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BRIGHTNESS ENHANCEMENT AT LOW LUMINANCE LEVELS

by
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(date)

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Abstract

The present study is an investigation of the variables which may produce or influence multiple pulse brightness enhancement at low luminance levels. Brightness enhancement is the term used as a label for the observation that a light flickering under certain conditions will appear brighter to an observer than a steady light of equal luminance. Investigators of brightness enhancement have tended to focus on either a retinal explanation using data showing that the duration of a pulse determines the magnitude of the enhancement effect or a central explanation using data showing that the rate of intermittency of the pulses determines the magnitude of the enhancement effect. Whether either of these approaches provide an entirely adequate explanation of brightness enhancement or not has not been satisfactorily demonstrated. This circumstance may, in part, be due to methodological difficulties which have made interpretation of many of the investigations of brightness enhancement questionable. The present study attempted to resolve the important methodological differences of two earlier studies which had produced conflicting results by using the general method of the one study to collect data at the luminance levels investigated in the other study.

Two observers matched the brightness of a flickering test stimulus at each of 84 combinations of luminance level and rate of intermittency to a steady comparison

field which was kept constant at each of the seven luminance levels used in the study.

Circular test and comparison stimuli subtending $3^{o}6'$ visual angle were presented under haploscopic viewing conditions by using a two channel Maxwellian view. The results of the study were that:

(1) No one rate of intermittency consistently produced either maximum enhancement or any other effect on the magnitude of the enhancement effect.

(2) Luminance level and pulse length generally combined to determine the magnitude of enhancement according to the relationship known as the Broca-Sulzer effect.

(3) Regardless of other factors, increasing the luminance of the standard generally increased the magnitude of enhancement.

(4) Generally speaking, increasing rate of intermittency at any luminance level decreased the magnitude of enhancement.

It was concluded that, although this study gives evidence for a Broca-Sulzer effect but no rate of intermittency effect in multiple pulse brightness enhancement, a complete explanation of brightness enhancement almost certainly will involve consideration of data which it has not been possible to collect using the methods of this and similar studies.

Introduction

The problem of brightness enhancement has been studied by the use of two somewhat different methods, each of which has produced a characteristic type of data and has tended to support an associated theoretical interpretation of its data. The one fact common to both methods has been that a light source presented for a short duration, usually less than 200 msec., will appear brighter to an observer than an equally bright source presented either steadily or for a duration greater than 200 msec. One method used for the study of brightness enhancement involves the comparison of a single brief pulse of light from a test source to a long duration pulse or continuous presentation from a standard light source. Data collected using this single pulse method suggest that, given that the single pulse is bright enough for the enhancement phenomenon to occur and is long enough to be effective in producing the phenomenon, the amount of brightness enhancement beyond the luminance of the standard source will be a function of the duration of the pulse, a pulse between 50 and 75 msec. being maximally effective at luminance levels between 100 and 1000 mL. This relationship, called the Broca-Sulzer effect after its discoverers (Broca and Sulzer, 1902), varies with luminance in that a somewhat longer pulse will produce maximum enhancement for luminances greater than 1000 mL or less than 100 mL. The second method used in the study of brightness enhancement, the multiple pulse method, involves, as the name suggests, the comparison of a train of short duration pulses to a train of longer duration pulses or to a steady presentation of a test source equal in brightness to the flickering source. The multiple pulse method has so far been used to test certain aspects of the Alternation of Response theory (Bartley, 1938b). In this theory, Bartley gives a centralist explanation, suggesting that the repetitive rate of pulses is the critical factor determining the amount of brightness enhancement, with maximum enhancement produced by a pulse rate of 10 cps. Since this maximally effective 10 cps rate corresponds to the cortical alpha rhythm, it is suggested that brightness enhancement may be explainable in terms of a sychronous alpha enhancement effect. However, a simpler explanation of Bartley's data may be suggested by a closer look at one aspect of his methods.

Metlay (1967) reviewed the procedures used by Bartley in his investigations of brightness enhancement and found that enhancement is maximum at 10 cps if one other condition is met as it has been in most of Bartley's work. The pulse-to-cycle fraction (PCF) of .5 combined with a 10 cps rate produced maximum enhancement. The interesting characteristic of this particular combination of PCF and rate is that it produces a 50 msec. pulse, the particular duration which is most effective in producing maximum enhancement in the Broca-Sulzer work. This fact led Metlay to suggest that the enhancement phenomenon seen by Bartley might well be nothing more than a Broca-Sulzer effect appearing in the multiple pulse procedure. Since no very elegant theories comparable to the Alternation of Response theory had resulted from the single pulse work, Metlay went on to propose a retinal theory of brightness enhancement based on the Broca-Sulzer data and on data concerned with single unit responses of visual receptors in Limulus (Miller, Ratliff, and Hartline, 1961). However, Bleck (1968) used a multiple pulse procedure to generate data which he at first considered to be supportive of Bartley's theory and would to a large extent explain brightness enhancement in terms of central processes rather than the receptor phenomena favored by Metlay. Bleck's thinking has changed several times since this study was initiated. I will discuss the final revision of Bleck's dissertation more fully in the discussion section below. The studies of Bleck and Metlay are not directly comparable for certain methodological reasons.

Metlay's study investigated a wide range of luminance levels between 3 mL and 1700 mL while that of Bleck was a more intensive study restricted to two luminance levels which were approximately 10 mL and 100 mL. Therefore, only one of the levels used by Metlay fell within the range of luminance levels used by Bleck and while there may be certain indications of the type of relationship found by Bleck in the data collected by Metlay, it is not possible to make any generalizations or to determine the validity of the data collected in either study in terms of the other study.

The present experiment is an attempt to discriminate among these two studies by resolving the important methodological differences between them. The experiment is designed to determine specifically whether the amount of enhancement produced in a multiple pulse procedure run at the relatively low luminance levels characteristic of the Bleck study can be said to vary with the repetitive rate of the train of pulses or rather with the duration of pulse.

Two different patterns of maximum enhancement are possible in this study depending upon whether rate of repetition or pulse duration is the critical factor in determining the amount of enhancement produced under conditions of flicker at low luminance levels.

(1) If amount of enhancement varies with the repetitive rate of pulses in accordance with the Alternation of Response theory, maximum enhancement should occur with a 10 cps pulse and it is possible that lesser maxima of enhancement will occur at submultiples of alpha, that is, at rates of 5 cps and at 2 cps. If evoked cortical after-discharges appearing at a 10 cps rate are instrumental in producing enhancement, it is likely that a similar pattern of enhancement should appear.

(2) If amount of enhancement varies with pulse durat-

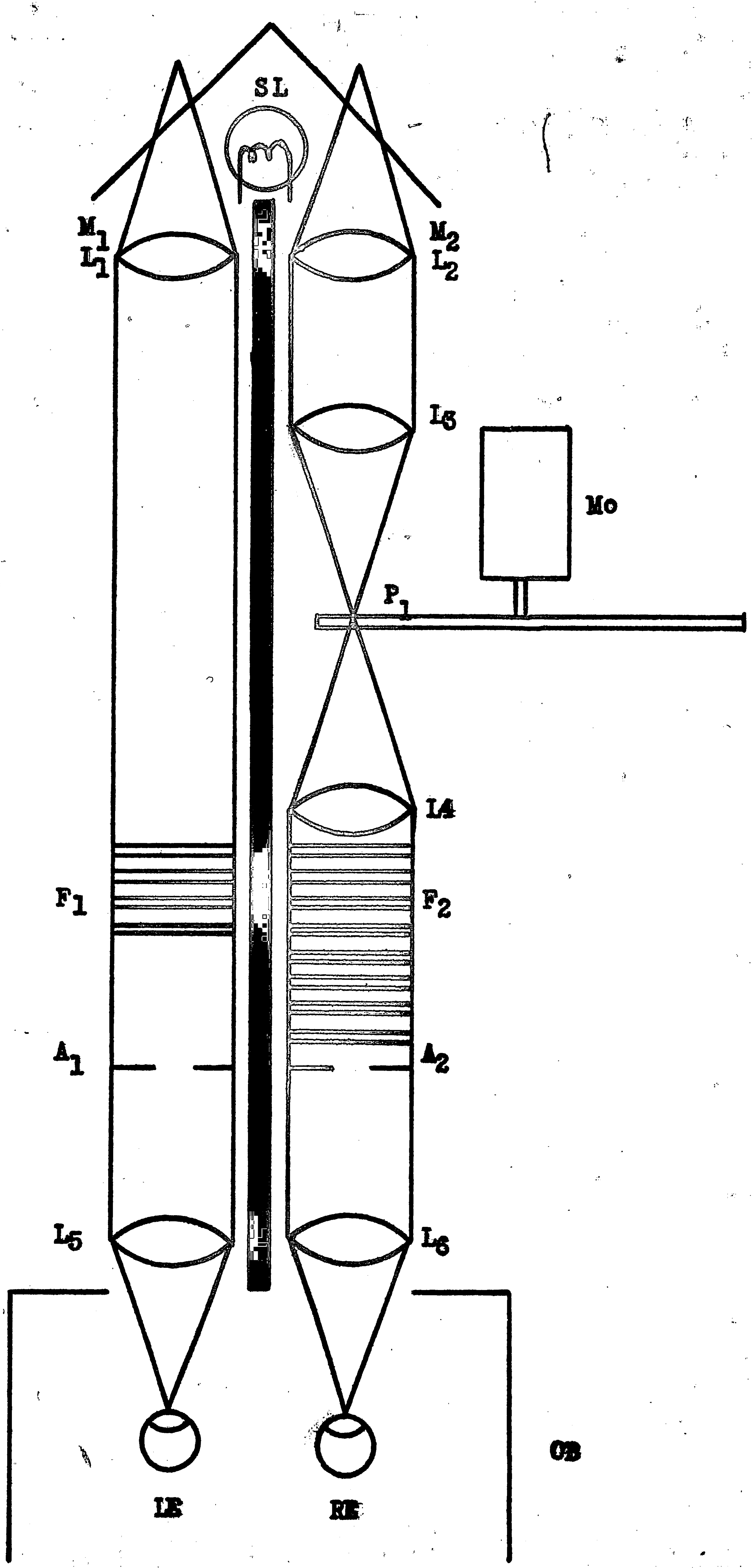
ion as in the Broca-Sulzer effect, maximum enhancement should occur with a 50 msec. or 6 cps pulse at a luminance level of about 100 mL. As luminance is decreased to about 10 mL, somewhat longer pulses should become more effective and the point of maximum enhancement should shift more toward a 100 msec. or 3 cps pulse.

Method

Observers: Two observers (Os) provided the data of this experiment. One observer, GH, was experienced in making brightness matches with intermittent stimuli and had full knowledge of the hypotheses of the experiment. This observer had normal vision. The other observer, DG, was unpracticed in making brightness matches and did not have detailed knowledge of the hypotheses of the experiment. This O normally uses eyeglasses to correct his near vision but did not find it necessary to do so in this experiment because he was able to focus easily and comfortably on the circular image in each channel with a slight adjustment of the final lens in each channel of the system.

Apparatus: The optical system is represented in schematic form in Fig. 1. O was seated inside a specially constructed booth painted black on the inside in order to minimize the occurrence of stray incident light during the experiment. O's head was immobilized by using a frame with a chin rest and a laterally adjustable rest at either temple. The entire frame was vertically adjustable. Use of this frame allowed the comparison and test fields to be held in focus respectively at the pupil of the left eye and the pupil of the right eye without introducing the physical discomfort accompanying use of the more generally employed bite bar. The light source was a General Electric #18A ribbon filament microscope illuminator

Fig. 1. Schematic arrangement of the optical system. The key is: M1 and M2, front surface mirrors; SL, G. E. #18A ribbon filament microscope illuminator bulb; L1, L2, L3, and L4, 112 mm focal length lenses; Mo, motor calibrated to revolve at 1 cycle per second; E, an episcotister, a slotted cardboard disc 18 inches in diameter; P1, focused image of the filament; F1 and F2, Wratten neutral density filters; A1 and A2, aperture stops subtending 3°6' of visual angle; L5 and L6, 74 mm focal length lenses; OB, specially constructed observation booth for observers.


SL
M_1
L_1
M_2
L_2
L_3
Mo
P_1
L_4
F_1
F_2
A_1
A_2
L_5
L_6
OB
LE
RE

bulb run at constant voltage with a 6 volt d.c. power supply. The image in the right Maxwellian system was focused at a point (P1) at which an episcotister was placed. The luminance of each channel was controlled by Wratten neutral density filters which could be placed into a collimated portion of the path by the experimenter. Circular artificial pupils, A1 and A2, which were placed at the focus of lenses L5 and L6 subtended $3^{o}6'$ visual angle and were separated by about 3^{o} visual angle when viewed under haploscopic presentation. O communicated with E by using a set of pushbutton switches which controlled signal lights visible at E's station.

Calibration of the system: Determination of the available illuminance in each Maxwellian channel was made by using a haploscopic matching procedure (see Westheimer, 1966). The primary source in the left channel of the system was blocked off and a small opal glass screen was inserted in the pathway behind the artificial pupil. This screen was transilluminated using a slide projector adjusted to a comfortable level of luminance. The luminance of the screen was measured with a Honeywell $3^{o}/21$ Pentax exposure meter. This provided observer GH with a measured circular image of the opal glass in the comparison field of the Maxwellian system and a defocused circular image of the filament in Maxwellian view in the right or test field. O then adjusted the right field by manipulating Wratten filters until the two fields appeared to be matched in brightness. The available luminance in the right field could then be calculated using the measured luminance of the opal glass screen and the total value of filters inserted into the right pathway. This procedure was repeated for the left pathway. The available luminance in the right (test) system was 134,000 mL; in the left (comparison) system, 153,300 mL.

Intermittent rate and pulse length: In order to investigate the effects of pulse length and rate of intermittency upon brightness enhancement each unconfounded by the other, it was necessary to choose values of these variables carefully so that the value of maximum enhancement for the one variable would not be coincident with the value of maximum enhancement for the other variable. This task was determined by the experimenter's choice of the method to be used to produce the necessary intermittency.

E decided to use different variations of an episcotister to interrupt the right pathway at (P1) to produce the desired intermittency. Each episcotister disc was a slotted black cardboard disc 18 inches in diameter mounted on the shaft of a constant speed electric motor calibrated to run at a speed of 1 revolution per second. This method was chosen because it allowed rate of intermittency to be changed quickly and readily simply by replacing one disc on the shaft by another, avoiding the relatively great delay and calibration problems involved in changing the speed of the motor and the inherent relative delicacy and unreliability of an electrically operated shutter in going from one rate of intermittency to another.

Given the method used to produce intermittency, E was able to select a set of discs which did not confound the hypothesized point of maximum enhancement for the rate of intermittency variable with the hypothesized point of maximum enhancement for the pulse duration variable by choosing a set of 12 discs with a pulse-to-cycle fraction (PCF) of .3. Table 1 shows the pulse lengths produced at the various rates of intermittency using a PCF of .3. As can be seen from the table, a 50 msec. pulse does not occur at a rate of 10 cps. This condition fulfills the primary requirement of unconfounding the effects of rate of intermittency and pulse length. In addition, longer pulse durations possibly of interest because of results obtained with the single pulse method at relatively low luminance levels do not coincide with submultiples of the 10 cps repetition rate which may be expected to produce lesser maxima of enhancement according to the Alternation of Response theory.

Procedure: The experimental design called for Os to match, using a haploscopic viewing procedure, the brightness of the test field, at each of 84 different combinations of luminance level and flicker rate, to a comparison field whose luminance was held constant. The luminance levels of the comparison field had been selected in order to provide intensive coverage of the range of luminances used by

Table 1

Pulse Durations in Milliseconds for the Rates of Intermittency Used When Pulse-to-cycle Fraction is Set at .3

Rate-cps	1	2	3	4	5	6
PCF=.3	300	150	100	75	60	50
Rate-cps	7	8	9	10	12	18
PCF=.3	43	37	33	30	25	17

Bleck, i.e., from 10 mL to about 100 mL and, in addition, to replicate one higher luminance condition used by Metlay. Six approximately equally spaced levels in the range used by Bleck and one higher level close to an intermediate level used by Metlay were accordingly chosen. A preliminary experimental session was then run to determine whether practice trials would be needed to reduce each O's variability and to find each O's test field steady match to the comparison field at each comparison field luminance level.

Preliminary session- Each O was given one preliminary session which lasted about one hour and during which his steady matches at all 7 luminance levels were determined. Each steady match served two purposes. Since an O's eyes might have differential light sensitivity under haploscopic viewing conditions, the only appropriate way to express enhancement is in terms of the physical value of a steady field presented to the right (test) eye which is matched psychophysically by O to a steady field presented to the left (comparison) eye at the desired luminance level. Such a steady match is also used in the test field at the begining of each main experimental session to light adapt O to the luminance level used for that session.

Any one match at a given luminance level was made using an ascending Method of Limits procedure. Using this procedure, O matched the test field to the comparison field by telling E when to stop increasing test field luminance by removing Wratten filters from the right optical pathway. Ten such matches at each luminance level were averaged to determine each O's steady matches or standards. The author concluded at the end of the preliminary session for each O that further practice sessions to reduce variability would not be needed before the main experiment.

Main experiment- The procedure used in the preliminary session was also used in the main experiment. The main experiment consisted of 14 one-hour sessions for each O. Within a session the various rates of intermittency were presented in a random order determined by E, six rates being presented in each one-hour session. This meant that O could only guess at the rate to which he was being exposed and, in any case, did not know the physical value of the matches he was making. The order of presentation of luminances in the main experiment was deliberately increased from the lowest level to the highest level in order to give each O additional practice in making brightness matches before attempting the higher and more difficult luminance levels.

At the start of any experimental session O was light adapted by viewing the comparison field and the standard in the test field for a period of 10 minutes. At the conclusion of this period E darkened the test field by inserting more Wratten filters into the pathway and simultaneously began to flicker the field by starting the constant speed motor. O again used the ascending Method of Limits procedure to match the test field to the comparison field. Ten such matches were made for every condition (rate). E darkened the test field after every match but varied the starting point as well as the sequence of removal of filters from the pathway.

After 10 matches were recorded at the initial rate, E changed the condition by replacing the first episcotister disc with the next in the random sequence. While the disc was being changed, O once again observed the standard in the test field and the comparison field in order to remain light adapted to the same level. This procedure was designed to reduce O's variability between conditions.

At the highest luminance level, 533 mL, observer DG expressed dissatisfaction with his previously determined standard. This standard was accordingly changed until it was acceptable to O and this newly determined standard value was used in the final computation of the standard value against which the data were compared to determine the amount of enhancement.

Results

Data showing the luminance of the test field as a function of the rate of intermittency of the test stimulus are plotted in Figs. 2-8. Each figure is a plot of the data of both Os at a specified luminance level. Each point on a curve is the arithmetic mean of ten brightness matches. The mean and the standard deviation of all such blocks of ten observations are presented in Tables 2 and 3 in the appendix. Inspection of the graphs shows the following:

(1) No one rate of intermittency produced maximum enhancement for both Os at all luminance levels of the standard. Indeed, no rate of intermittency produced any consistent effect on the magnitude of the enhancement effect for both Os at all luminance levels of the standard.

(2) Generally speaking, the luminance level to which the test standard was matched determined the pulse length which was most effective in producing enhancement. This can be demonstrated by examining the graphs to determine which rate produced maximum enhancement. It can be seen that faster rates and, therefore, shorter pulses are more effective the higher the luminance level. This particular relationship is more easily seen in the data of GH than in that of DG because several maxima are present in the data of DG at both the 134.0 mL steady match luminance level and the 151.3 mL steady match luminance level. Note, however, that although the most effective pulses at these

Fig. 2. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. The luminance of the comparison field was 19.3 mL.

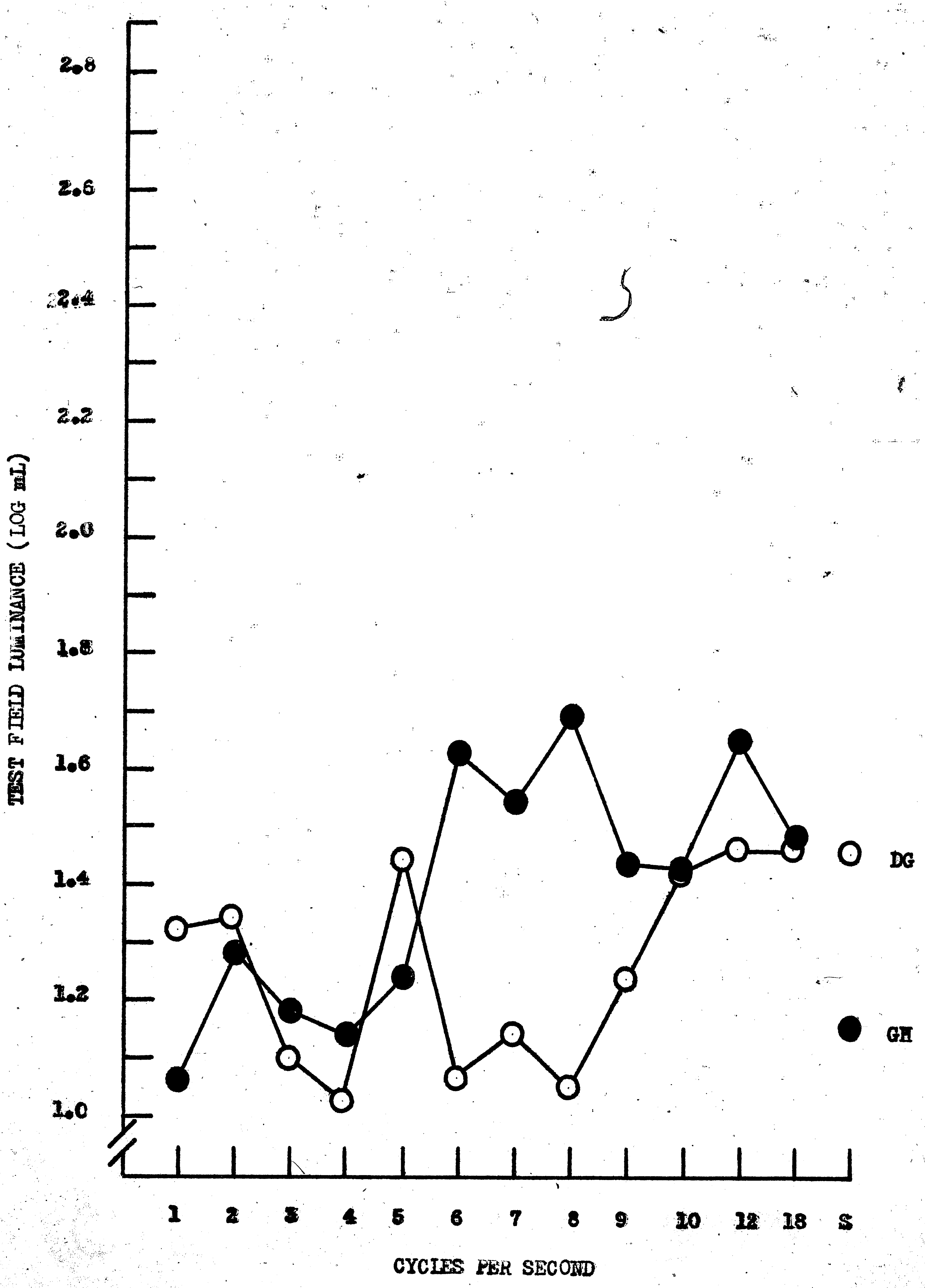

TEST FIELD LUMINANCE (LOG mL)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
1
2
3
4
5
6
7
8
9
10
12
18
S
CYCLES PER SECOND
DG
GH

Fig. 3. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. The luminance of the comparison field was 38.5 mL.

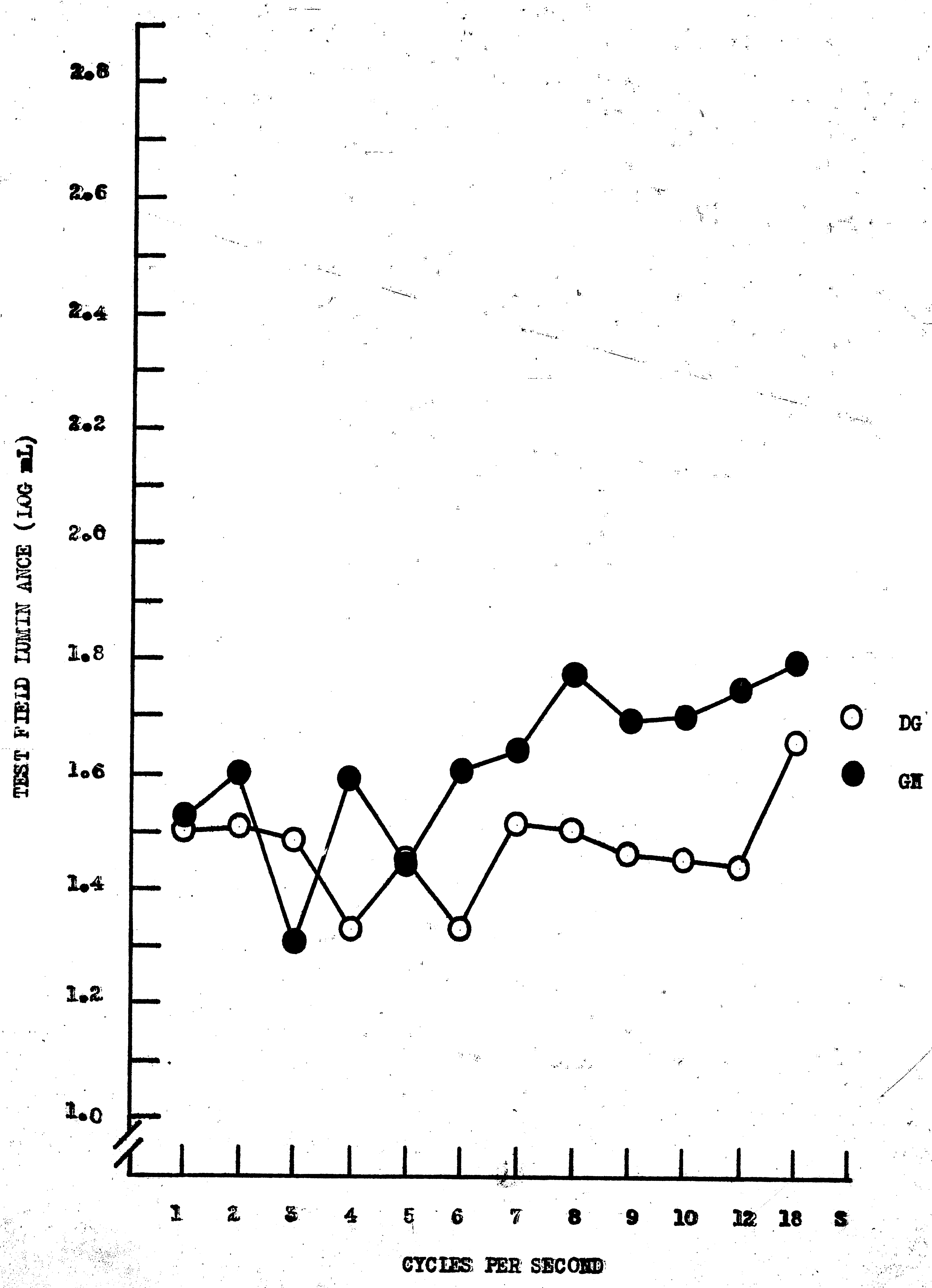

TEST FIELD LUMINANCE (LOG mL)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
1
2
3
4
5
6
7
8
9
10
12
18
S
CYCLES PER SECOND
DG
GN

Fig. 4. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. The luminance of the comparison field was 61.0 mL.

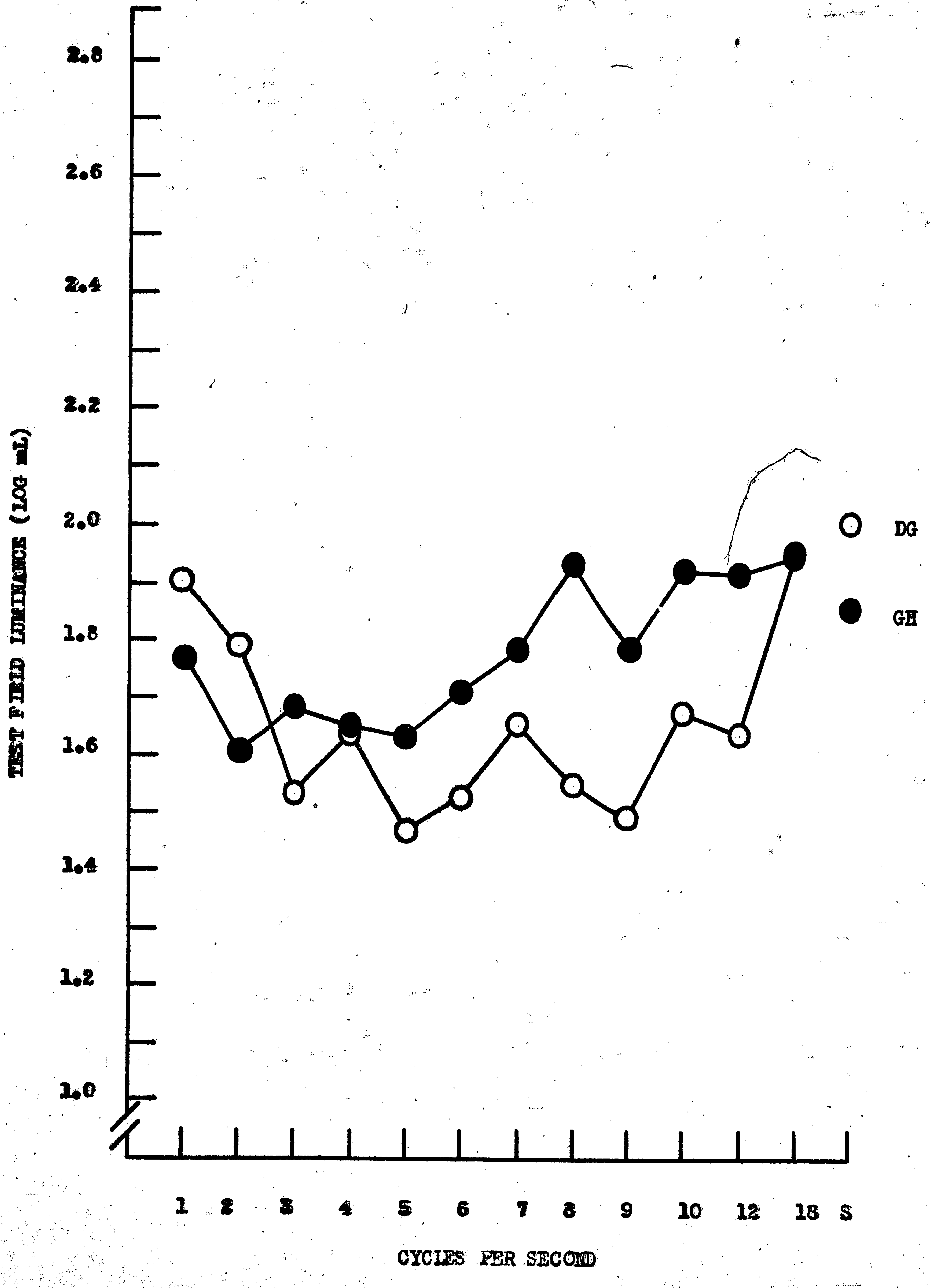

TEST FIELD LUMINANCE (LOG mL)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
1
2
3
4
5
6
7
8
9
10
12
18
S
CYCLES PER SECOND
○ DG
● GH

Fig. 5. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. The luminance of the comparison field was 76.8 mL.

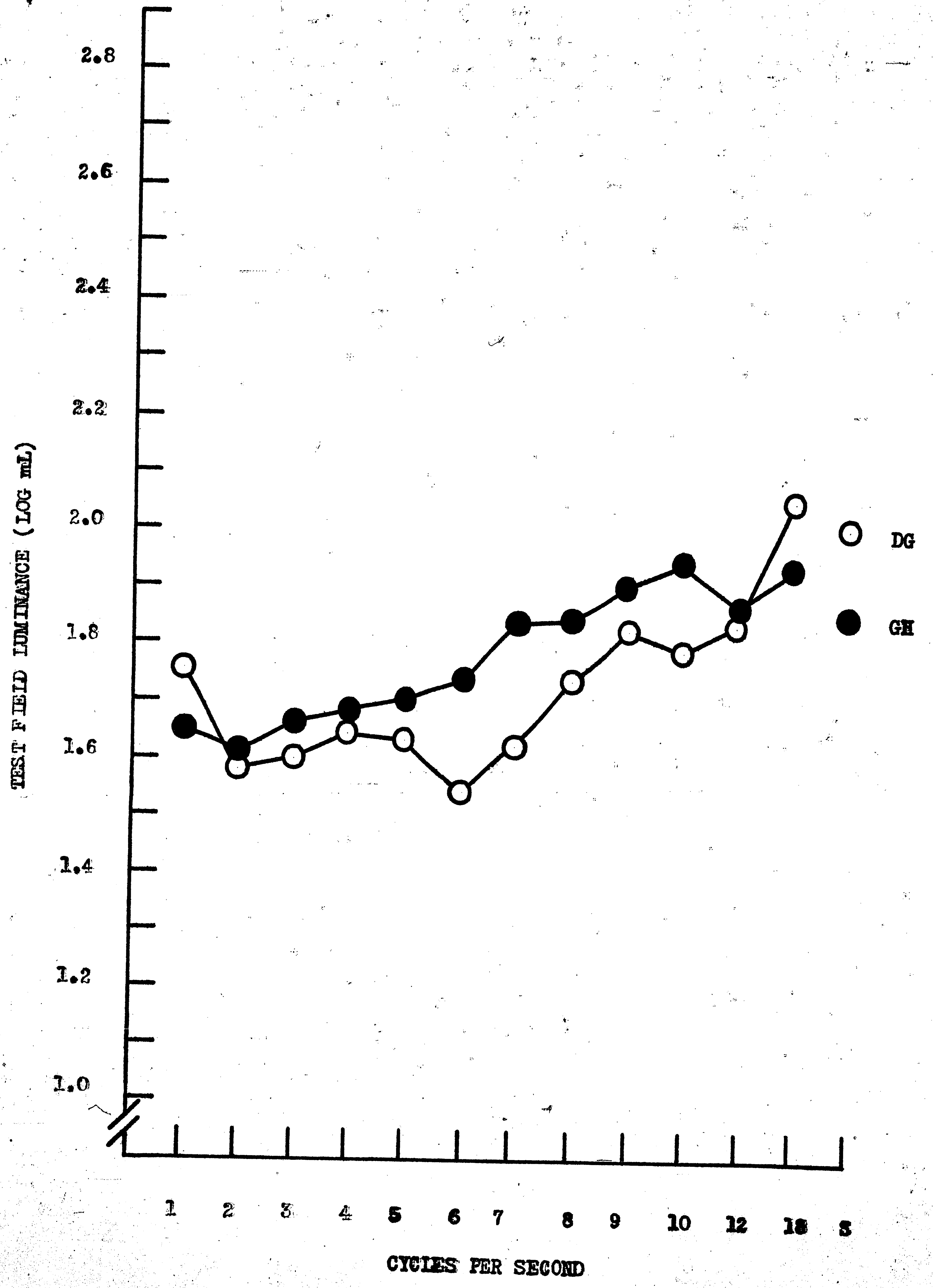

TEST FIELD LUMINANCE (LOG mL)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
1
2
3
4
5
6
7
8
9
10
12
18
S
CYCLES PER SECOND
○ DG
● GH

Fig. 6. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. The luminance of the comparison field was 96.7 mL.

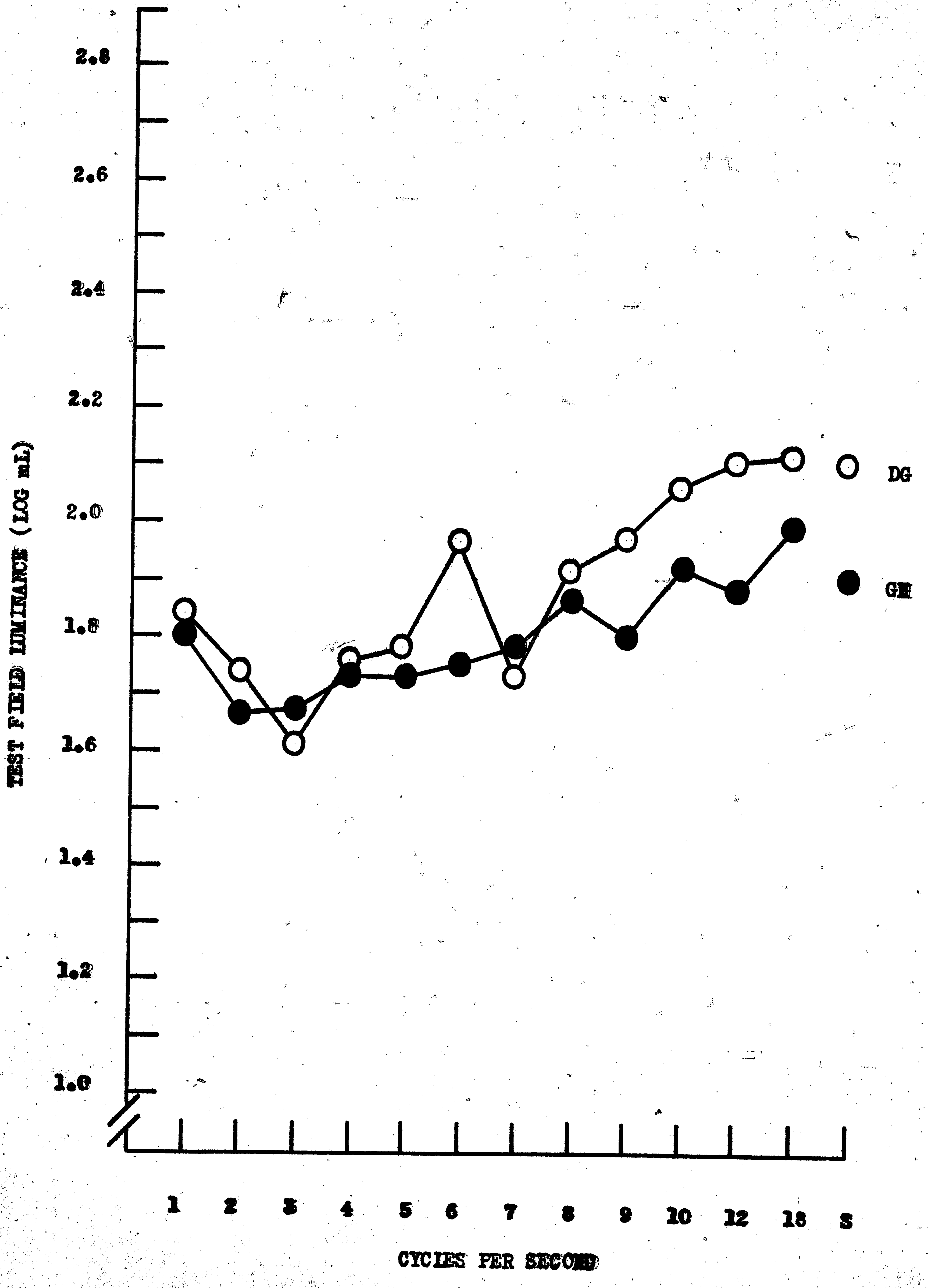

TEST FIELD LUMINANCE (LOG mL)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
1
2
3
4
5
6
7
8
9
10
12
18
S
CYCLES PER SECOND
○ DG
● GH

Fig. 7. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. The luminance of the comparison field was 121.8 mL.

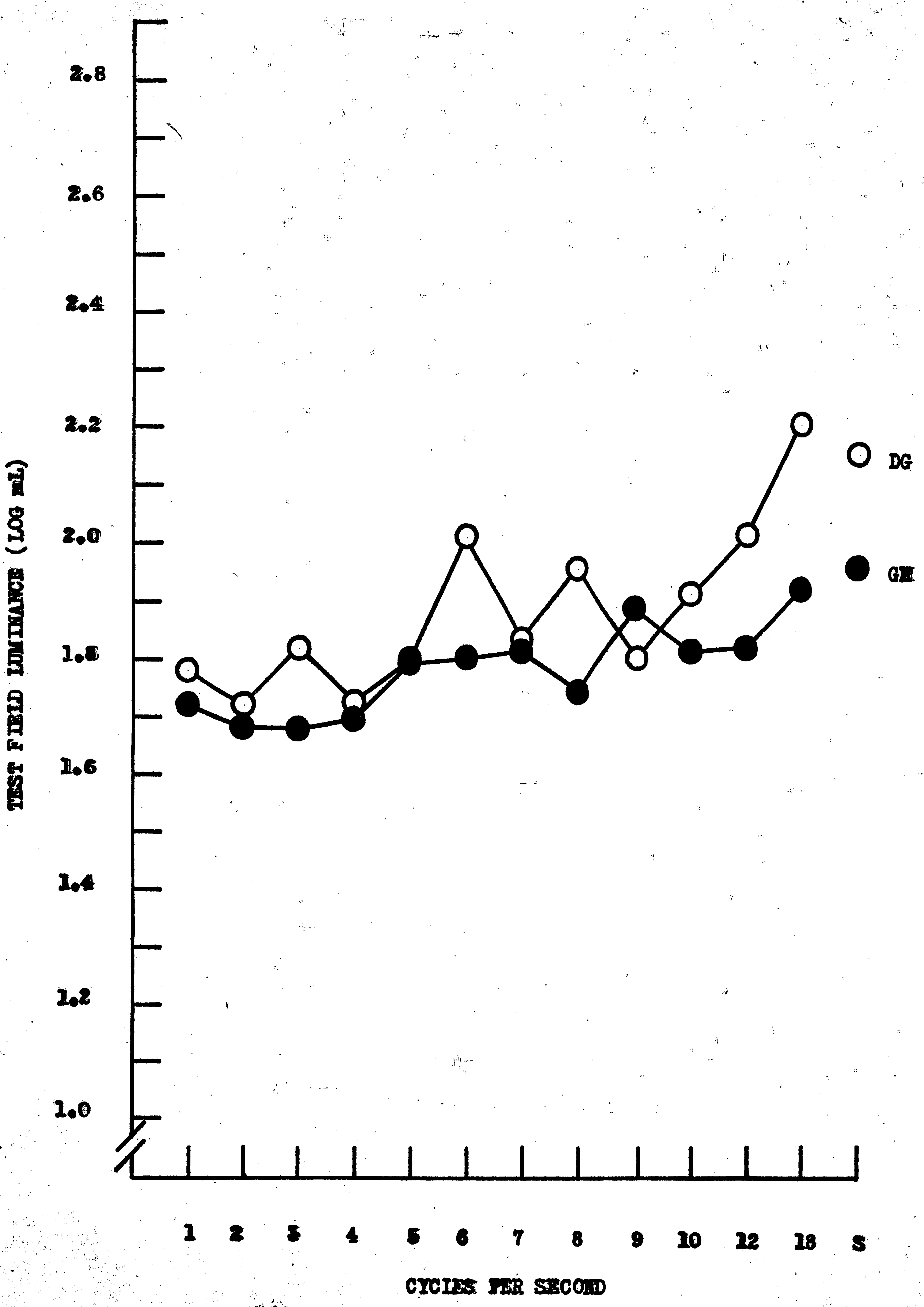
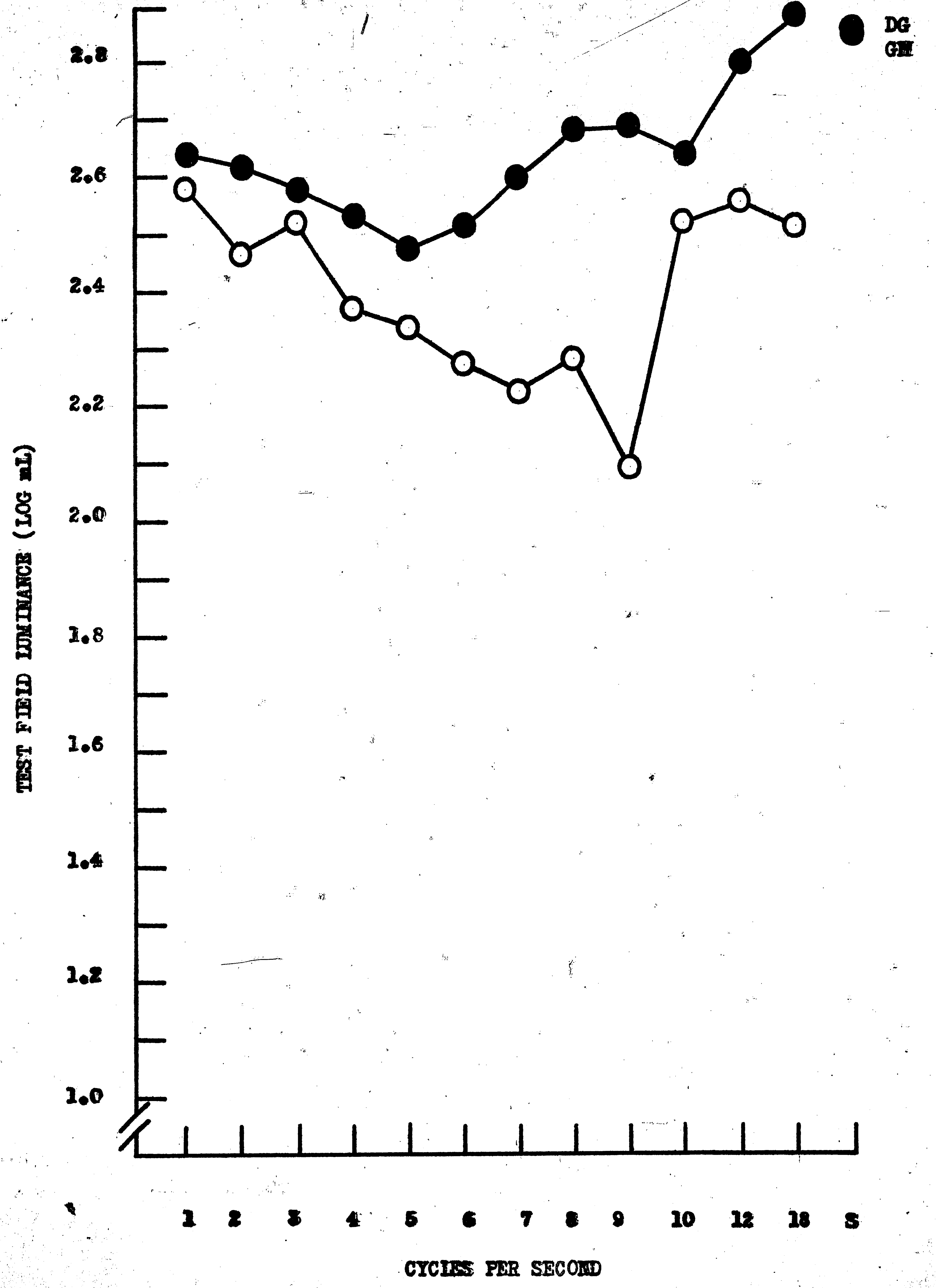

2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
TEST FIELD LUMINANCE (LOG mL)
1
2
3
4
5
6
7
8
9
10
12
18
S
CYCLES PER SECOND
DG
GH

Fig. 8. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. The luminance of the comparison field was 610.2 mL.


DG
GH
TEST FIELD LUMINANCE (LOG mL)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
1
2
3
4
5
6
7
8
9
10
12
18
S
CYCLES PER SECOND

two levels are of relatively long duration, the lesser maxima are at rates which are congruent with the general trend of the relationship between maximum effective pulse length and luminance level which holds for the remainder of the data.

(3) Within the limits of this study, increasing the luminance of the standard resulted in a general increase of the magnitude of the enhancement effect, regardless of pulse length or rate of intermittency. That is, presenting a given pulse at a higher luminance level generally resulted in a greater enhancement effect.

(4) Although there is an exception to this, as a rule it is true that increasing the rate of intermittency at any given luminance level decreased the effectiveness of the pulse in producing enhancement.

It should again be mentioned that the point of maximum enhancement did not consistently occur at any given rate of intermittency. Also, the point of maximum enhancement was never at 10 cps for any group of observations; in fact, 10 cps seems not to have had any special effect consistently. Almost the same thing can be said of the primary submultiple of 10 cps although the point of maximum enhancement was 5 cps in two cases.

As stated above, one luminance level was selected so as to be considerably outside the range of the other levels used and close to one of the intermediate levels used by Metlay. Metlay also used one luminance level which falls inside the range investigated in this study. Figures 9 and 10 are plots of Metlav's data for both of these levels. Each curve is a plot for one observer showing the relationship between luminance of the test field and rate of intermittency of the test stimulus for a PCF of .3 since a PCF of .3 was used in the present study. These figures may be compared with Figs. 4 and 8 respectively. These curves show essentially that the present study replicates Metlav in its results. Observer GH is the same person in both cases and his judgments are quite similar to one another. Interestingly enough, the data of observer DG bear some resemblance to those of observer WM in Metlav's study.

Fig. 9. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. Comparison field luminance for WM was 60 mL; for GH, 67 mL.

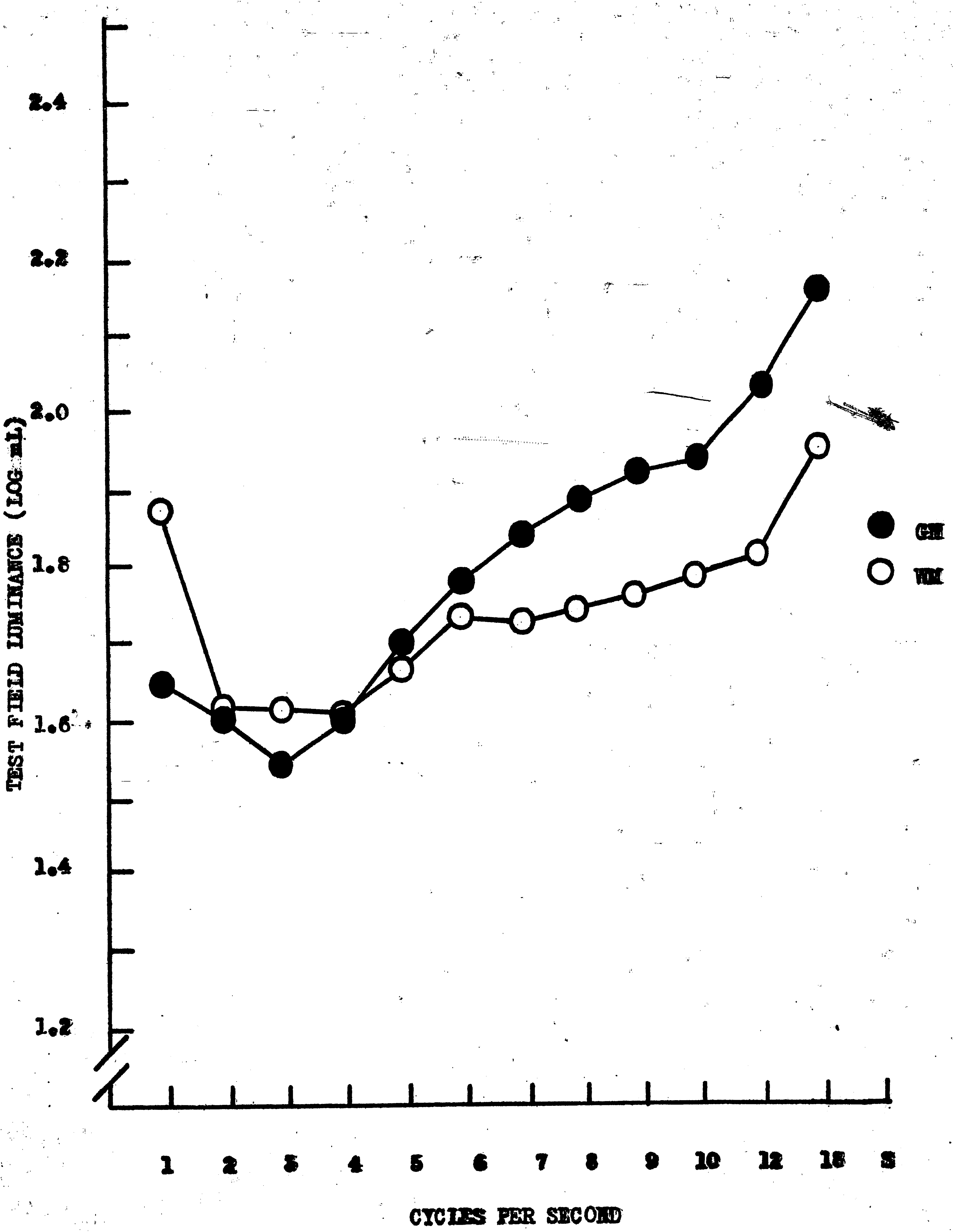
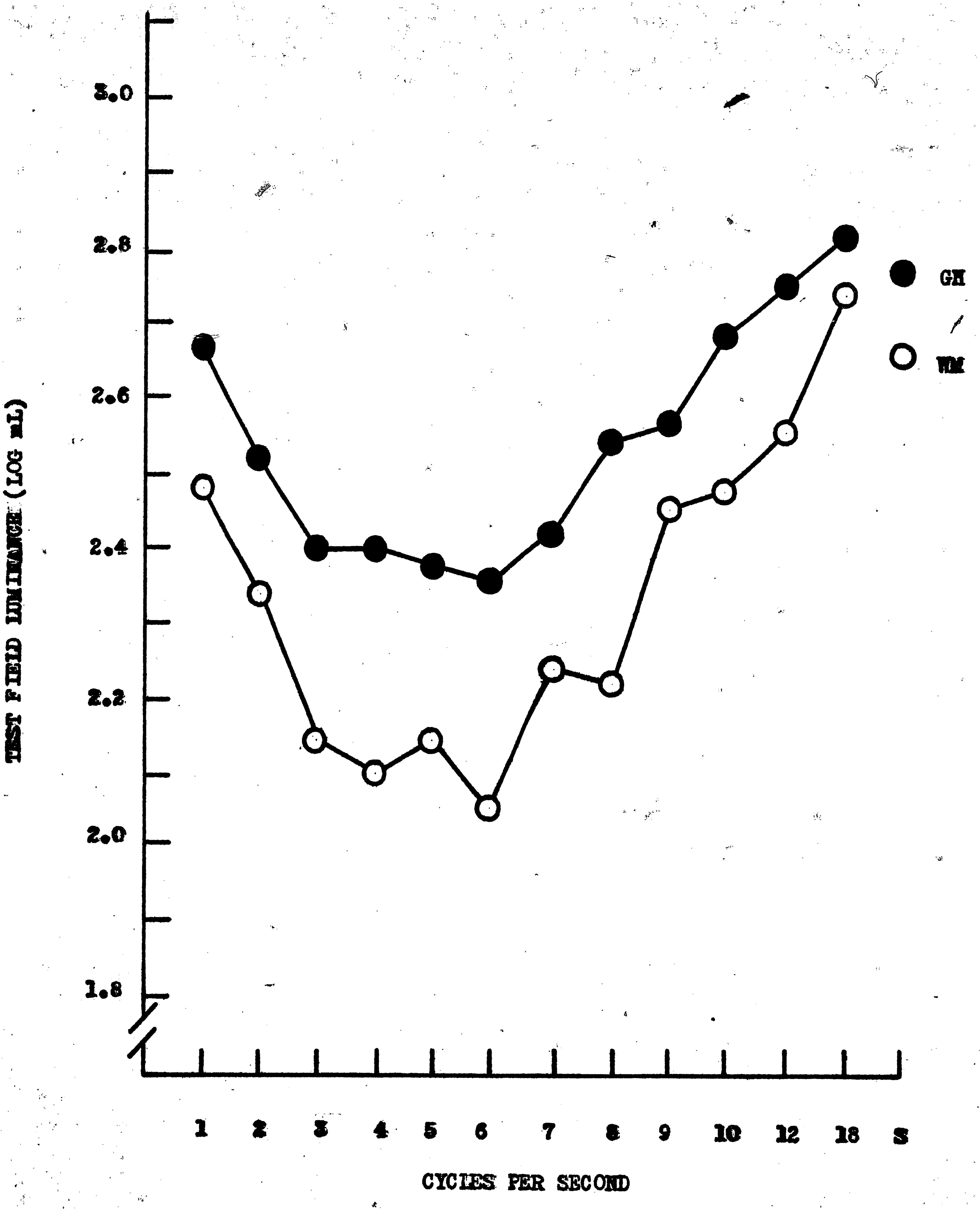

TEST FIELD LUMINANCE (LOG mL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1
2
3
4
5
6
7
8
9
10
12
15
S
CYCLES PER SECOND
● GH
○ WM

Fig. 10. Test field luminance (log mL) vs cycles per second. Each curve represents the data of one observer. Comparison field luminance for WM was 448 mL; for GH, 581 mL.


TEST FIELD LUMINANCE (LOG mL)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1
2
3
4
5
6
7
8
9
10
12
18
S
CYCLES PER SECOND
● GH
○ WM

Discussion

This study was originally intended to serve the purpose of comparing several theories which use rate of intermittency as the variable determining magnitude of enhancement to a tentative model based upon the hypothesis that the variable determining the magnitude of the brightness enhancement effect is in fact pulse length by determining which of these alternative explanations explained the results of this study more adequately. This comparison was thought to be a suitable method of deciding among the explanatory concepts because its method combined the general method of a study which gave evidence for a model employing the pulse length explanation of brightness enhancement with the luminance levels used in a similar study the results of which were more favorable to a rate of intermittency explanation. The original intentions of this study have been successfully carried out since the results do allow one to discriminate successfully among the hypotheses in terms of their ability to handle the data.

Of primary interest is the fact that no particular rate of intermittency produced any consistent effect on the magnitude of enhancement and the fact that pulse duration considered in relation to luminance level seems to have had about the effect on enhancement which would be predicted if the Broca-Sulzer effect holds for data collected using a multiple pulse procedure. This finding agrees quite well with the results Metlay obtained for observations at intermediate and high luminance levels. In fact, all the results of this study are consistent with the results of Metlay's study.

The obvious conclusion which can be drawn is that the magnitude of brightness enhancement at all levels where the phenomenon does occur is determined by a sensory mechanism which processes information about pulse length and luminance level in a manner described by the Broca-Sulzer effect. Given such a result it must follow that the alpha enhancement hypothesis of the Alternation of Response theory cannot be seriously considered to be of much value in explaining the occurrence of the brightness enhancement phenomena. Bleck had reached the same conclusion about the Alternation of Response theory but he considered that his results favored the use of evoked cortical potentials to account for brightness enhancement while the present study does not give evidence for evoked cortical potentials. A word about this inconsistency is in order.

Bleck presented both the test stimulus and the comparison stimulus to the same eye of his observers while Metlay used a haploscopic viewing procedure. The interpretation of Bleck's data is therefore open to criticism because of the possibility that these data were influenced by retinal interaction effects. Metlay protected himself from such an objection.

Bleck also has not demonstrated that evoked cortical potentials can be used validly in explaining brightness enhancement. Certainly such potentials exist but their involvement with multiple pulse brightness enhancement was not shown. Kohn and Salisbury (1967) had failed to detect any correlation between recordings of such potentials and the magnitude of the enhancement effect. An informal observation made in the course of this study and that of Metlay may also bear on this point.

An observation made repeatedly, if not in every case, by all the observers of both the present study and the study of Metlay was that there was a pronounced enhancement effect initially observable when the test source was first flickered at the beginning of a block of trials and also whenever E increased the luminance of the test pathway in the course of a trial. This pronounced initial effect apparently adapted out in a second or two and O then proceeded to make the match on what appeared to be a flickering stimulus of constant brightness. It seems reasonable to suppose that this momentary augmentation of the enhancement effect was the result of the sort of repetitive afterdischarge mechanism which Bleck feels is responsible for the paired pulse data. If this is the case, Bleck may well be doing violence to visual mechanisms by using paired pulse results to explain multiple pulse brightness enhancement since such initial afterdischarge effects appear to adapt out almost immediately and probably make no great contribution to multiple pulse brightness enhancement.

However, it must be said that Bleck's final conclusion is that, while both the Broca-Sulzer effect and paired pulse results may be of some use in explaining brightness enhancement, the major part of the data is still not accounted for and a complete explanation of the enhancement phenomenon will necessarily involve consideration of mechanisms at all levels of the visual system and will not be expressed as simply as the current models used to try to explain brightness enhancement. The present author agrees completely with this conclusion and would add that the data necessary to explain brightness enhancement more satisfactorily will probably be the result of research methods fundamentally different from those used by Bleck, Metlay, and the author of this paper. Speculation about the nature of the sensory mechanisms responsible for the data of this study must await such further experimentation and is outside the province of this thesis which has successfully accomplished its purpose of determining which of several possible hypotheses better describes the phenomena of brightness enhancement at low luminance levels.

Summary

The present study is an investigation of the variables which may produce or influence multiple pulse brightness enhancement at low luminance levels. The present study attempted to resolve the important methodological differences of two earlier studies which had produced conflicting results by using the general method of the one study to collect data at the luminance levels investigated in the other study.

Two observers matched the brightness of a flickering test stimulus at each of 84 combinations of luminance level and rate of intermittency to a steady comparison field which was kept constant at each of the seven luminance levels used in the study.

Circular test and comparison stimuli subtending $3^{\circ}6'$ visual angle were presented under haploscopic viewing conditions by using a two channel Maxwellian view. The results of the study were that:

(1) No one rate of intermittency consistently produced either maximum enhancement or any other effect on the magnitude of the enhancement effect.

(2) Luminance level and pulse length generally combined to determine the magnitude of enhancement according to the relationship known as the Broca-Sulzer effect.

(3) Regardless of other factors, increasing the luminance of the standard generally increased the magnitude of enhancement.

(4) Generally speaking, increasing rate of intermittency at any luminance level decreased the magnitude of enhancement.

It was concluded that, although this study gives evidence for a Broca-Sulzer effect but no rate of intermittency effect in multiple pulse brightness enhancement, a complete explanation of brightness enhancement almost certainly will involve consideration of data which it has not been possible to collect using the methods of this and similar studies.

Appendix

Tables 2 and 3 show the mean of ten matches made by both observers under all conditions of the experiment. The variability around the mean is given in standard deviation units. The tables also show the mean and standard deviation for the steady matches.

Table 2

Means and Standard Deviations of Brightness Matches in mL for Test and Standard Fields

Observer GH

Rate-cps	Comparison Luminance Level						
	19.3	38.5	61.0	76.8	96.7	121.8	610.2
S Mean	15.1	42.4	75.9	75.9	84.6	95.5	758.6
S.D.	1.15	3.27	5.59	5.34	6.07	6.87	53.48
1 Mean	11.6	33.5	59.6	44.7	63.8	52.5	446.7
S.D.	1.25	3.21	5.69	5.73	5.96	7.09	54.02
2 Mean	19.3	39.4	40.7	40.7	46.8	47.9	421.7
S.D.	1.21	3.19	6.10	5.24	6.23	6.66	56.48
3 Mean	15.3	20.2	48.4	46.2	47.3	47.9	389.0
S.D.	1.09	3.53	5.27	5.61	6.23	6.80	58.43
4 Mean	14.0	38.9	44.7	48.4	55.0	49.6	346.7
S.D.	1.10	3.17	5.38	5.47	6.10	6.83	57.88
5 Mean	17.6	27.5	43.2	50.7	53.7	62.4	305.5
S.D.	1.17	3.31	6.15	5.32	6.04	7.10	52.91
6 Mean	42.2	40.3	51.9	55.0	56.9	63.1	331.1
S.D.	1.14	2.98	5.27	5.36	5.96	6.63	53.06
7 Mean	35.5	43.7	61.0	69.2	61.0	64.6	402.7
S.D.	1.19	3.06	5.27	5.24	6.13	6.60	54.42
8 Mean	45.6	59.6	86.1	69.2	73.3	55.0	489.8
S.D.	1.08	3.07	5.55	5.24	5.90	6.75	52.56
9 Mean	27.2	49.0	61.0	79.4	63.1	76.7	495.5
S.D.	1.18	2.93	5.47	0.00	6.13	6.89	53.41
10 Mean	26.9	50.7	83.2	88.1	83.2	64.6	441.6
S.D.	1.15	3.04	5.56	5.42	5.92	6.97	53.41
12 Mean	45.2	55.6	82.2	73.3	76.7	65.4	638.3
S.D.	1.13	3.16	5.27	5.55	6.13	6.78	53.41
18 Mean	30.6	62.4	89.1	86.1	98.9	83.2	767.4
S.D.	1.16	3.25	5.47	5.27	6.24	6.66	52.91

Table 3

Means and Standard Deviations of Brightness Matches in mL for Test and Standard Fields

Observer DG

Rate-cps		Comparison Luminance Level						
		19.3	38.5	61.0	76.8	96.7	121.8	610.2
S	Mean	30.2	53.3	106.4	106.4	134.0	151.3	758.6
	S.D.	2.19	4.26	8.01	8.03	9.94	10.62	54.97
1	Mean	20.9	32.0	80.4	57.5	70.0	61.0	389.0
	S.D.	2.16	5.27	8.20	7.92	10.03	10.76	53.81
2	Mean	22.1	32.4	62.4	38.5	55.6	53.1	295.1
	S.D.	2.32	5.29	7.45	7.53	9.78	11.25	55.02
3	Mean	12.6	30.9	34.3	39.8	41.2	66.8	335.0
	S.D.	2.27	3.96	7.66	7.53	9.38	11.38	53.16
4	Mean	10.5	21.4	43.7	44.7	58.2	53.7	237.1
	S.D.	2.22	3.98	8.15	8.02	10.48	11.48	55.02
5	Mean	27.9	28.5	29.5	43.2	61.7	63.1	218.8
	S.D.	2.20	3.99	8.61	7.85	10.26	11.67	57.88
6	Mean	11.8	21.4	33.5	35.1	93.3	103.5	188.4
	S.D.	2.38	3.98	7.55	7.59	9.75	11.35	56.48
7	Mean	14.0	32.4	45.2	42.2	54.3	68.4	167.9
	S.D.	2.28	3.75	7.59	7.67	9.58	11.86	57.13
8	Mean	11.2	32.0	35.5	55.0	83.2	91.2	192.8
	S.D.	2.24	3.62	7.85	8.07	9.41	10.89	57.53
9	Mean	17.4	29.5	30.9	66.8	94.4	63.1	123.0
	S.D.	2.33	3.98	8.15	8.32	10.01	11.46	56.17
10	Mean	26.3	28.8	47.3	61.7	116.1	82.2	327.3
	S.D.	2.22	3.81	7.55	8.15	10.10	10.54	54.92
12	Mean	28.8	27.5	43.2	68.4	127.4	103.5	363.1
	S.D.	2.31	4.00	7.66	8.09	9.92	10.94	57.38
18	Mean	28.8	45.7	89.1	112.2	130.3	162.2	323.6
	S.D.	2.18	3.96	7.95	8.02	9.87	10.47	56.83

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Vita

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