is the intermittent half of the target and SS is the steady half.

To summarize, the variables employed in the experiment were manipulated in the following way.

1. The steady source was driven by the modified Grass S-4 stimulator and was not changed throughout the experiment.

2. The neutral density wedge (W_1) was moved to the left or right in front of the steady source and was used to raise or lower the intensity level when O was making a match.

3. The Grason-Stadler flicker-fusion apparatus was used to manipulate the intermittency rate and PCF and was controlled by the experimenter.

4. The size of the target was controlled by the experimenter changing the field stop in RS_2.

5. The four intensity levels used in the experiment were obtained by using no filter for 440 c/ft^2, .2 neutral density for 280 c/ft^2, .5 neutral density for 130 c/ft^2 and .8 neutral density for 70 c/ft^2.

Experimental Conditions

The variables manipulated in this experiment were rate of intermittency, pulse-to-cycle fraction (PCF), target intensity and target size.

1. Rates of intermittency employed were 20, 10 and 5 pps.

2. The PCFs employed were 0.9, 0.7, 0.5, 0.4, 0.3, 0.2, and 0.1.

3. The target intensity levels employed were 440 c/ft^2, 280 c/ft^2, 130 c/ft^2 and 70 c/ft^2.

4. The two target sizes employed subtended 3.5° and 1.75° of visual angle.

All of these variables were combined to form a total of 168 different conditions.

Observers

Two males, both graduate students in psychology served as observers. One of the observers (J.K.) had observed in another brightness discrimination experiment prior to this investigation for a minimum of 80 hours. The other observer (C.W.S.) had minimal experience in brightness discrimination experiments except for ten days of practice immediately before the experiment during which time he made over 1000 observations.

Procedure

Under all conditions used in this experiment the observer was required to manipulate the neutral density wedge in front of the steady source in order to make a match with the intermittent source. In any session, which usually lasted an average of 45 minutes, the observer made 5 ascending and 5 descending matches under 7 PCFs at each one of the three rates. The PCFs and rate were randomized in every session, but intensity and target size were held constant during the session. In every session the observer also made 5 ascending and 5 descending matches when both targets were steady before and after observing under intermittent conditions. Every condition was observed in four separate sessions so each observer made a total of 40 matches under each of the 168 conditions for a total of 6720 observations plus another 320 matches made when both targets were steady.

Measures

The neutral density wedge used to make the match was calibrated so that all values obtained could be converted to the percentage of transmission of energy required for a match. After 40 observations had been made under a particular condition a mean of the values was computed and this was used as the percentage of transmission required to make the two targets appear equally bright. The mean percentage of transmission required to make a match when both targets were steady is based on 320 observations. This value was multiplied by each PCF to obtain the expected percentages required for a match at each PCF. The obtained percentage of transmission required to make a match under the various conditions was then divided by the expected percentage to obtain a ratio of effectiveness.

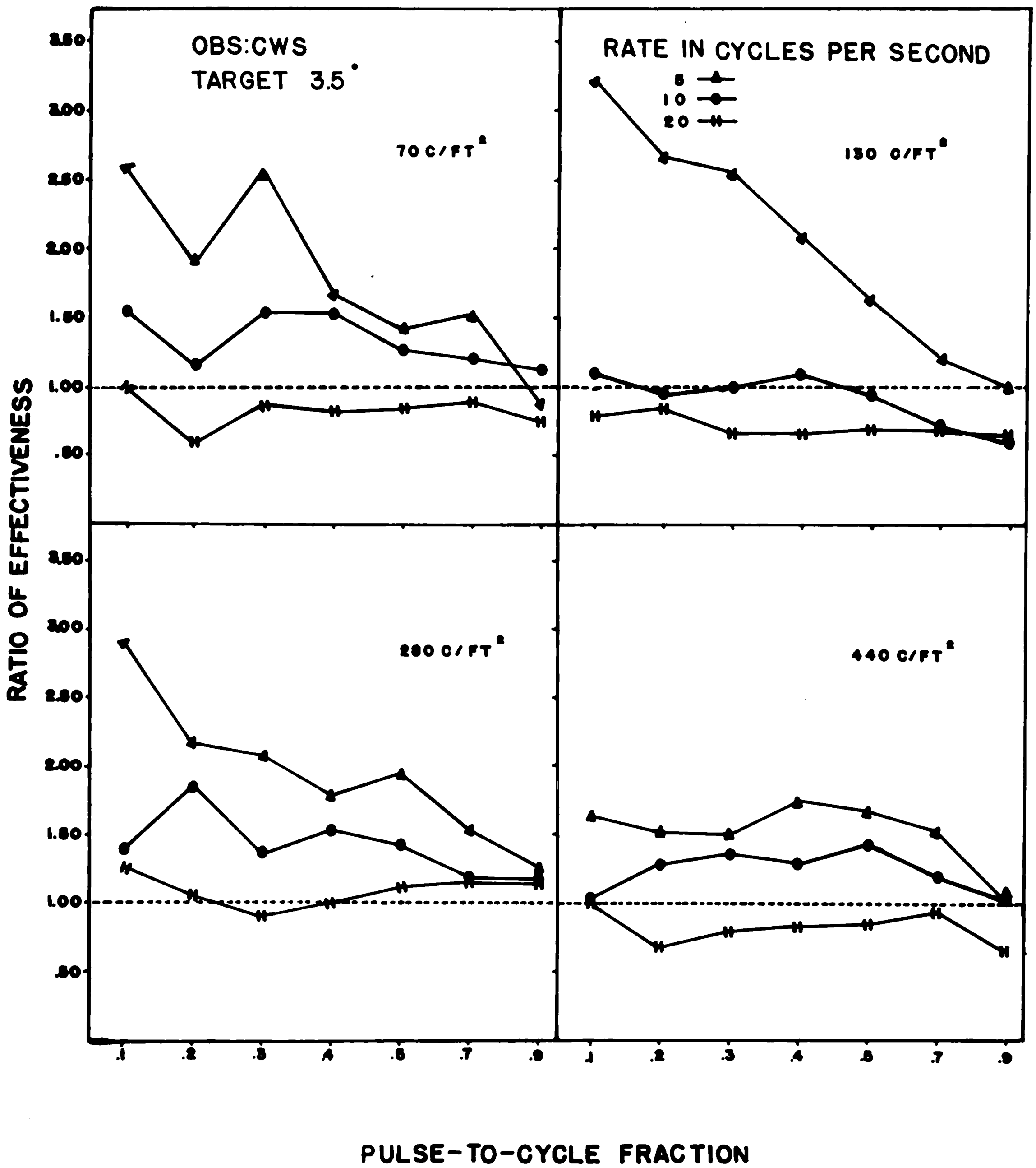
These data are presented graphically in the following section.

RESULTS

In Figures 2 and 3 the ratios of effectiveness (RE) are plotted to show the relationship of the intermittency rate of PCF at the 4 intensity levels and the 3.5° target for both observers. The reader is reminded that the RE is the quotient obtained by dividing the obtained percentage of transmission by the expected percentage. If the RE for a PCF of 0.1 is higher than the RE for 0.4 at the same rate this means that proportionally more energy was required for a match. It does not necessarily mean that the one looked brighter than the other. However, if the RE at 0.1 PCF is higher than the RE at 0.1 at a different rate it does indicate that one appeared brighter than the other.

Let us first consider the relationship of frequency to PCF under the different intensity levels. As is indicated in Figures 2 and 3 an intermittency of 5 pps is clearly the most effective rate under all intensity levels for both observers. The RE begins at or near the expected value at the 0.9 PCF and gradually increases as the PCF is decreased. One exception to this finding is at 440 c/ft^2 where the RE increased to a maximum at 0.4 and then decreased slightly for both observers. The most effective intensity at 5 pps is 130 c/ft^2. It is interesting to note that both subjects obtained their maximum RE at a 0.1 PCF at this same rate and intensity

Fig. 2. Ratios of effectiveness obtained by observer CWS with three rates and seven PCFs at four different intensity levels with the 3.5° target.



OBS:CWS
TARGET 3.5°
RATE IN CYCLES PER SECOND
5
10
20
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
RATIO OF EFFECTIVENESS
PULSE-TO-CYCLE FRACTION

Figure 2

Fig. 3. Ratios of effectiveness obtained by observer JK with three rates and seven PCFs at four different intensity levels with the 3.5° target.

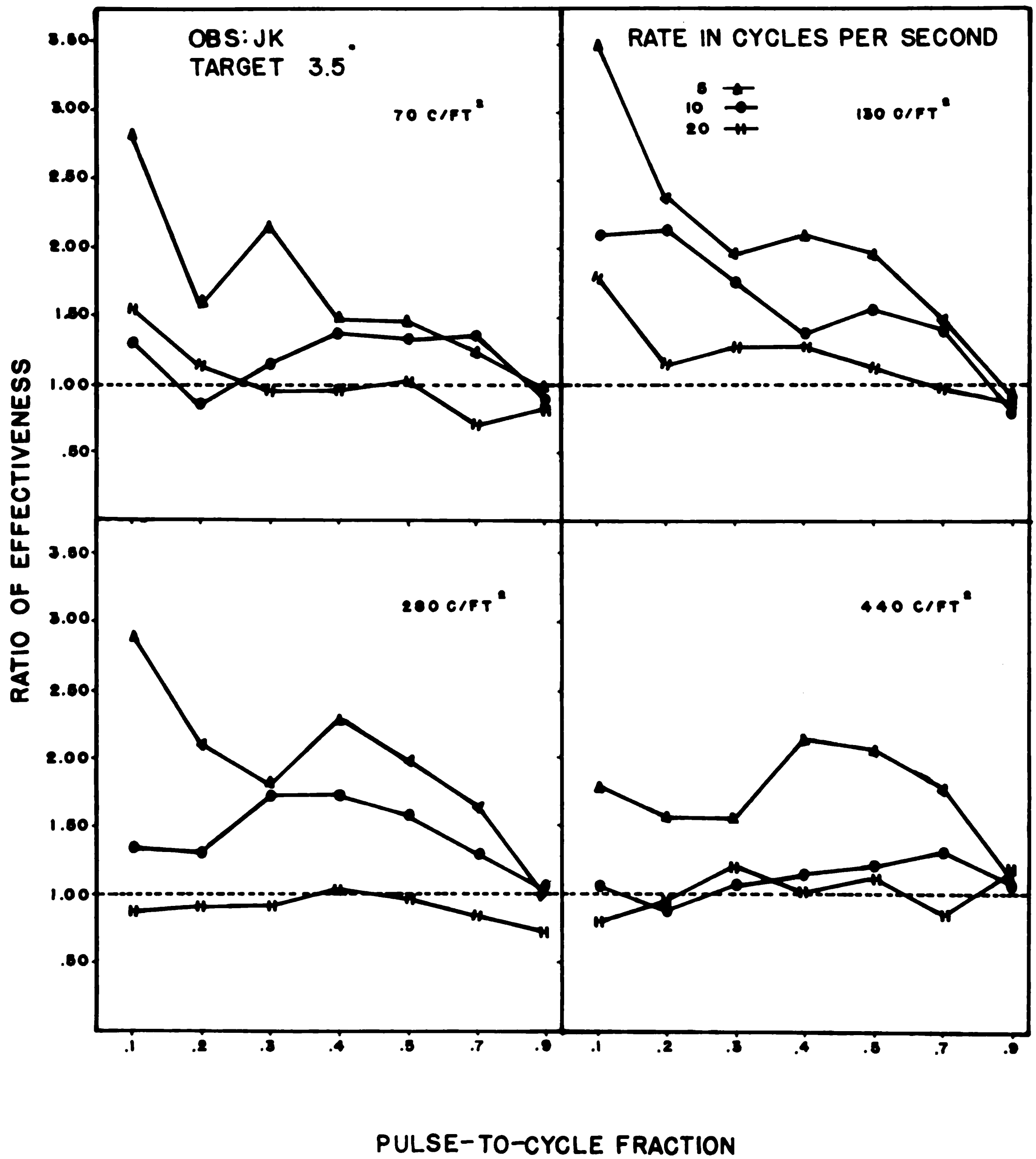

OBS: JK
TARGET 3.5°
70 C/FT²
RATE IN CYCLES PER SECOND
5
10
20
130 C/FT²
280 C/FT²
440 C/FT²
RATIO OF EFFECTIVENESS
3.50
3.00
2.50
2.00
1.50
1.00
.50
.1
.2
.3
.4
.5
.7
.9
PULSE-TO-CYCLE FRACTION

Figure 3

level. This is also the point where the time between pulses is maximal, 180 milliseconds.

There are certain rather striking similarities between the curves obtained by the two observers at 5 pps under each intensity level. At 70 c/ft^2 a peak RE is found at 0.3 and 0.1 PCF, and there is an unusual drop in RE at the 0.2 PCF. At the intensity levels of 70, 130 and 280 c/ft^2 the change in RE as PCF decreases tends to be linear with a maximum at 0.1 and a minimum at 0.9. At 440 c/ft^2 there is a shift in the peak RE to a PCF of 0.4 for both observers. The shifts in these curves are so regular for both observers that it is doubtful that they could be due to chance.

The next most effective rate is 10 pps. The maximum RE varies from one PCF to another as the intensity level is changed. For observer CWS the effectiveness dropped below the expected level at 130 c/ft^2 where 5 pps was actually found to be maximal. For the most part 10 pps was more effective for observer JK than for CWS except at 440 c/ft^2 where it dropped below the expected level and even below 20 pps for the three shortest PCFs.

The least effective rate is 20 pps. It is generally below or near the expected level under all intensity levels. The curves are relatively flat indicating that the PCF has very little effect at this intermittency.

In Figures 4 and 5 the ratios of effectiveness are plotted to show the relationship of intermittency and PCF for

Fig. 4. Ratios of effectiveness obtained by observer CWS with three rates and seven PCFs at four different intensity levels with the 1.75° target.

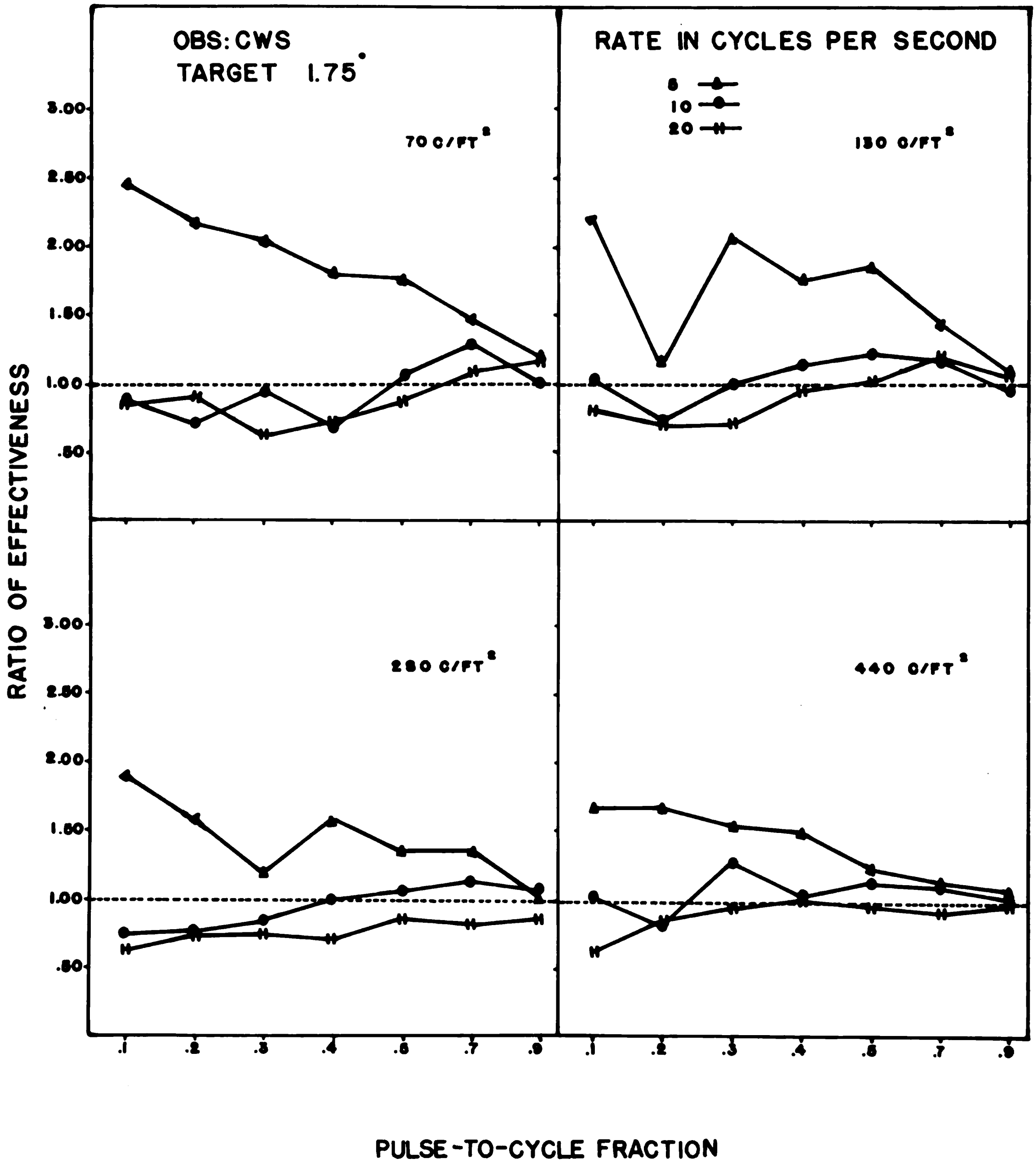

OBS: CWS
TARGET 1.75°
RATE IN CYCLES PER SECOND
5
10
20
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
3.00
2.50
2.00
1.50
1.00
.50
RATIO OF EFFECTIVENESS
.1
.2
.3
.4
.5
.7
.9
PULSE-TO-CYCLE FRACTION

Figure 4

Fig. 5. Ratios of effectiveness obtained by observer JK with three rates and seven PCFs at four different intensity levels with the 1.75° target.

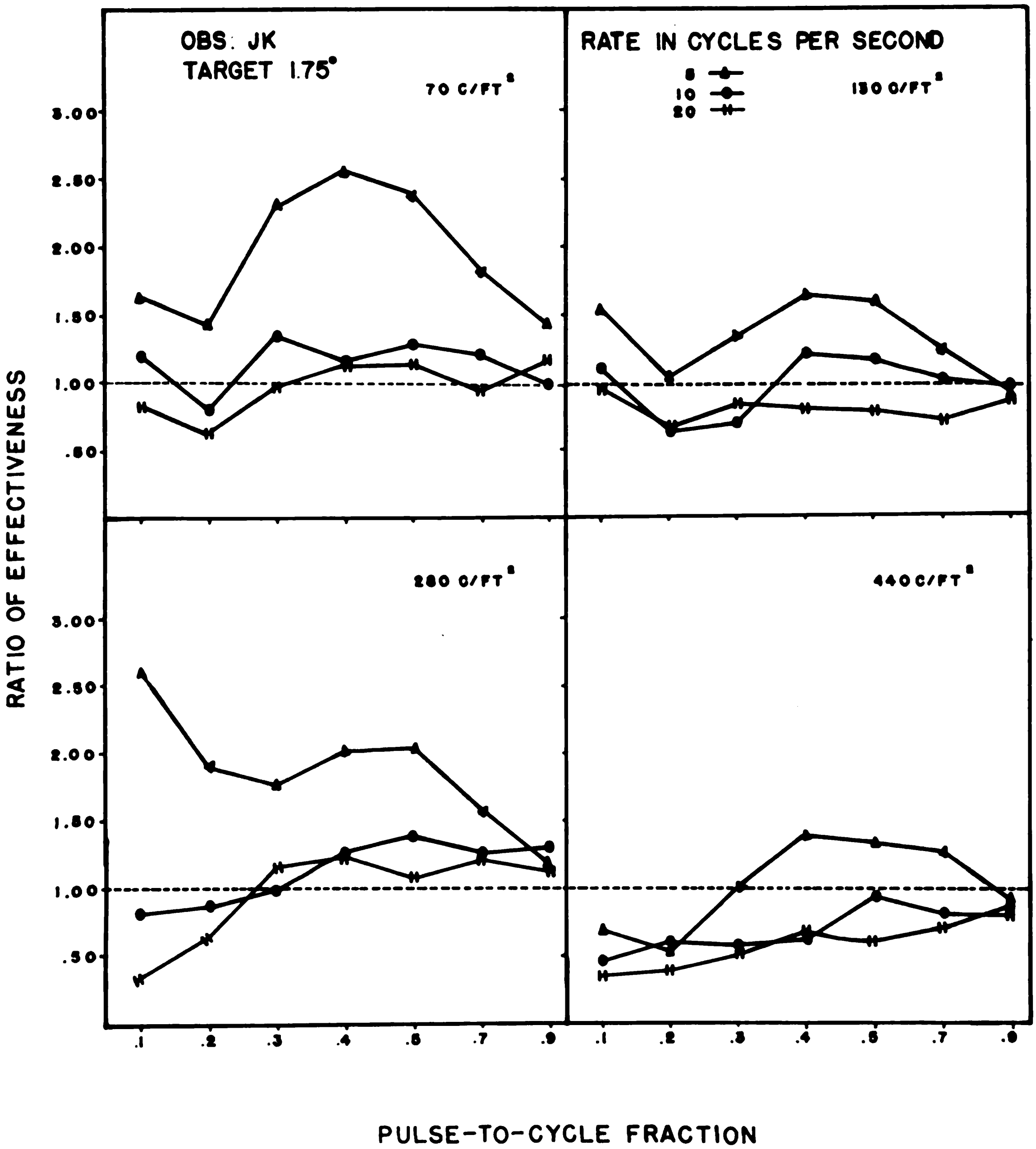

OBS: JK
TARGET 1.75°
RATE IN CYCLES PER SECOND
5
10
20
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
RATIO OF EFFECTIVENESS
3.00
2.50
2.00
1.50
1.00
.50
.1
.2
.3
.4
.5
.7
.9
PULSE-TO-CYCLE FRACTION

Figure 5

both observers at the four intensity levels with the 1.75° target. There are some rather gross changes in effectiveness which appear to be directly related to the change in target size. The intermittency rate of 5 pps is still more effective than the other rates, but it is not as far above the expected level as it was with the large target. The overall effectiveness at 130 c/ft^2 which was at its maximum with the large target is now second in effectiveness to that obtained with 70 c/ft^2. While the maximum effectiveness is still at 0.1 PCF for observer CWS the peak has shifted to 0.4 PCF for the other observer. One exception is at 280 c/ft^2 where the peak remained at 0.1. At 130 c/ft^2 the drop in the curve at 0.2 PCF is even more exaggerated with the small target. At 440 c/ft^2 the effectiveness for the PCFs of 0.2 and 0.1 are far below the expected value for observer JK.

In general, the change in RE for observer CWS tends to be linear with the maximum at 0.1 and the minimum at 0.9 PCF under all intensity levels. The curves for observer JK tend to take the form of an inverted "U" with the maximum at 0.4.

The relatively ordered relationship that existed between 10 and 20 pps with the large target tends to break down with the small target. The curves for both frequencies now cross frequently in an unsystematic fashion for both observers at all intensity levels. They tend to fall slightly below the expected level as the PCF is decreased. In general, the change in intensity level does not appear to produce any significant alteration in the RE level of the curves.

Figure 6 shows the relationship between rate and intensity for the two target sizes and both observers. The points on the curve were obtained by computing a mean RE for the seven PCFs at each intensity level under a particular rate. At 5 pps the mean RE obtained at 70, 120 and 280 c/ft^2 are very close for both observers. At 440 c/ft^2 the RE drops below that of 10 pps for observer CWS. At 10 pps the mean RE for both observers are again very close at 70, 280 and 440 c/ft^2, but the mean RE for observer CWS dropped below the expected level at 130 c/ft^2. The RE for both observers are near or below the expected level at 20 pps.

The peak effectiveness for both observers with the 1.75^o target is at 70 c/ft^2 and 5 pps in contrast to the 3.5^o target where it was at 130 c/ft^2. Observer JK shows a significant drop in RE at 130 and 440 c/ft^2 with the smaller target. The RE obtained by both observers at 10 and 20 pps tend to be below those obtained with the larger target.

In Figures 7, 8, 9, and 10 the range of effectiveness for different PCF's at the three experimental frequencies is shown for both observers, and the following trends are evident. The largest spread in effectiveness was obtained at 5 pps with the 3.5^o target. Under this same target size 10 pps yields the next largest spread and 20 pps the least.

Fig. 6. Mean ratios of effectiveness for the seven PCFs at each intensity level, frequency and target size for both observers.

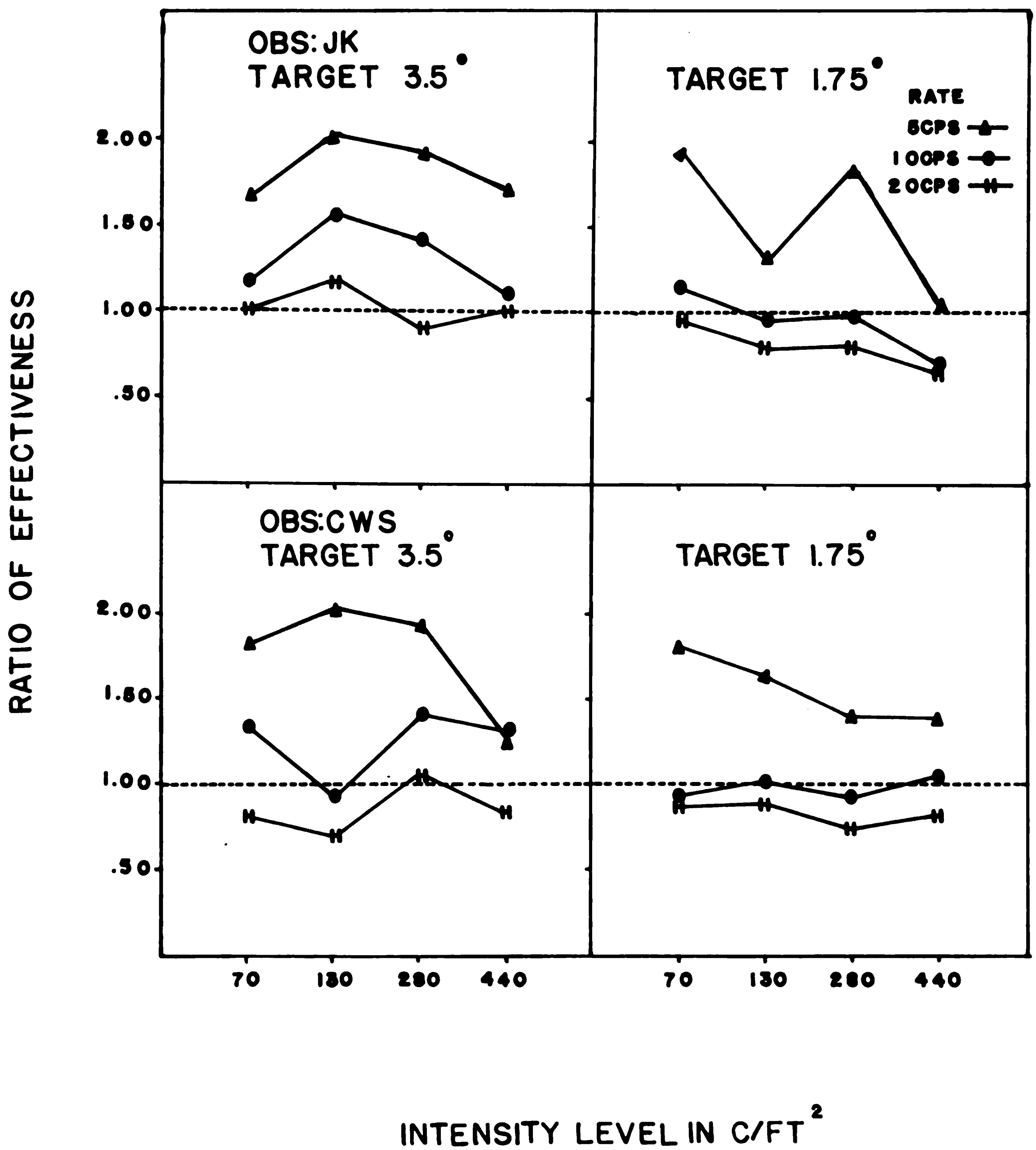
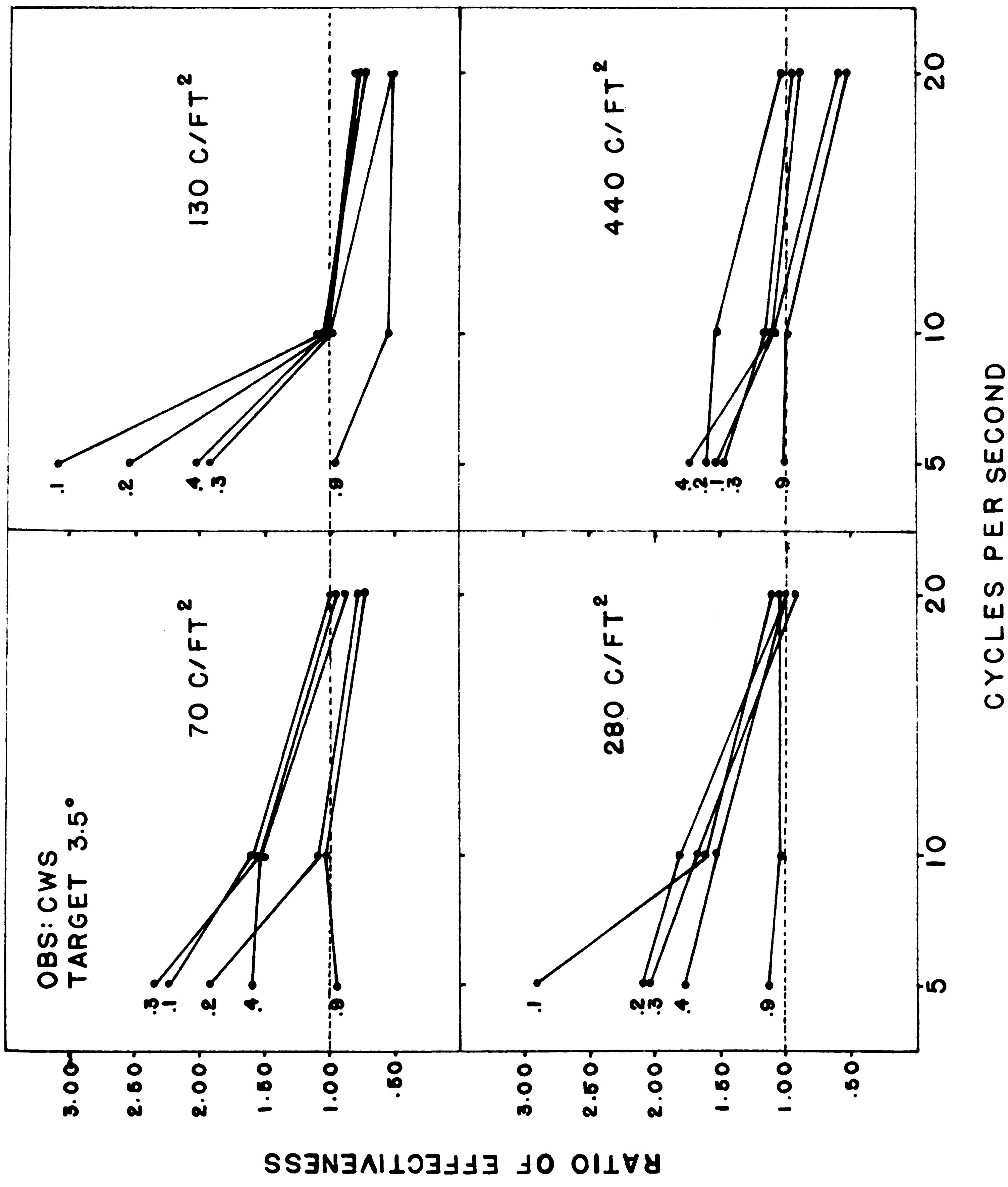

OBS: JK
TARGET 3.5°
TARGET 1.75°
RATE
5CPS
10CPS
20CPS
2.00
1.50
1.00
.50
OBS:CWS
TARGET 3.5°
TARGET 1.75°
2.00
1.50
1.00
.50
RATIO OF EFFECTIVENESS
70
130
280
440
70
130
280
440
INTENSITY LEVEL IN C/FT²

Figure 6

Fig. 7. Range of effectiveness obtained by observer CWS with five PCFs at each frequency, intensity level and 3.5° target.

Figure 7



OBS: CWS
TARGET 3.5°
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
CYCLES PER SECOND
RATIO OF EFFECTIVENESS
3.00
2.50
2.00
1.50
1.00
.50
5
10
20
.1
.2
.3
.4
.9

Fig. 8. Range of effectiveness obtained by observer CWS with five PCFs at each frequency, intensity level and 1.75° target.

Figure 8

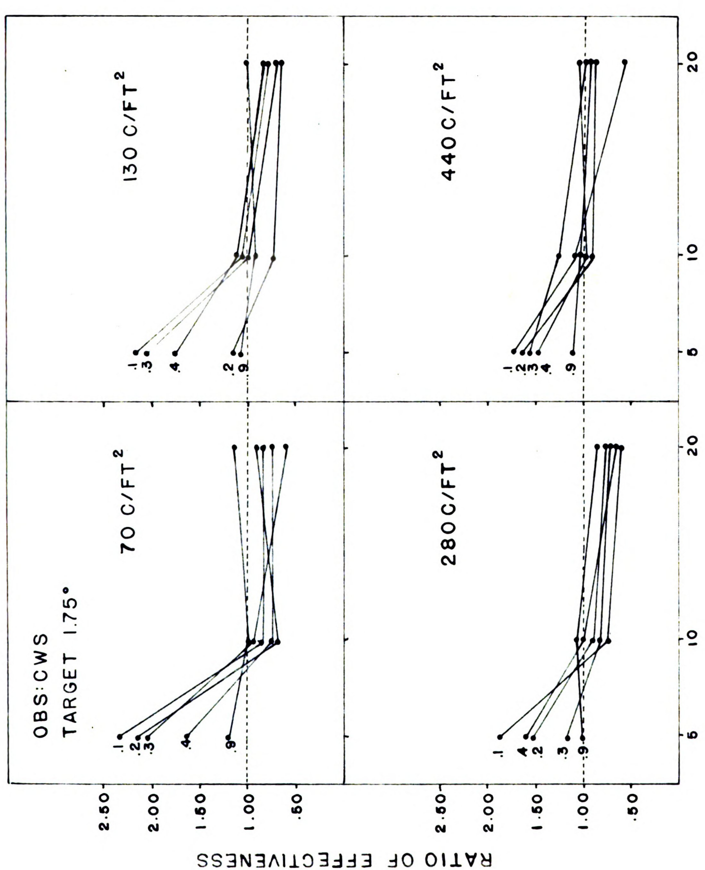

OBS: CWS
TARGET 1.75°
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
RATIO OF EFFECTIVENESS
CYCLES PER SECOND
2.50
2.00
1.50
1.00
.50
5
10
20

Fig. 9. Range of effectiveness obtained by observer JK with five PCFs at each frequency, intensity level and 3.5° target.

Figure 9

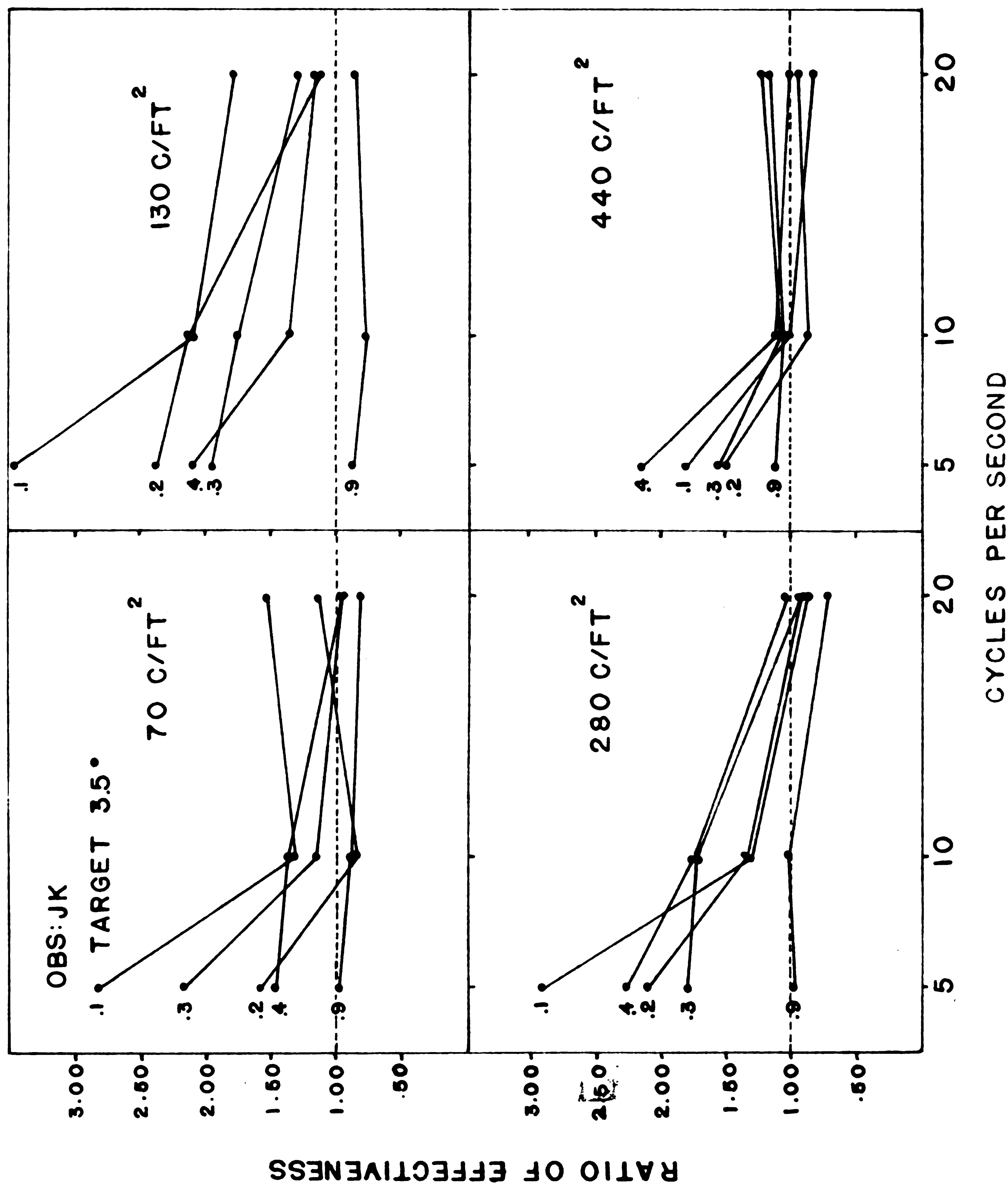
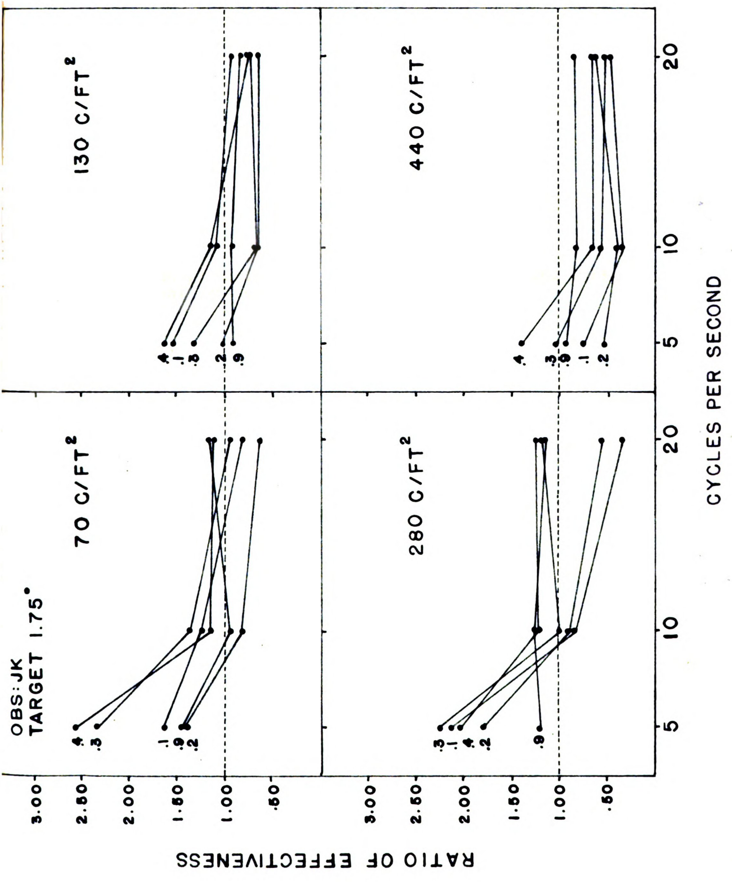

OBS: JK
TARGET 3.5°
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
RATIO OF EFFECTIVENESS
CYCLES PER SECOND
3.00
2.50
2.00
1.50
1.00
.50
5
10
20
.1
.2
.3
.4
.9

Fig. 10. Range of effectiveness obtained by observer JK with five PCFs at each frequency, intensity level and 1.75° target.

Figure 10



OBS: JK
TARGET 1.75°
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
CYCLES PER SECOND
RATIO OF EFFECTIVENESS

At the highest intensity level the range of effectiveness between the largest and smallest PCF's tends to be equivalent at all three frequencies. With the 1.75° target the range of effectiveness is decreased for 5 pps, but it is still larger than the range obtained at 10 and 20 pps which now tends to be equivalent. The range of effectiveness at the highest intensity level tends, as with the large target, to be equivalent at all three rates.

Also evident in these figures is a frequent crossing of curves as we move from one rate to the other which indicates that the order of effectiveness of PCF varies with rate. This is most evident with the smaller target. The order of effectiveness of the PCF's appears to be more systematic at 5 pps than it is at 10 or 20 pps. The peak PCF is at 0.1 with a frequency of 5 pps under most conditions, and the peak PCF at the other rates tends to vary between 0.1 and 0.3 as the intensity level or target size are manipulated.

In Figures 11, 12, and 13 the relationship between target size and PCF's of 0.9, 0.4 and 0.1 is shown for both observers at the three experimental rates and four intensity levels. There are some rather clear trends which emerge as the PCF is decreased. At a PCF of 0.9 a shift in target size has a slight and unsystematic effect. At a PCF of 0.4 a trend begins to develop in which a decrease in target size tends to produce a decrease in effectiveness at most intensity

Fig. 11. Levels of effectiveness obtained at each target size with three PCFs and four intensity levels at 5 pps by both observers.

Figure 11

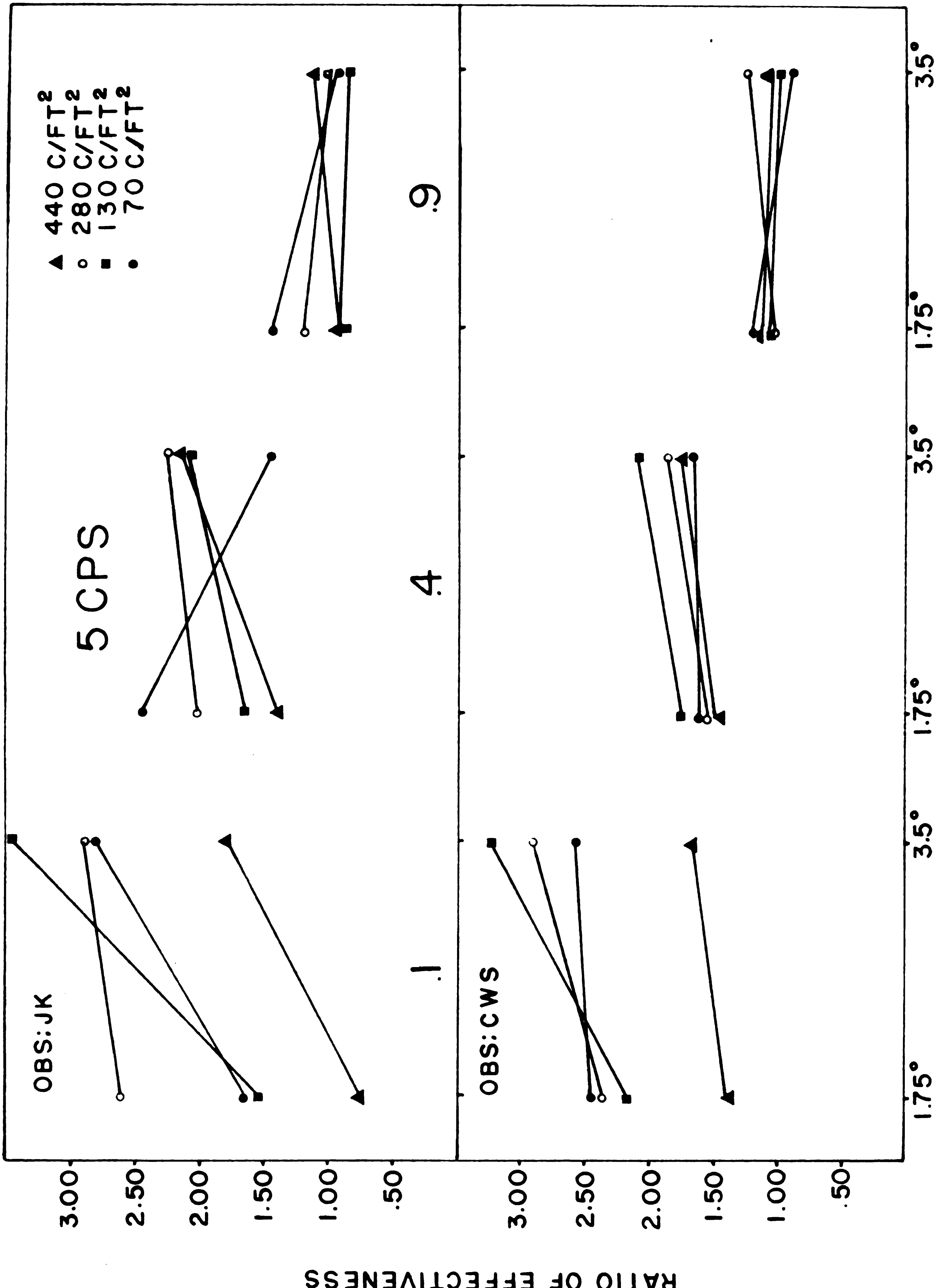

5 CPS
OBS:JK
OBS:CWS
440 C/FT²
280 C/FT²
130 C/FT²
70 C/FT²
.1
4.
9
3.00
2.50
2.00
1.50
1.00
.50
1.75°
3.5°
TARGET SIZE
RATIO OF EFFECTIVENESS

Fig. 12. Levels of effectiveness obtained at each target size with three PCFs and four intensity levels at 10 pps by obth observers.

Figure 12

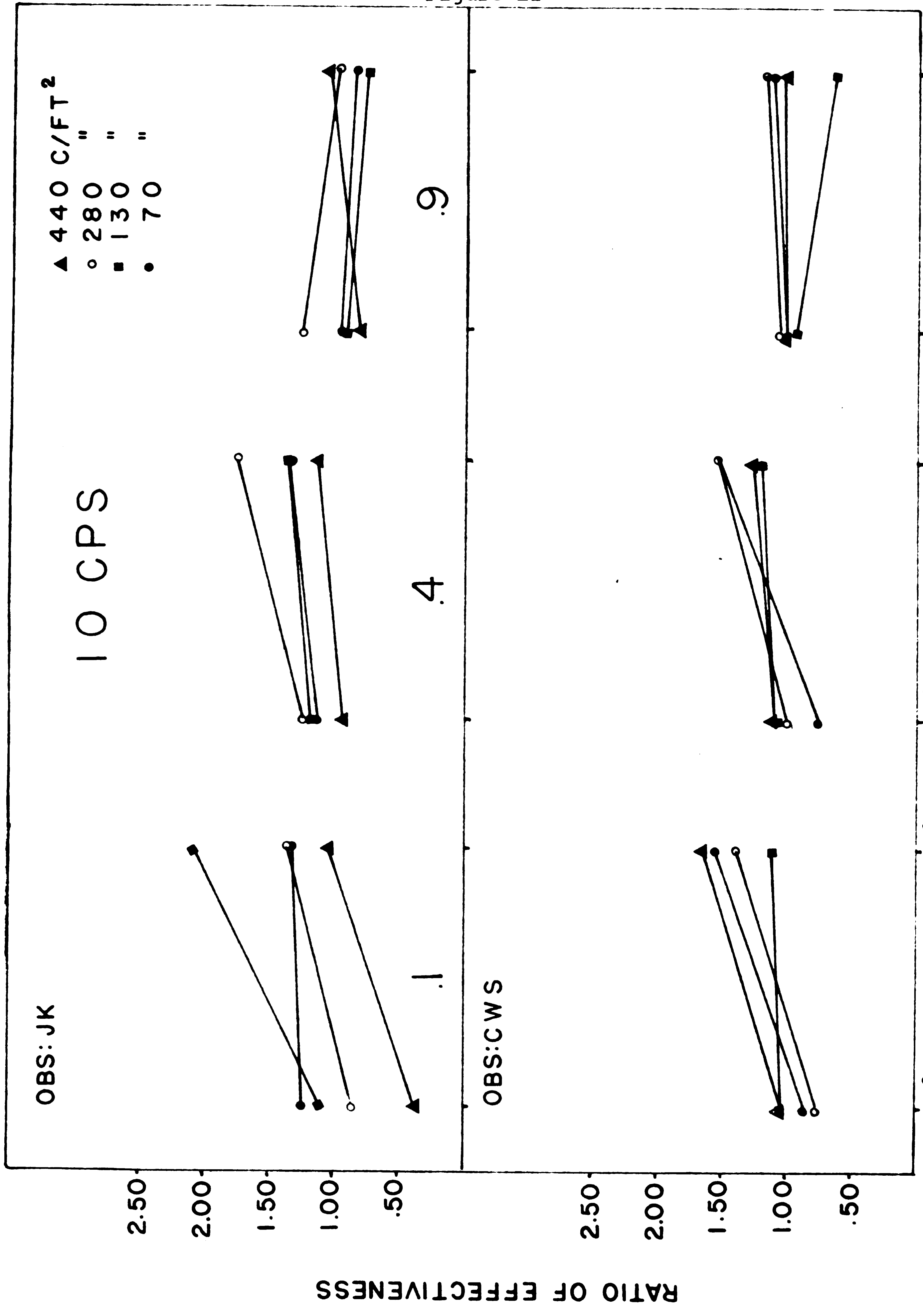
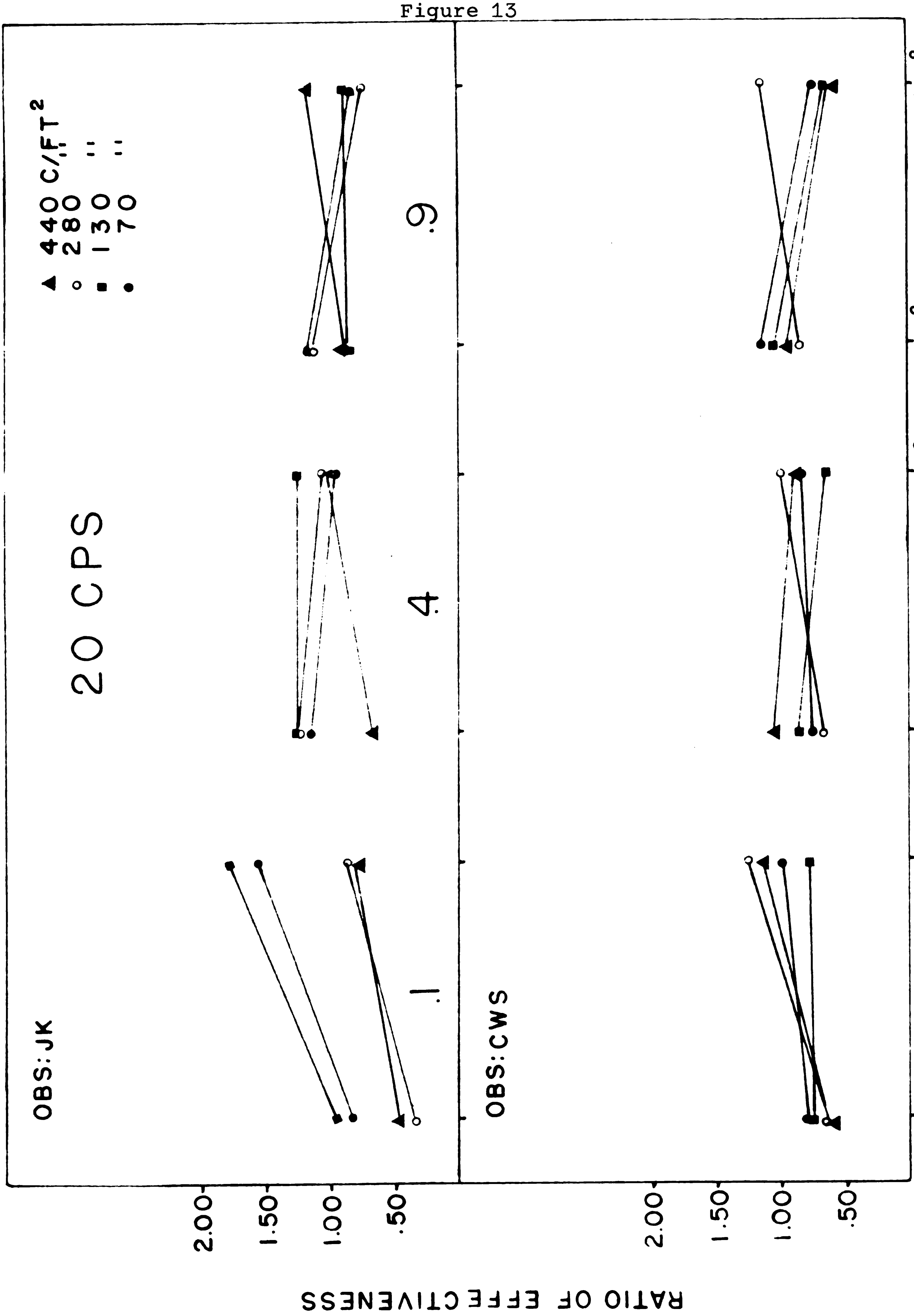

10 CPS
OBS: JK
OBS: CWS
▲ 440 C/FT²
○ 280 " "
■ 130 " "
● 70 " "
.1
4
9
1.75°
3.5°
2.50
2.00
1.50
1.00
.50
RATIO OF EFFECTIVENESS

Fig. 13. Levels of effectiveness obtained at each target size with three PCFs and four intensity levels at 20 pps by both observers.

Figure 13


20 CPS
OBS: JK
OBS: CWS
1
4
9
440 C/FT²
280 "
130 "
70 "
2.00
1.50
1.00
.50
1.75°
3.5°
RATIO OF EFFECTIVENESS

levels. At a PCF of 0.1 a decrease in target size results in a large decrease in effectiveness at practically all intensity levels for both observers. The above relationship held under all frequencies.

Figures 14, 15, 16, and 17 contain the standard deviations (SD) for both subjects with 3 PCF's and each experimental rate. There is a definite trend present in which the SD's become larger as the pulse rate is decreased, and the SD's for the 0.1 PCF were the largest in every instance but one. This finding is rather interesting since it was also at this point that the highest ratio of effectiveness was obtained. In general, the SD's for observer CWS are larger, particularly with the 3.5° target, than those of observer JK. This is not unusual since observer JK had 80 hours of experience before entering this investigation, and observer CWS was essentially naive.

The difficulty in making brightness matches with very short pulses is well known. However, the SD's for this condition were so high at most intensity levels that a closer analysis was made of the raw data for this condition. It was found that the percentages of transmission required for a match tended to cluster around two extreme points. Furthermore, if the high percentage cluster was removed the remaining cluster yielded ratios of effectiveness below the expected level. This suggested that the observer may be shifting his criterion under these difficult observational conditions.

Fig. 14. Standard deviations for observer CWS at three PCFs and each frequency under the four intensity levels and 3.5° target.

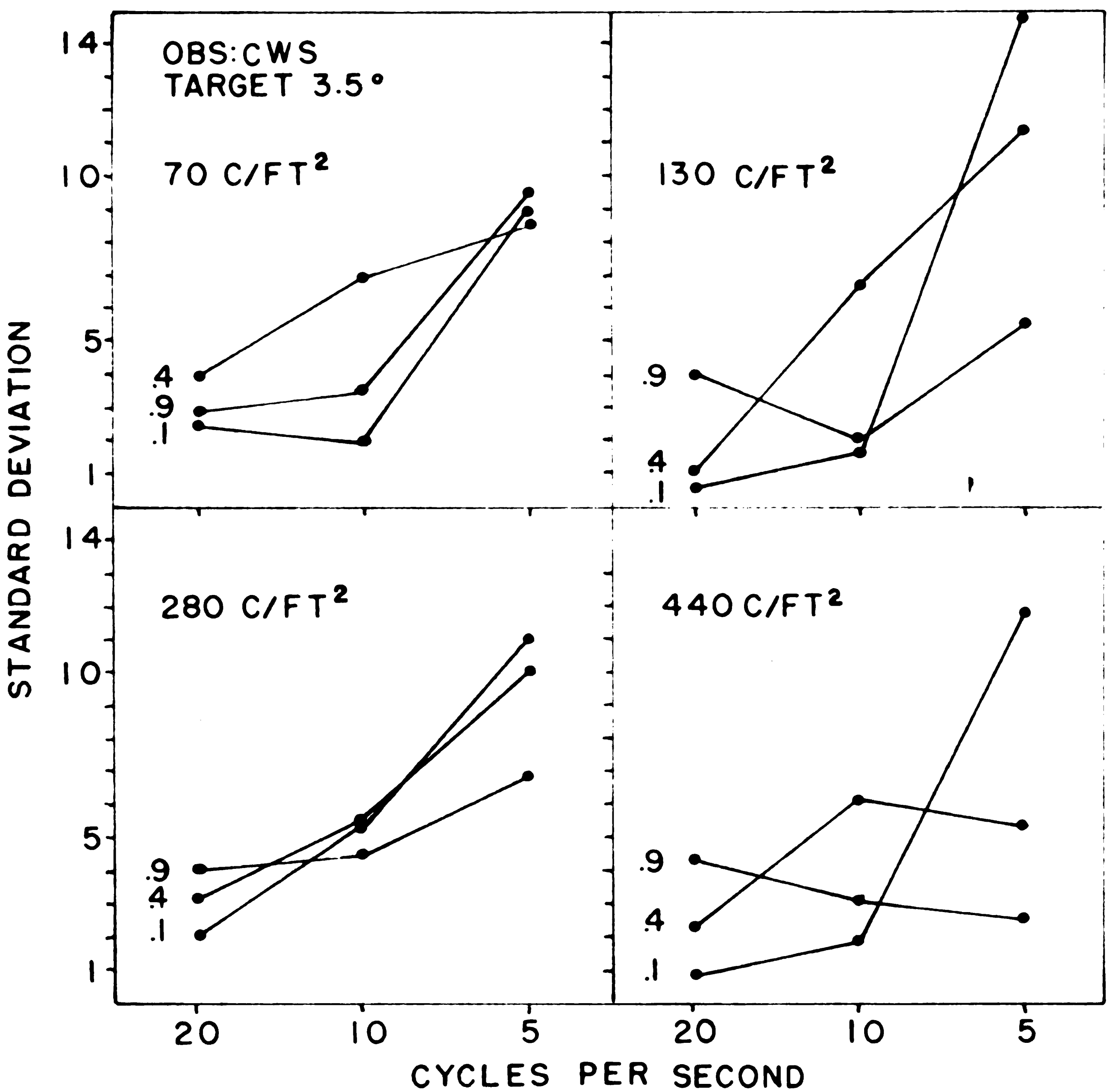
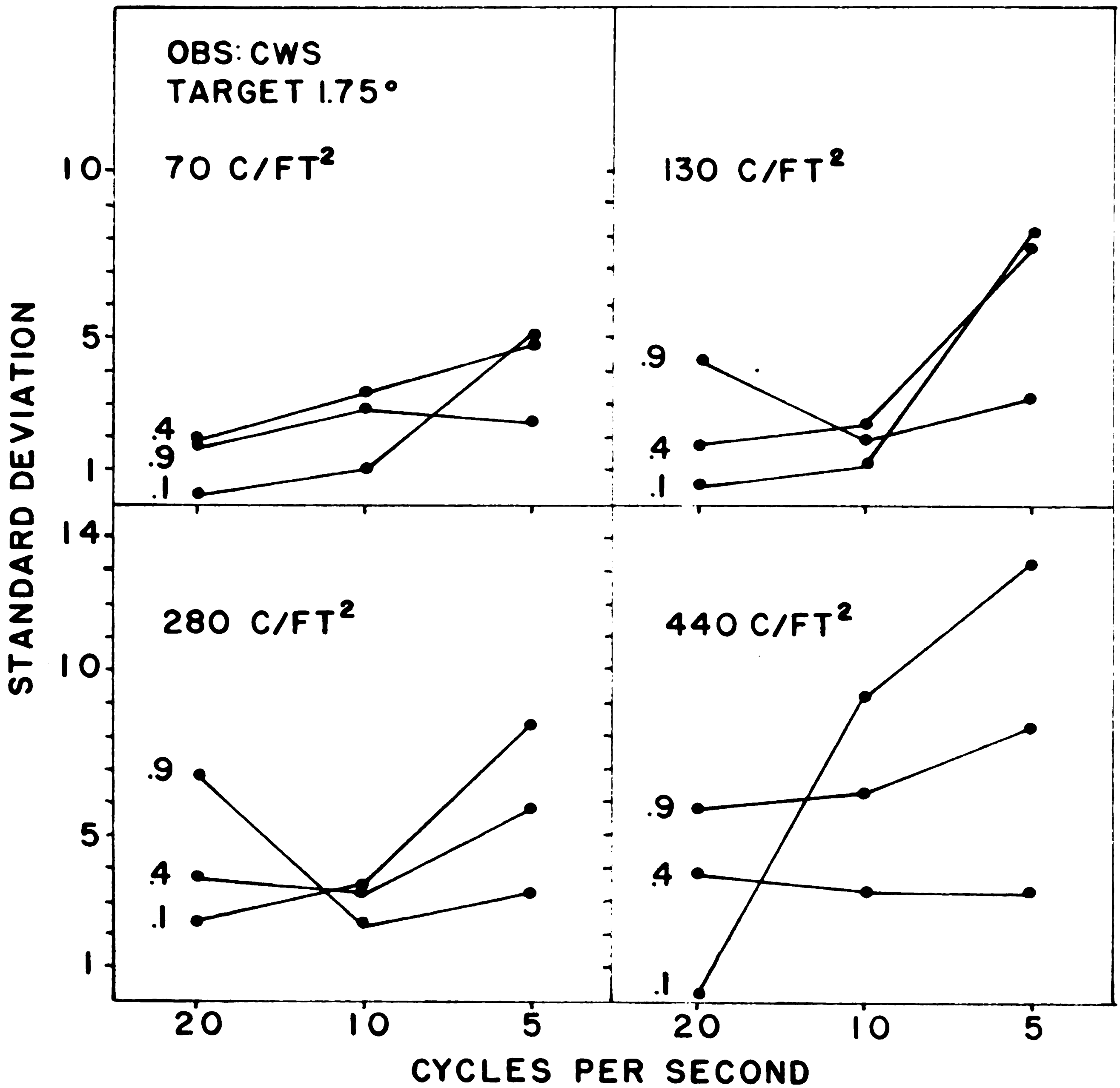

OBS: CWS
TARGET 3.5°
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
STANDARD DEVIATION
CYCLES PER SECOND
14
10
5
1
.4
.9
.1
20
10
5

Figure 14

Fig. 15. Standard deviations for observer CWS at three PCFs and each frequency under the four intensity levels with the 1.75° target.



OBS: CWS
TARGET 1.75°
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
STANDARD DEVIATION
CYCLES PER SECOND
10
5
1
14
10
5
1
20
10
5
20
10
5
.4
.9
.1
.9
.4
.1
.9
.4
.1
.9
.4
.1

Figure 15

Fig. 16. Standard deviations for observer JK at three PCFs and each frequency under the four intensity levels with the 3.5° target.

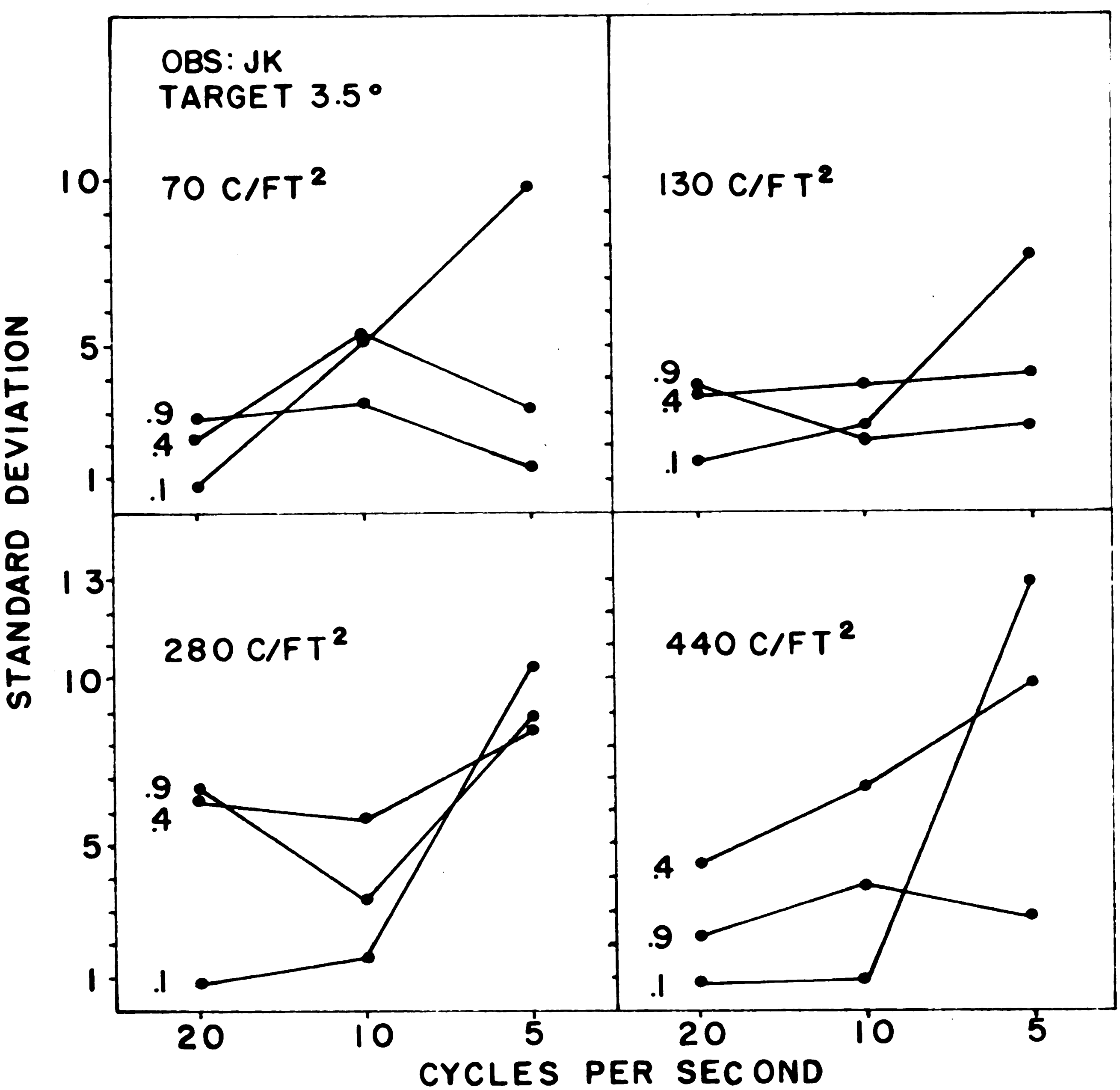

OBS: JK
TARGET 3.5°
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
STANDARD DEVIATION
CYCLES PER SECOND
10
5
1
13
10
5
1
.9
.4
.1
20
10
5
20
10
5

Figure 16

Fig. 17. Standard deviations for observer JK at three PCFs and each frequency under the four intensity levels with the 1.75° target.

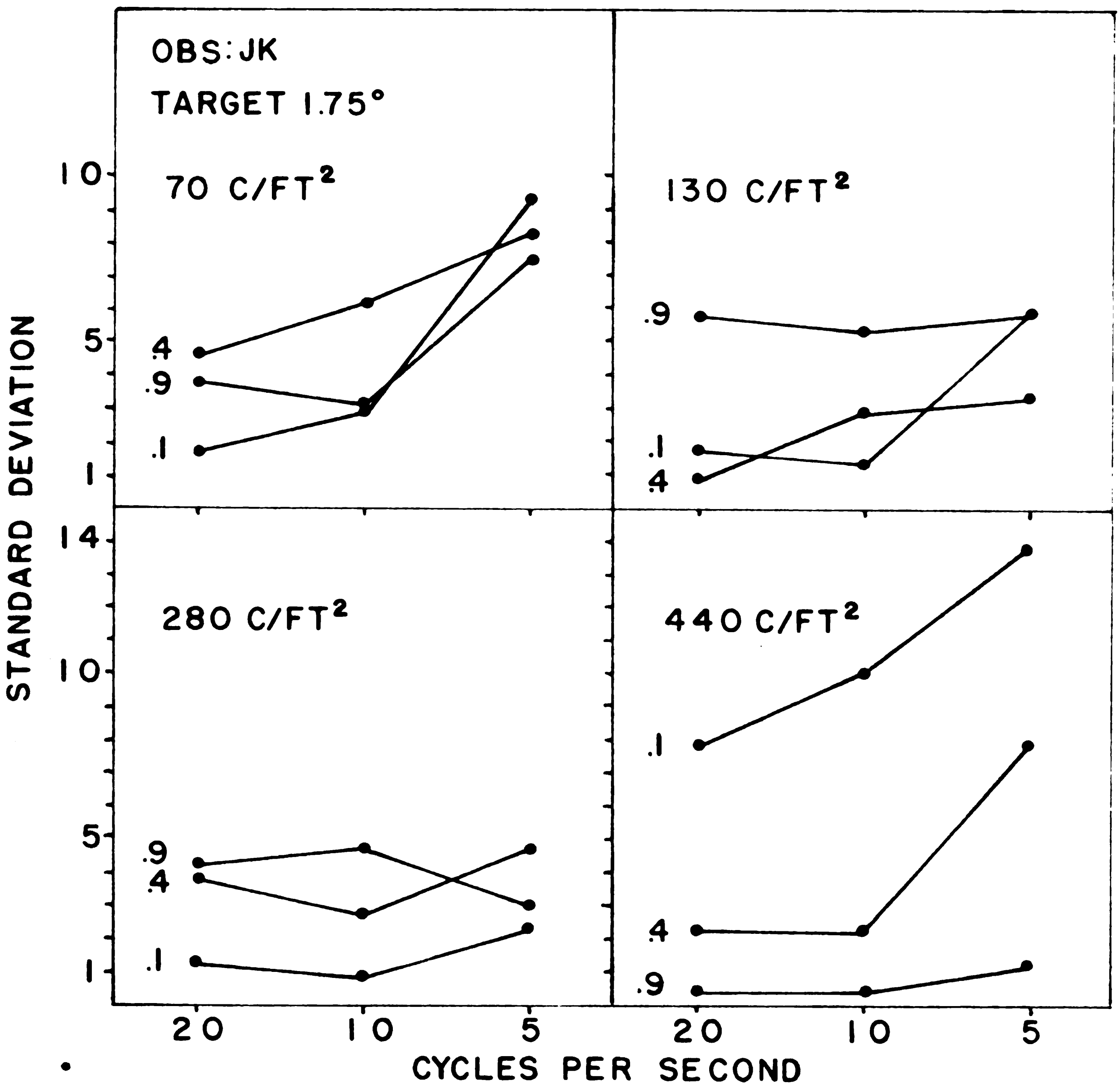

OBS: JK
TARGET 1.75°
70 C/FT²
130 C/FT²
280 C/FT²
440 C/FT²
STANDARD DEVIATION
CYCLES PER SECOND
1
5
10
14
20
5
.1
.4
.9

Figure 17

This finding led to a further investigation in which a 20 millisecond pulse was presented at 130 c/ft^2, 3.5° and at frequencies of 20, 10, 6, 5, 4, 3, 2 and 1 pps. The data were handled in the usual fashion and are presented graphically in Figure 18. In general, the RE for both observers increases as the rate decreases. The RE tends to level off somewhat at 6, 5, 4 and 3 pps, and there is a rather large increase with 2 and 1 pps. In Figure 19 the SD's for each condition are presented. The SD tends to reach a maximum at 5 pps and then drop off for both observers. As with the previous data the SD's for CWS are higher than those of JK.

There was a tendency for the percentage of transmission to cluster at 6, 5, 4 and 3 pps for observer JK and at 6, 5 and 4 pps for CWS. Even though the SD's are large at 2 and 1 pps for both observers, there was no strong tendency toward the bimodal clustering mentioned previously.

The distribution of ratios of effectiveness are shown in Figure 20. Each point is an RE based on 10 observations in each session. The bimodality in the distribution is illustrated most strongly at 5 pps.

These findings suggest that the observer may shift his criterion more than once as the frequency is decreased, and the phenomenal change from flicker to a series of flashes occurs.

Fig. 18. Ratios of effectiveness with a 20 millisecond pulse at certain frequencies between 20 and 1 pps, 130 c/ft^2 and 3.5° target size for both observers.

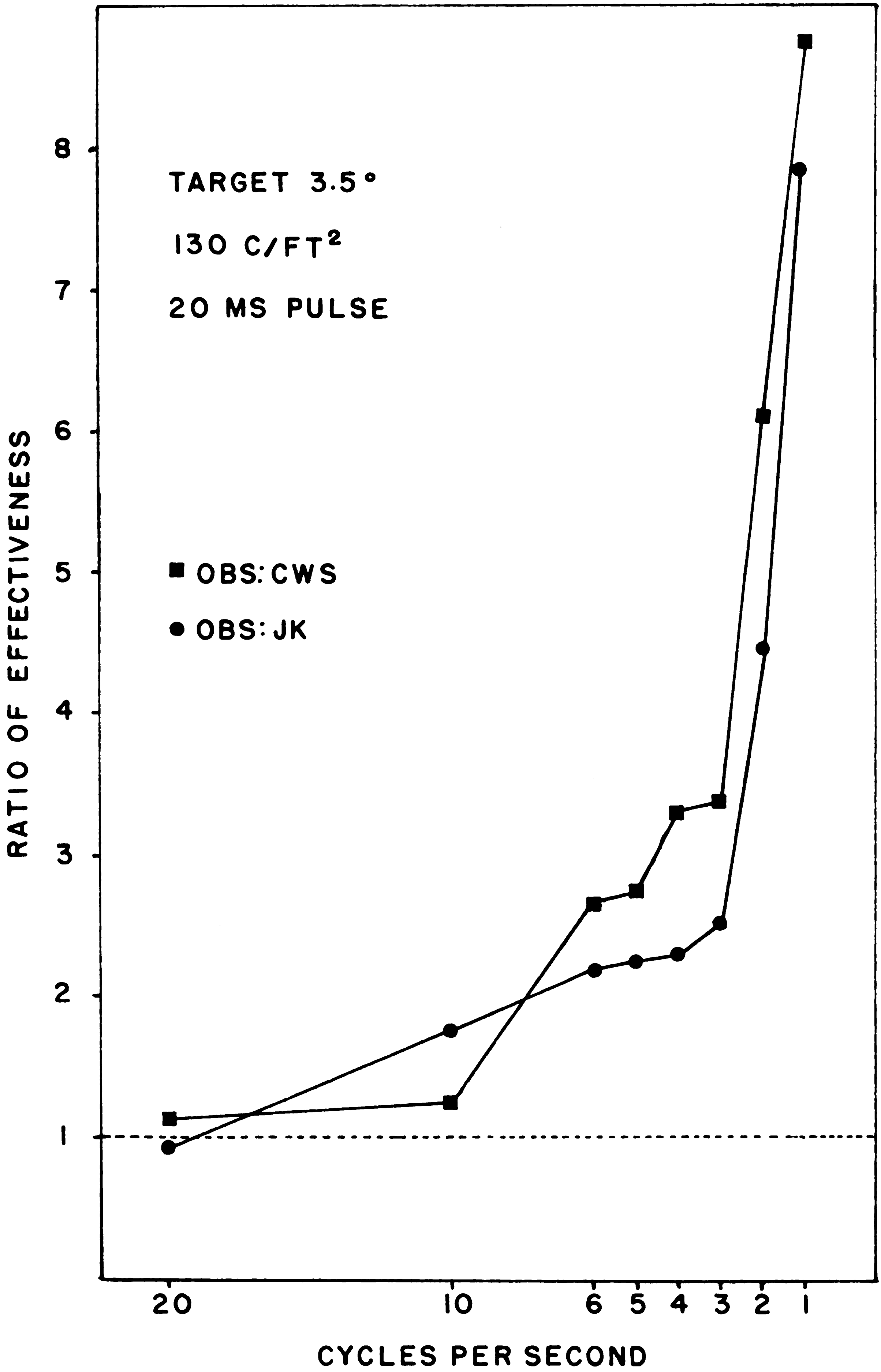
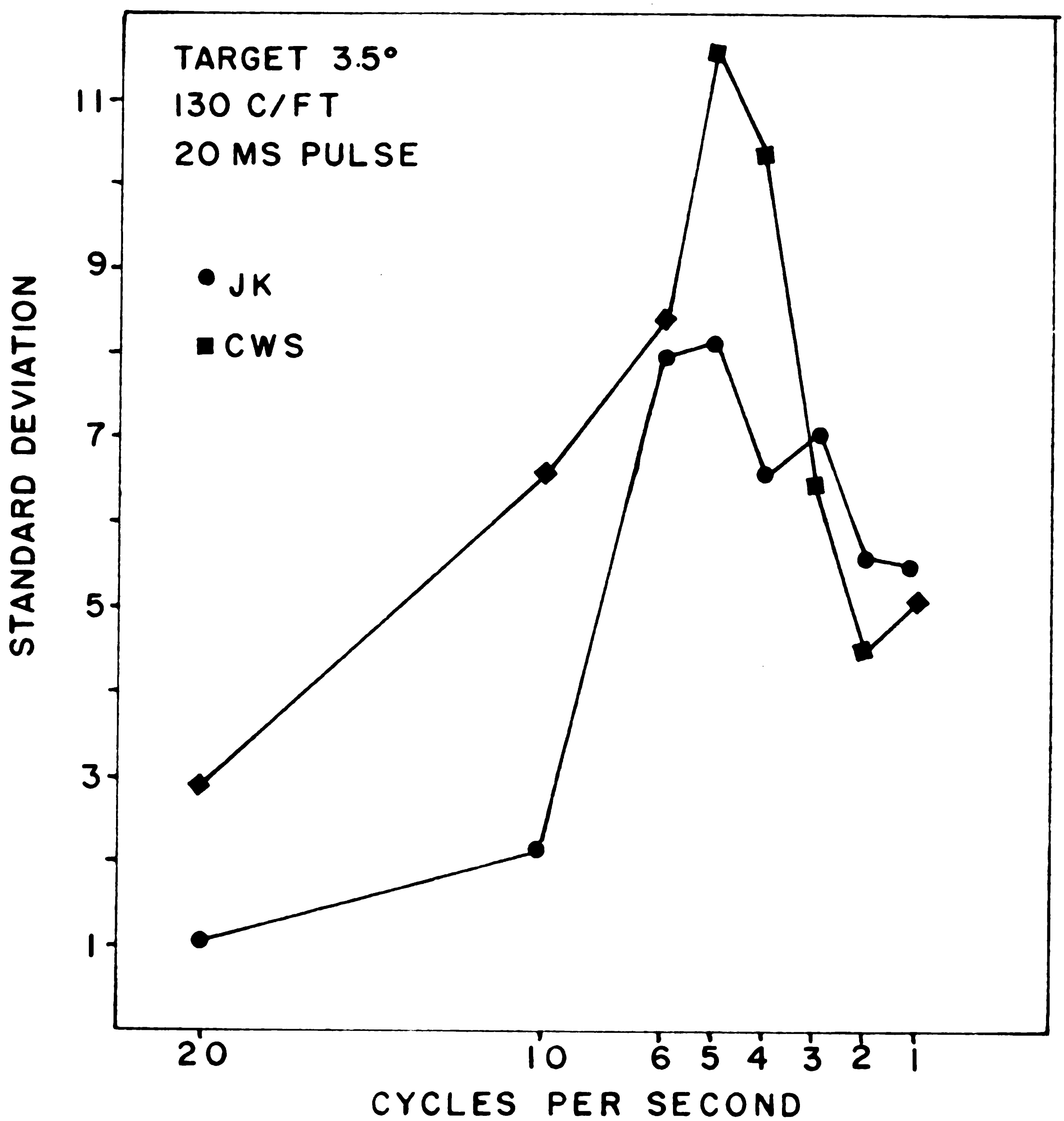

TARGET 3.5°
130 C/FT²
20 MS PULSE
OBS: CWS
OBS: JK
RATIO OF EFFECTIVENESS
1
2
3
4
5
6
7
8
20
10
6
5
4
3
2
1
CYCLES PER SECOND

Figure 18

Fig. 19. Standard deviations for both observers related to those conditions in Figure 18.



TARGET 3.5°
130 C/FT
20 MS PULSE
JK
CWS
STANDARD DEVIATION
11
9
7
5
3
1
20
10
6
5
4
3
2
1
CYCLES PER SECOND

Figure 19

Fig. 20. Distribution of ratios of effectiveness obtained under the conditions in Figure 18.

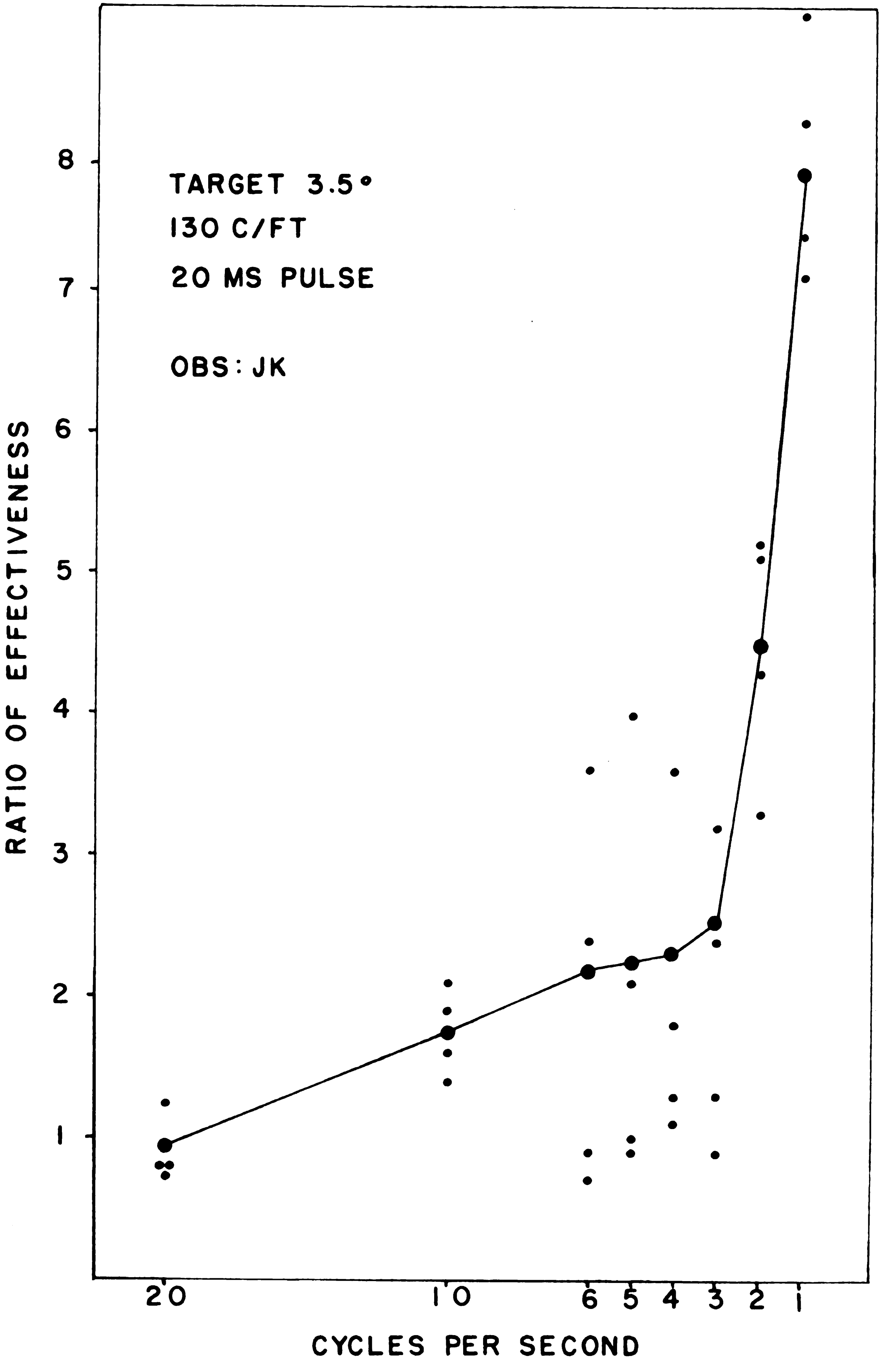

TARGET 3.5°
130 C/FT
20 MS PULSE
OBS: JK
RATIO OF EFFECTIVENESS
1
2
3
4
5
6
7
8
20
10
6
5
4
3
2
1
CYCLES PER SECOND

Figure 20

Summary of the Results

1. The smaller target tended to reduce effectiveness to a greater degree for the shorter PCF's than the longer ones.

2. With the large target, the RE at 5 pps was far above the expected level for the shorter PCFs except at 440 c/ft^2.

3. With the small target the RE at 5 pps was maximal at 0.1 PCF for one observer and at 0.4 for the other observer.

4. With the large target the RE at 5 pps tends to change in a linear fashion for both observers. As PCF decreased the RE increased. There are occasional unexplainable drops in the RE, particularly at the 0.2 PCF.

5. With the large target 10 pps was found to be the next most effective rate and 20 pps the least effective rate under all intensity levels.

6. With the small target the effectiveness at 10 and 20 pps was greatly reduced and tended to fall below the expected level as the PCF decreased.

7. The RE curves for the 5 pps rate suggest that although this rate is more effective than the others, it is affected more by changes in intensity, target size and PCF.

8. The RE at a rate of 10 pps was altered by changes in PCF, but changes in intensity and target size appeared to produce more extensive alterations.

9. The effectiveness at 20 pps changed very little as PCF was altered with the large target. However, with the smaller target alterations in PCF seemed to have a more systematic effect, i.e., RE decreased as PCF became smaller.

10. The highest RE obtained by both observers occurred at 5 pps, PCF of 0.1 and intensity level at 130 c/ft^2 with the 3.5° target. Under this condition the null period was maximal, 180 milliseconds.

11. In general, those conditions which produced maximal effectiveness were characterized by large standard deviations.

12. Decreasing frequency of stimulation down to 1 pps results in a continuing rise in the ratio of effectiveness with some leveling off between 6 and 3 pps.

13. Decreasing frequency from 20 to 5 pps produces a progressive increase in SD, but decreases in frequency below that point yield smaller SD's.

14. These results suggest that the observer may be shifting his criterion at frequencies below 10 pps.

DISCUSSION

It was suggested earlier that the varied results which have been obtained by previous investigators utilizing conditions of intermittent stimulation may be explained on the basis of an interrelationship among the variables and that this variable relationship was orderly and explainable. The results of the present investigation support this assumption, and certain relationships have been revealed which were previously not known.

The results of this investigation also suggest that as the frequency of stimulation is decreased below 10 pps a new phenomenon may emerge, and the observer is no longer able to maintain the criterion used to make brightness matches on the same basis as at higher frequencies.

First, let us consider the relationship found to exist among the variables employed in this investigation. It is evident from the results that manipulation of the time-based variables, namely frequency and PCF, will have a greater influence on the effectiveness than manipulation of the time static variables, such as target size or intensity. However, the effectiveness levels obtained with those combinations of frequency and PCF which produce a maximum will be affected more by alterations of the other variables in the field than the effectiveness levels obtained with those combinations of frequency and PCF which produce levels near or below that expected. For example, 5 pps in combination with a PCF of 0.1 produced maximal effectiveness at 130 c/ft^2 and 3.5° target size. Increasing intensity to 440 c/ft^2 or decreasing target size greatly reduced the effectiveness level. In contrast to this is the level obtained at 20 pps which is affected very little by manipulations of target size, intensity or PCF.

Certain rather interesting relationships have been found to exist between PCF and each of the other variables. The effectiveness of the large PCF's which always yield ratios near the expected level is not altered in any systematic fashion by manipulation of the other variables. However, as the PCF is decreased certain systematic patterns emerge.

A shift in target size from 3.5° to 1.75° has no systematic effect on ratio of effectiveness with the large PCF, but as the PCF is gradually reduced a decrease in target size results in a decrease in effectiveness which is most pronounced at 0.1. This relationship holds under all frequencies, and the extent of the decrease will depend on the magnitude of the ratio obtained with the larger target. For example, at 440 c/ft^2 the effectiveness is already reduced by the intensity, so although there is a decrement associated with the decreased target size it will not appear as large as it would at some other intensity level.

The relationship of intensity and PCF is less clear. Large ratios of effectiveness obtained with smaller PCF's are affected by changes in intensity just as they are by target size, and the effectiveness of the large ones is hardly influenced at all. In general, it appears that the effect which intensity alterations will have on effectiveness levels with particular PCF's depends on the frequency and target size. At 5 pps and 3.5° target the three lower intensity levels were almost equivalent in effectiveness, but the highest intensity reduces effectiveness considerably. At 10 pps the highest intensity reduced the effectiveness to the expected level for one observer and not the other. At 20 pps a shift in intensity has little or no influence on effectiveness, regardless of PCF or target size.

In general, the following conclusions may be drawn from the findings of this investigation.

1. Effectiveness will increase as PCF is decreased at those frequencies which are most effective.

2. At those frequencies which are maximally effective and the smaller the PCF the greater will be the influence of manipulations of intensity or target size on effectiveness.

3. The effectiveness of the smaller PCF's will be reduced as target size is decreased.

4. The effectiveness levels obtained with the higher frequencies will be close to the expected level and will be influenced very little by manipulations of PCF, intensity or target size.

5. The effectiveness levels obtained with larger PCF's will be close to the expected level and will be influenced very little by changes of intensity, target size or frequency.

The above relationships may not necessarily hold when another variable such as wavelength is added to the field. In fact it may be that an entirely new set of relationships will unfold as each new variable is incorporated into the structure.

Let us now turn our attention to the problem of <u>observer criterion</u> and the implications it may have for the findings in this investigation. In the alternation-of-response theory Bartley (14,15,16) suggested that maximal effectiveness should be obtained at those frequencies which are synchronous with the intrinsic cortical periodicity of the organism. In the human this would be somewhere between 8 and 12 pps. However, as we have seen in this investigation and others the level of effectiveness continues to increase as the frequency is decreased. However, the findings of the present investigation suggest that at the lower frequencies where the observer sees a series of discrete flashes rather than flicker (a rapid undulation of light and dark period with no discrete onset or termination between pulses), which is a phenomenon limited to higher frequencies, we may be dealing with a different phenomenon. Brightness enhancement as defined by Bartley may be a phenomenon which must be limited to those frequencies which produce flicker rather than a series of discrete flashes. It is well known that a single flash is more effective than any other type of stimulus presentation in producing brightness, and the problem in which we are interested here is determining where the phenomenon associated with single pulses ends and that associated with flicker begins as the frequency is increased from single pulse presentation.

The first thing that must be considered is what it is that an observer is doing when he matches a steady target to an intermittent one. At high frequencies, such as 20 to 10 pps, the observer sees what appears to be a rapid fluctuation or undulation in the intensity level. He is unable to distinguish any clear onset or termination associated with each pulse. What he sees is a field whose brightness could be described as a field with a large steady component with a fluctuation superimposed upon it. When he makes a match at these frequencies he is matching to what may best be described as an average between the light and dark components. The nature of the stimulus conditions make this a relatively easy task. However, as the frequency decreases a situation arises in which the observer sees discrete flashes separated by long dark periods, and he finds that it is now extremely difficult, if possible, to match to an average. The result is that he must shift his criterion to one in which his matches are made to the flash.

It was found that there are large increases in the variance with a frequency of 5 pps. It was also noted that the observations tend to cluster around two extreme points. These two findings suggest that the observer is shifting his criterion from one where he is attempting to match to an average, as he did at 10 pps, to one where he is matching only to the flash and ignoring the dark period. I am not implying that he does this consciously. The observer may only be aware of the difficulty in what he is doing and not aware of the shift he has made in his criterion.

In Figure 18 it was shown that the level of effectiveness increases between 20 and 6 pps, levels off some between 6 and 3 pps and then there is a large increase at 2 and 1 pps. In Figure 19 we see that the variance increases until we reach 5 pps, falls slightly and reaches a lower point again at 2 and 1 pps. It was also found that a bimodal cluster existed at 6, 5 and 4 pps for one observer and at 6, 5, 4 and 3 pps for the other observer. This cluster was not manifested at 2 and 1 pps.

These findings suggest that the criterion level changes as the frequency is decreased from 20 pps to 1 pps. Between 20 and 10 pps the observer is able to match to an average between the light and dark period. Below 10 pps there is a transition zone which is reached somewhere around 6 pps and lasts until about 3 pps. During this transition period the observer is attempting to match to an average at one time and to the flash at another time. This vacillation in criterion does not occur within one session but rather from one session to the next. This transition zone is characterized by a large variance and the bimodal distribution in the percentage of transmission required for a match. At frequencies of 2 and 1 pps the observer can only match to the flash, and thus a new criterion level has been reached in which variance is diminished.

These findings suggest that the lower frequencies may actually be associated with a phenomenon related to single pulses, and the Bartley effect should be limited to define those phenomena which occur under those frequencies which produce flicker rather than a series of flashes.

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