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LB 30977

AN INVESTIGATION OF THE EFFECTS OF PULSED LIGHTING UPON AIRCRAFT DISPLAYS RELATIVE TO THE PRESERVATION OF DARK ADAPTATION FOR NIGHT FLYING

DOUGLAS AIRCRAFT DIVISION • LONG BEACH, CALIFORNIA

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PREPARED BY L.R. Uyeda B.H. Levedahl
L.R. Uyeda & B.H. Levedahl

SECTION OR GROUP Systems Research

APPROVED BY H.L. Wolbers
H. L. Wolbers, Chief
Systems Research

APPROVED BY C. S. Glasgow
C. S. Glasgow
Chief Engineer

A. A. Burrows
A. A. Burrows, Head
Life Sciences group

REVISIONS

LETTER	DATE	PAGES AFFECTED	REMARKS

ABSTRACT

The relationship of pulsed and continuous lighting upon a compensatory task, and its subsequent effect on scotopic detection performance was examined under two levels of illumination. Response latency of detecting Landolt rings as well as the number of detection errors incurred was an index of the time required to effectively regain dark adaptation.

On the basis of the results obtained, it is concluded that dark adaptation may be preserved if the visual display to which an individual is attending is illuminated with pulsed lighting in the frequency range of 5 to 15 cps. In this condition, the experimental vehicular tracking performance appears unimpaired.

1.0 TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

APPENDICES

2.0 INTRODUCTION

A visual state of dark adaptation is mandatory in many military situations where activities of various natures are conducted during conditions of very low illumination. In many situations, some type of artificial illumination must be introduced in order to conduct meaningful activity, such as in the case of night instrument flying.

In considering critical primary displays which must be viewed continuously, the problem then may be stated from one point of view as, "Will the intensity of illumination on a tracking display destroy or degrade the pilot's immediate ability to look out into the night sky, and detect obstacles, terrains, landing strips, or a carrier upon which he is about to make a landing?" If it is imperative that the pilot maintain his night vision, then what can be done regarding the illumination in order to preserve dark adaptation?

This experiment proposes to investigate the effects of "pulsed" lighting upon dark adaptation. During such intermittent presentation of light energy, the light-to-dark ratio of each cycle can be made strongly to favor "dark-time". It is possible that if the eye is in the dark for the greater part of each cycle, the condition may be favorable for maintaining dark adaption. There are two factors pertinent to this study. One is the phenomenon of dark adaptation, or the increase in light sensitivity as a function of time spent in the dark, and the other is the critical fusion frequency (CFF).

Fusion-frequency increases with the intensity of the illumination (Ferry-Porter law) as well as the area illuminated (Woodworth, 1954). An important graph is presented in Figure 1 (Lythgoe and Tansley, 1929). It can be seen that the CFF falls as illumination of the surround is decreased from a high level but that vision remains in the cone region. However, as dark adaptation proceeds and illumination decreases still further, the rod region is effective and there is a concomitant rise in CFF.

*When the frequency of a light-dark cycle is increased, there is initially a definite flicker which with further increase in frequency, smooths out and eventually appears as a fused, continuous light. The frequency at which the fusion occurs is the CFF.

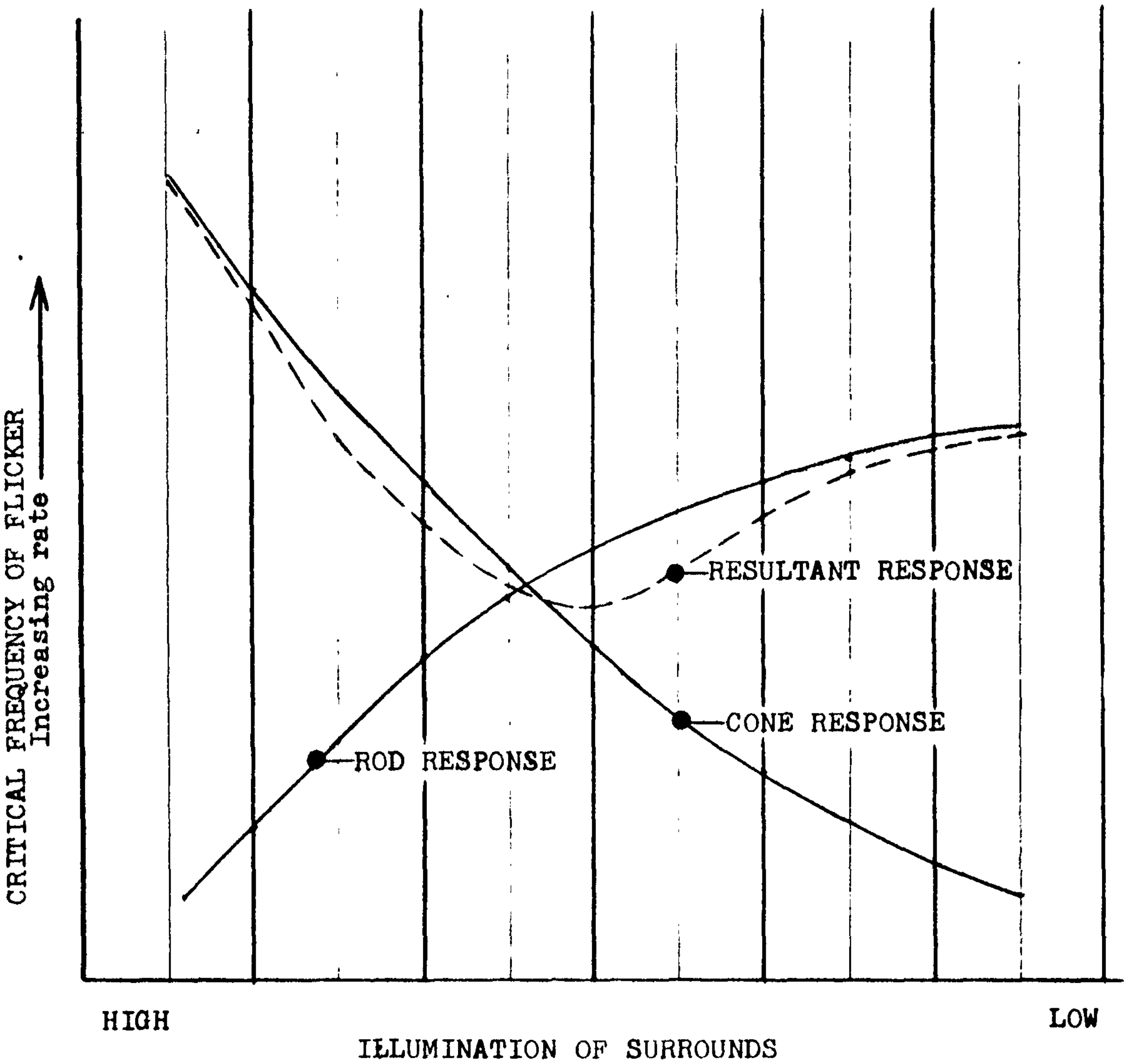


Figure 1. The graph shows the way in which it is hypothesized that the resultant value of the critical frequency is dependent on the individual values of the rods and cones. (Adapted from Lythgoe and Tansley)

Findings of early investigators (Lythgoe and Tansley, 1929; Lythoe, 1926; Suchman and Weld, 1937) are basic to this study as are the contributions of current investigators (Wald, 1951; Spragg and Wulfeck, 1953; Peckham and Arner, 1952; Mote and Reed, 1951 ; Grant and Mote, 1948; Tufts University series on Dark Adaptation, 1955-60).

3.0 METHOD AND PROCEDURE

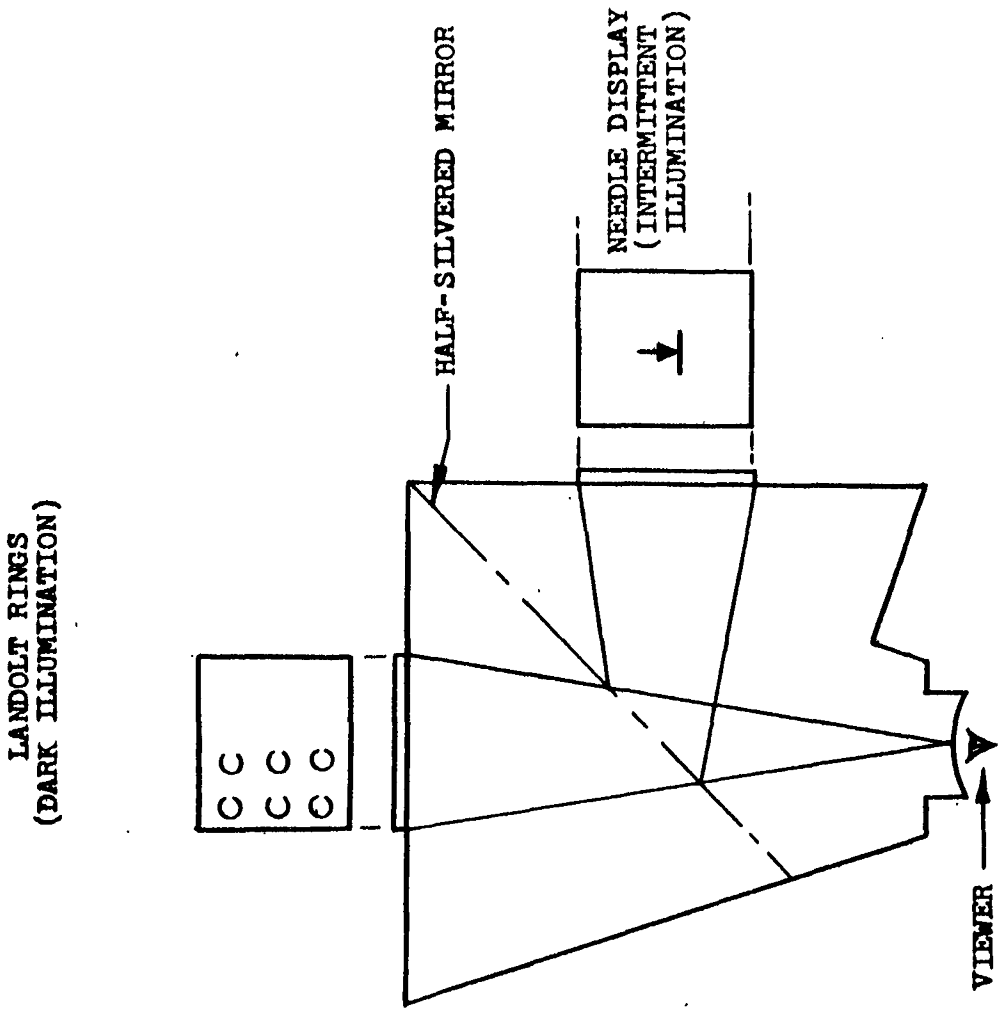
3.1 Apparatus

The apparatus used in the experiment was a mirror-tachistoscope (see Fig. 2) designed and built at Douglas Aircraft Company. A box, approximately 3' x 3' x 3' was fitted with two chambers, separated by a semi-silvered mirror mounted at 45° in the plane of the viewer's eyes. By turning a light on in one chamber, the test field located in that chamber could be seen. With the lights on in both chambers, the two test fields could be seen, superimposed upon each other, in one display. The distance from the fitted binocular eyepiece to the superimposed field was 34". The 8" x 11" test field had an immediate surround of 30" x 30". In order to reduce glare and reflection, the entire surface of the box was coated with Flok-Kraft #D-405 black flock. All stimulus materials were painted with Shiva Casein Titanium white paint to insure maximum contrast.

The tracking display, located in the right chamber of the tachistoscope, consisted of a Simpson D.C. galvanometer (Model 1227 c) mounted on the face of an 8" x 11" cut film holder. The needle of the galvanometer was replaced by a pointer 1" long that flared out to 1/ 8" width for half the distance of the pointer. In the second chamber directly ahead of the viewer's eyes, there was a display consisting of 6 Landolt rings, which could be rotated remotely (see Fig. 3). The illumination in each chamber was controlled by means of General-Radio Variacs. Visual angles of the various elements making up the test fields are presented in Appendix A.

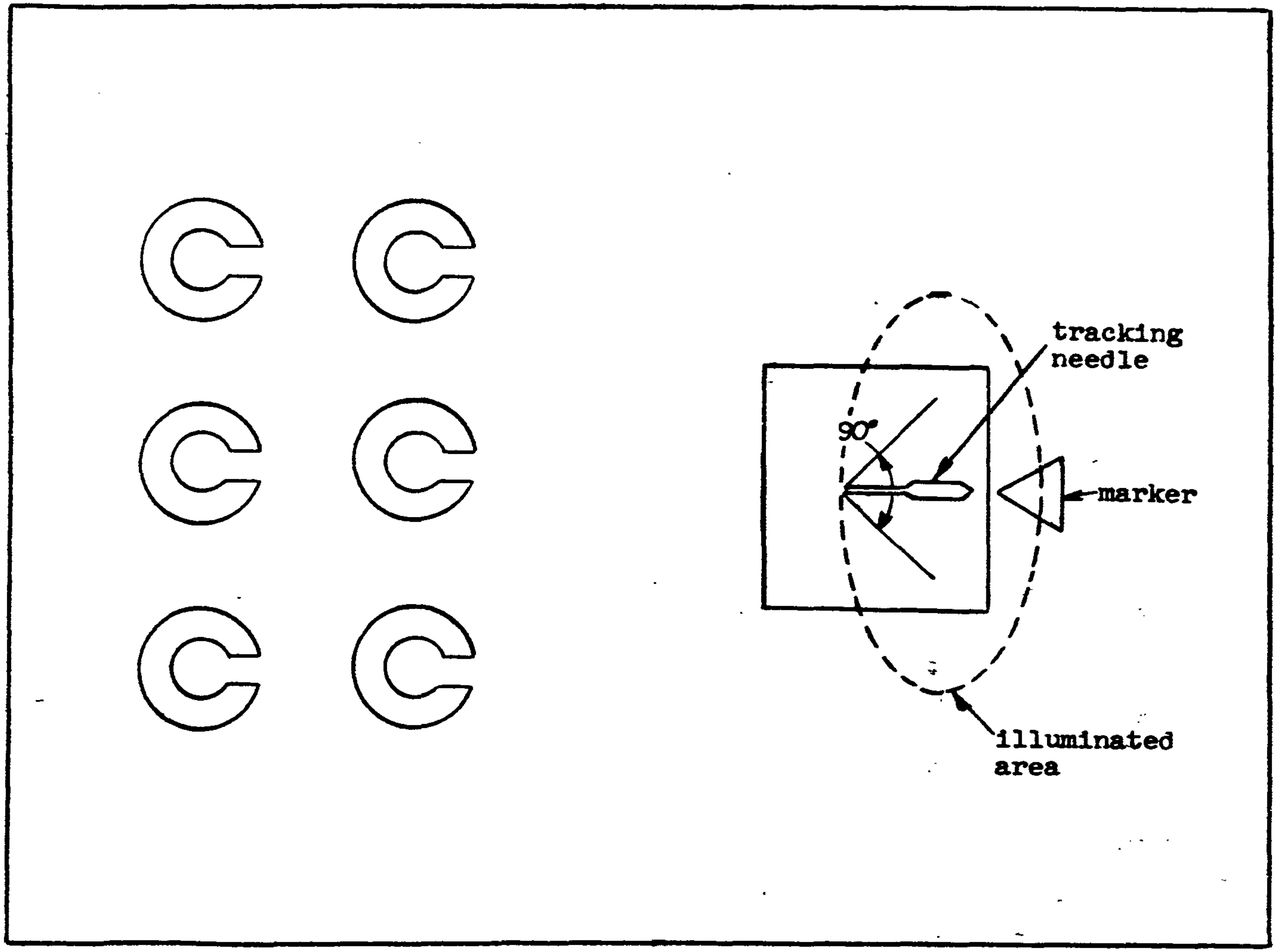
Pulsing of the light was accomplished by inserting a rotating, sectored disc, between the light source and the tracking needle. A pulse duration of .022 seconds was held constant for all conditions. That is, at all frequencies used (5, 15, 30, and 60 cycles per second) duration of the on-time of light was maintained at the above figure. (The wave forms of the various light pulses are shown in Appendix B).

The light source used was a 500 watt Revere 888 35mm projector. The seven inch lens of the projector was fitted with a variable density polarizing filter (#51,231 Edmund Scientific Co.) to enable intensity control at a virtually constant color temperature.



EXPERIMENTAL APPARATUS

Fig. 2



Superimposed test field. Three-fourths actual size.

Fig. 3

Frequency changes were obtained by using discs with different numbers of cutouts. The disc was mounted on the shaft of a 300 rpm constant speed synchronous motor. One cutout on the disc yielded 5 pulses of light per second. Three and six cutouts yielded 15 and 30 cps respectively. The cutout subtended a constant angle of 14 3/4° which allowed a maximum pulse duration of 0.022 sec.

A Douglas Aircraft Company designed and built side-stick controller was used for the compensatory tracking task, feeding an EAI type TR-10 computer. Equations used were stable second order longitudinal dynamics. (See Appendix C)

3.2 Measures of Performance

Three measures of performance were obtained:

1) Absolute integrated error (voltage)
2) Number of Landolt rings missed out of six
3) Median response latencies in reading Landolt rings

Subjects were required to neutralize the needle and detect the Landolt change. To avoid fatigue, and also because of the time element involved, search of the rings was limited to ten seconds. It was assumed from the outset that if the subject was unable to read the rings in ten seconds, he was not able to read the rings at all.

The ten second-cutoff criterion must be taken into account when distribution of response latencies and misses on the Landolt rings are being considered. That is, if there were not time limits used, the subjects may have been able to read the rings in 11 seconds or 11 minutes. In order to attenuate the contributions of extreme and aberrant scores, the scores for the number of misses and the median response latencies were first determined for each subject and then the means of these scores was used in the statistical analysis.

3.3 Subjects

Subjects were recruited from a pool of electronic technicians and professional engineers. The general age range was between 25 and 35. They were initially selected with the one restriction that they had uncorrected vision. This limitation was imposed not only because of the acuity factor involved but also because of the size restriction of the binocular viewing aperture on the tachistoscope. An after-the-fact visual acuity check (Snellen) and a color vision test (A O H-R-R Pseudoisochromatic Plates, American Optical Company) disclosed no serious departures from normal (see Appendix D).

3.4 Procedure

The subject was seated inside the darkened test booth. A set of instructions (see Appendix E) was then read to the subject. When it was apparent that the subject understood the task set before him, learning trials for the compensatory tracking task was commenced. As soon as a learning asymptote was reached for the tracking task, learning was started on the task of reading the Landolt rings. When relatively constant reading times were obtained, the subject was dark-adapted by remaining in the dark for a period of 30 minutes.

At the end of 30 minutes, the subjects were required to read the Landolt rings within the time limit. The intensity on the rings were pre-set according to the value (0.001 ft-L) and was maintained at this level throughout the experiment.

When it was established that the subject could read each ring accurately and within two-seconds time, the experimental runs were begun according to the Master Schedule (Table I). Each experimental condition (rate of pulsing) was presented only after a period of complete dark adaptation. This was to insure that changes observed were due to this variable alone, and did not result from the effects of the pre-test illumination conditions.*

The subjects tracked each condition for a total period of four minutes. The subject began by tracking for one minute, and then the Landolt rings were turned individually for six timed trials. The rings initially were all aligned with the breaks or gaps in one direction. One ring at a time was moved 180 degrees out of phase in a randomized sequence. The time to detect a change was recorded to the nearest half second. The ring was returned to the original position after a lapse of ten seconds. A 20-second rest between the presentations was observed for each subject.

* Luminance or photometric brightness of pulsed light may be established in two ways. One is to calculate the physical brightness or the actual amount of light energy entering the subject's eyes. However, once this energy reaches the eyes, the ensuing experience of brightness is due to interpretation of energy by the subject and the second method of measure must take this factor into account. Such an interpretation

or evaluation depends on many factors, including the condition of the subject's retina, the nature of the light source (intermittent or continuous) the differences in the light-dark ratio , and perhaps most important, the contrast and brightness of the immediate surroundings. This measurement is commonly referred to as apparent brightness. The difference between the two types of measurements may not be readily perceived. However, it becomes apparent when the manner in which measurements are made is considered. In the physical brightness measurement, the readings are taken directly and objectively. In the apparent brightness measurements, there is a definite subjective involvement of the values read. That is, there has to be a human operator making value judgments in order to arrive at a reading.

To determine whether any of the resulting effects might be due to the manner of establishing and measuring two types of brightness readings, the experiment was conducted twice, once using each type of brightness measurement. In the one case, the brightness (apparent) was measured with the MacBeth Illuminometer (No. 6800), and for the second case, brightness (physical) was established using the Spectral Brightness Meter (Photo Research Corp.).

3.5 Experimental Design

Four experimental conditions of frequency (5, 15, 30 and 60 cycles per second) were presented to five subjects (physical brightness) and to eight subjects (apparent brightness) with illumination of the tracking task at low and high level (see Table I) of luminance. The experimental framework was one of treatment-times-subject design with each subject serving as his own control. The order of the conditions was counterbalanced and the presentation of the Landolt rings was randomized to avoid the effects of systematic bias. Reference to the Master Schedule (Table I) will indicate that the counterbalancing of conditions was standard with one exception. It was decided during the design stage that there would be a time saving of 30 minutes per subject if the 60 cycles or continuous condition (condition D in Master Schedule) was presented following the three conditions.

"High level" presentations were three times greater than the "low levels". These values are summarized in Table II and equated in terms of time-intensity or the number of foot-lamberts seconds.

Time intensity factors were determined through the use of 1.00 and 3.00 ft.-lamberts luminance as the basis for the low and high level presentations. For example, in the low level physical brightness presentation, 1.00 ft-L was selected as the base for condition D (see appendix F). For the other three conditions, the actual input arrived at was this base number plus the per cent dark time multiplied by the base. After the input was corrected according to Talbot's Law (see Table II), the correction was multiplied by the number of cycles per second in order to arrive at time-intensity figures.

viz: $I = I_B \cdot f\,{}^{L}\!/\!_{D}$

where I_B = intensity of base

f = cycles per sec.

${}^{L}\!/\!_{D}$ = light-dark ratio

4.0 RESULTS AND COMMENTS

The results of the two experiments are presented as the effects of controlled interruption of light on three measures of performance: 1) Number of misses on the Landolt rings, 2) Response latency in detecting change in the Landolt rings, and 3) Absolute integral tracking error, recorded in voltages. (See Tables III through V) The statistical analysis of the data is shown in Table VII. Curves obtained from the three performance measures as function of time-intensity factors are presented in Figures 4 and 5.

4.1 Number of Landolt Rings Missed

The missed responses are reported in Tables III through VI as the number of misses out of six presentations for each subject and for each experimental condition. All data were then pooled and the median number of misses out of six tries for each experimental condition was determined. These data are shown plotted in Figures 4 and 5.

Apparent Brightness Measurements

The two detection curves generated under the apparent brightness measurements showed very little decrement in performance (see Figures 4 and 5). A Friedman two-way analysis of variance across the four conditions indicated no significant difference in the number of Landolt rings detected for either of the two luminance levels (see Table VII).

Physical Brightness Measurements

The two detection curves determined through the use of physical brightness measurements, produced results somewhat different than the above findings (see Figures 4 and 5). The measurements at the low level produced a curve that indicated no significant difference between conditions (see Table VII). However, the curve obtained at the high level showed a definite decrement in detection performance as a function of increase in pulse repetition frequency or the number of foot-lamberts per second presented at the eye. A Friedman Two-way Analysis of Variance indicated that this difference was significant at the .01 level.

Here again, care must be taken in interpreting the results because of the cut-off criterion in effect. Since the subjects were not allowed unlimited time to respond, the

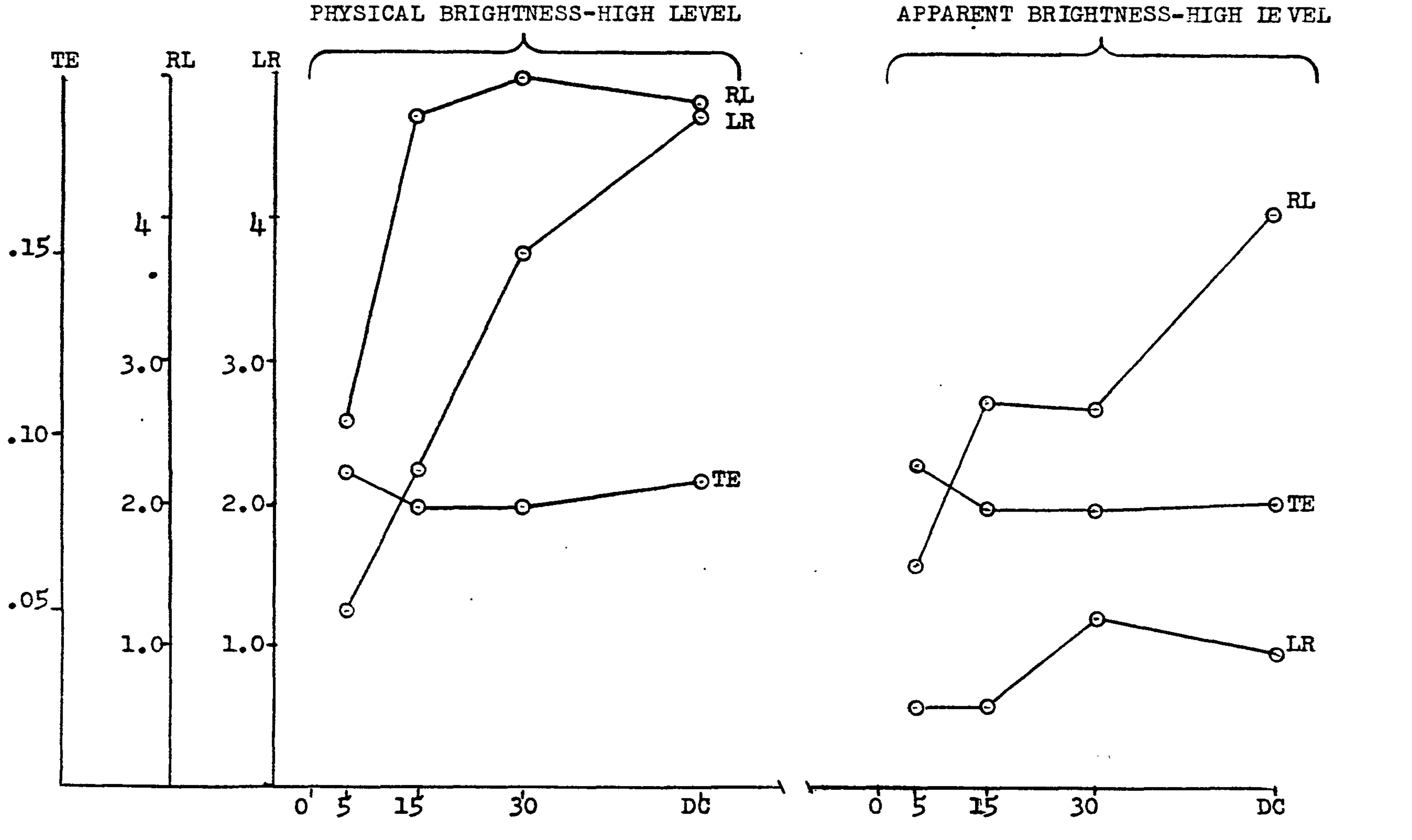


FIG. 4
TRACKING ERROR, RESPONSE LATENCY, AND NUMBER OF LANDOLT RING MISSES AS FUNCTIONS OF PULSED LIGHTING.

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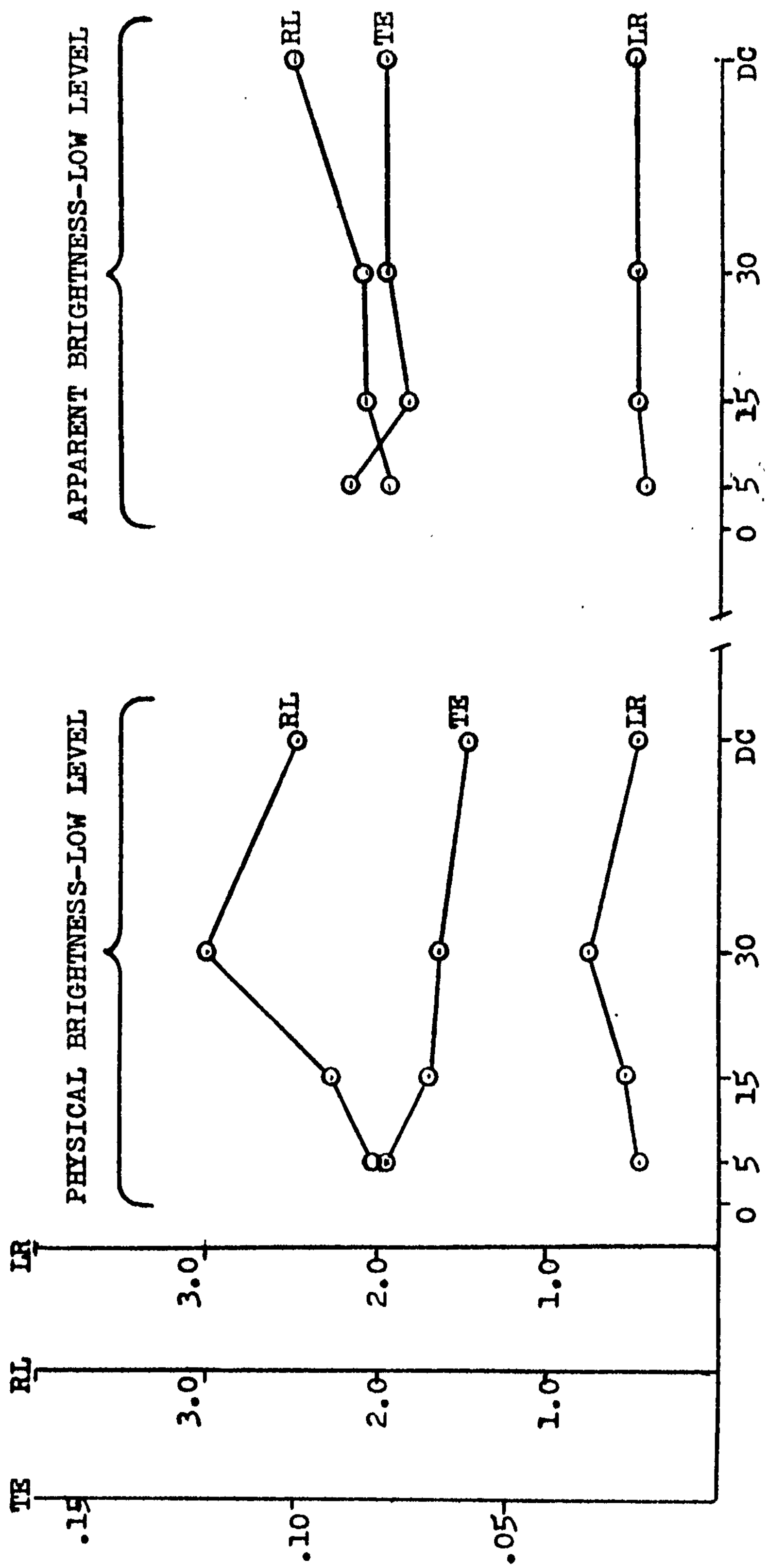

RL- Response Latency
TE- Tracking Error
LR- Number of Landolt Rings Missed.

FIG. 5

TRACKING ERROR, RESPONSE LA TENCY, AND NUMBER OF LANDOLT RING MISSES AS FUNCTIONS OF PULSED LIGHTING.

scores were not necessarily dependent nor continuously distributed. These factors immediately rule out the use of a parametric test.

4.2 Response Latency Measurements

For both the apparent and physical brightness conditions at the low level presentation, the response latency curves do not appear to show a significant difference across conditions(See figs. 4 & 5)but the low level physical brightness presentation did reach a level that was sufficient to reject the Null hypothesis of no difference (see Table VII). At the high level, for both physical and apparent brightness conditions, there were differences across conditions using the Friedman Two-Way Analysis of Variance. For the apparent brightness condition, the significance level was beyond .001. It appears then that except for the low apparent brightness presentations, response latencies for all conditions suffered as a function of increased pulse frequency rates or the number of foot-Lamberts per second actually reaching the eye. The same precaution in interpreting the number-of-misses curves should be utilized when examining the response latency curves.

4.3 Compensatory Tracking Error Measurements

The absolute integrated error sampled over five-second intervals was obtained for each subject for each experimental condition. These data points were averaged and presented as means in Tables III through VI. The overall means for each condition are plotted as curves in Figures 4 and 5.

Since these scores satisfied the conditions necessary for a parametric analysis, a Bartlett Test for determining homogeneity of variance was performed on each of the four tracking curves.

Homogeneity was demonstrated only for the apparent brightness measurements. A one-way analysis of variance across conditions for both curves (obtained under high and low level presentations) indicated no significant differences (see Table VII).

Heterogeniety of variance was disclosed by the Bartlett Test for the two curves generated under the conditions utilizing physical brightness measurements. A Friedman Two-way Analysis of Variance indicated no significant difference between conditions for each curve (see Table VII).

The four tracking curves were then processed with the Bartlett Test and a one-way analysis of variance was performed across the four curves. A non-significant F-ratio was obtained (see Table VII).

From these results, it can be stated with some degree of confidence that compensatory tracking performance is not influenced by:

1) Pulsed lighting in the range, 5 to 60 cps
2) Time-intensity energy of 12,000 Ft.-Lamberts seconds or less.
3) Type of luminance measurements (physical or apparent).

5.0 DISCUSSION

This experiment was originally designed as a two-part test, each subject first exposed to the four experimental conditions at the low level luminance, and then repeating the same experiment at a level three times higher than the first. The question was then raised as to the method of light measurement, and to the fact that the subjects, due to the subjective interpretation do not necessarily perceive the same physical intensity of light that is reflected from a test plate. The problem was resolved by collecting data twice using identical condition insofar as possible, the only difference between the two experiments being the apparatus used in measuring the brightness of the light , and some confounding of subjects. The Spectral Photometer measures physical luminance directly in foot lamberts while the Macbeth Illuminometer purports to yield subjective values in apparent foot candles.

The plan was then to use seven subjects in a two-part experiment, each of which was further subdivided into two levels of luminance. Unfortunately, during the latter part of the first run, the facility in which the experiment was being conducted was subject to change in location which resulted in many disruptions, chief among them was the loss of subjects. Some subjects were thus retained who met the condition of testing under identical conditions of two levels of brightness. In the second part of the experiment, seven subjects completed the experiment, again under two levels of brightness. It was not possible to achieve the desired result of obtaining data on seven subjects testing under identical conditions for the two-part experiment. Thus, some of the resulting differences between the apparent and physical brightness measurements may be due to the discrepancy in the number of subjects used.

Since there was such disparity between physical and apparent brightness readings as related to detection performance, an analysis was made on the distributional contributions of the Landolt rings. The rings were arranged in two columns of three rings for a total of six rings. The number of misses on each ring for all subjects in the two-part experiment was tabulated and statistically analyzed. For the high and low level apparent ft-candle brightness, and the low level physical brightness, non-significant Chi squares were obtained (all with probability larger than .30). However, for the high level physical brightness, a Chi square significant at 0.01 was obtained on the distribution of Landolt rings. An inspection of the data indicated that the column of rings appearing immediately adjacent to the tracking field showed a higher percentage of misses as compared to the other column located further away. Even though the pulsed light was fed through a funnel and thereby illuminating a field less than 1 x 1.5 inches, some of the light may have been diffused from the mirror surface to confuse the readings by reducing the contrast on the closest column of rings. If this were the proper explanation for differences noted at high level (physical brightness) it is not clear why it should not also be a factor for the high level condition where no differences were noted. Under either experimental condition when the illumination on the tracking needle was turned off, the subject could immediately perceive the rings, and could detect any changes without going through a period of dark adaptation. The implication to be noted is that subjects were somehow able to retain their dark adaptation in spite of pulsed light of high level intensity. Whether this is true under continuous lighting was not verified but is apparently not so as implied by the rapid fall-off in latency response time when using the fused lighting condition.

6.0 SUMMARY

This study examined the relationship of pulsed and continuous lighting upon a compensatory tracking task and its subsequent effects on scotopic detection performance.

The light for the tracking task was presented at two levels (high and low level measurements in foot-lamberts, and high and low level measurements in apparent foot-candle), and measured by two photometers, one designed to yield physical luminance (Spectral Photometer) and the other, apparent brightness (Macbeth Illuminometer). The lighting for the search task was maintained at 0.001 ft.L for all studies.

Three performance measurements were obtained:

1) Response latency in detecting phase changes in the Landolt rings
2) Number of hits or misses on the Landolt rings; and
3) Absolute tracking error in voltage figures

The principle results obtained were:

a) The frequency of pulsed lighting (5 to 60 cps yielding less than 12,000 ft-Lamberts Secs.) directed upon a tracking display did not significantly alter the performance of tracking a second-order pitch equation for all conditions ($p. < .05$, Friedman Two-way Analysis Variance and the parametric one-way analysis of variance when homogeniety of variance demonstrated). The forcing function of the tracking task was one of medium difficulty.

b) Response latency as a function of increasing pulse rate with time-intensity of 12,000 ft-Lamberts per sec. or less was significant at the .05 level for all conditions except the low level apparent brightness presentation.

Physical Brightness	low level ft-L, Chi square*, $.05 > p > .02$
	high level, ft-L Chi square, $.05 > p > .02$

Apparent Brightness	low level, apparent foot-candle (Chi square, $20 > p > 10$)
	high level, apparent foot-candle (Chi square, $.01 > p > .001$
	*Friedman Chi Square

c) Median number of Landolt ring misses as a function of increasing pulse rate (5 cps to 60 cps with time-intensity of 12,000 ft-Lamberts Secs. or less) was not significant for all conditions except for the high level physical brightness presentation.

Physical Brightness	low level ft-L (~~Chi squ~~are*, $.80 > p > .70$)
	high level ft-L (Chi square, $.01 > p > .001$
Apparent Brightness	low level, apparent foot-candle (Chi square, $.98 > p > .95$)
	high level, apparent foot-candle (Chi square, $.30 > p > .20$)
	*Friedman Chi Square

7.0 RECOMMENDATIONS

On the basis of the limited results presented, it may be concluded that dark adaptation may be preserved if the visual display to which an individual is attending is illuminated with pulsed lighting in the frequency range of 5 to 15 cps with a time-intensity factor of 500 Foot-Lamberts seconds or less reaching the eye. In this condition, a fairly critical vehicular tracking performance appears unimpaired.

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EXPERIMENT 1. PHYSICAL LUMINANCE

Subject	Low Level Order of presentation				High Level order of presentation			
R.H.	B	C	A	D	A	B	C	D
E.B.	C	A	B	D	B	C	A	D
K.G.	A	C	B	D	C	A	B	D
P.H.	B	A	C	D	C	B	A	D
D.P.	C	B	A	D	B	A	C	D

EXPERIMENT 2. APPARENT LUMINANCE

Subject	Low Level Order of presentation				High Level order of presentation			
N.S.	A	B	C	D	A	B	C	D
A.K.	B	C	A	D	B	C	A	D
D.F.	C	A	B	D	C	A	B	D
P.H.	B	A	C	D	B	A	C	D
B.L.	A	C	B	D	A	C	B	D
B.T.	C	B	A	D	C	B	A	D
E.B.	B	A	C	D	B	A	C	D
J.R.	A	B	C	D	A	B	C	D

A = 5 cps
B = 15 cps
C = 30 cps
D = 60 cps

MASTER SCHEDULE

TABLE I

PHYSICAL BRIGHTNESS

	LOW LEVEL						HIGH LEVEL					
% light time	Condi-tion	Cycles Per Sec.	Actual Input Ft.L.	Talbot Cor-rection	Ft.L. Per Sec.	Ft.L. Secs.	Condi-tion	Cycles Per Sec.	Actual Input Ft.L.	Talbot Cor-rection	Ft.L. Per Sec.	Ft.L. SECS.
.072	A	5	1.93	0.14	.70	42	A	5	5.79	0.39	1.95	117
.22	B	15	1.78	0.39	5.83	350	B	15	5.34	1.17	17.55	1053
.43	C	30	1.57	0.68	20.40	1224	C	30	4.71	2.03	60.90	3654
1.00	D	60	1.00	1.00	60.00	3600	D	60	3.00	3.00	180.00	10,800

APPARENT BRIGHTNESS

	LOW LEVEL						HIGH LEVEL					
% light time	Condi-tion	Cycles Per Sec.	Actual Input Ft.L.	Talbot Cor-rection	Ft.L. per Sec.	Ft.L. Secs.*	Condi-tion	Cycles Per Sec.	Actual Input Ft.L.	Talbot Cor-rection	Ft.L. per Sec.	Ft.L. Secs.*
.072	A	5	2.41	0.174	0.87	42	A	5	7.24	.521	2.61	124
.22	B	15	2.23	0.491	7.37	354	B	15	6.68	1.47	22.05	1058
.43	C	30	1.96	0.843	25.29	1213	C	30	5.89	2.53	75.90	3643
1.00	D	60	1.25	1.25	75.00	3600	D	60	3.75	3.75	225.00	10,800

*.80 reflectivity correction

TABLE II

Tabulation of light input data.

Subj	5 cps			15 cps			30 cps			D. C.		
	# Miss/6 on Landolt rings	Median Reaction Time (Rings)	Mean Tracking Error	(same as 5cps)			9(same as 5cps)			(same as 5 cps)		
RH	0	2.70	.087	1	3.15	.061	1	3.45	.053	0	3.45	.046
DP	0	1.67	.069	0	3.90	.063	1	4.68	.095	0	1.90	.066
EB	0	1.90	.083	0	1.90	.070	0	2.90	.060	0	2.90	.066
KG	0	1.54	.074	0	1.70	.063	0	2.90	.048	0	2.90	.053
PH	0	1.66	.080	0	1.33	.060	0	1.45	.068	0	1.67	.061
	Md # of rings missed	Mean Reaction Time (rings)	Mean Tracking Error	(same as 5cps)			(same as 5 cps)			(same as 5 cps)		
	.45	1.89	.079	.56	2.40	.063	.75	3.08	.065	.45	2.56	.058

TABLE III

PHYSICAL BRIGHTNESS
Criterion Measures (low level)

Subj.	5 cps			15 cps			30 cps			D.C.		
	# Miss/6 on Landolt Rings	Median Reaction Time (Rings)	Mean Tracking Error	(same as 5cps)			(same as 5cps)			(same as under 5cps)		
FI	1	3.75	.101	1	4.23	.080	4	4.0	.080	3	7.22	.091
DP	3	3.75	.090	4	6.0	.087	5	-	.082	5	4.0	.085
EE	0	2.67	.068	2	5.40	.071	3	8.23	.072	5	3.00	.069
HC	1	1.45	.088	1	5.40	.065	3	4.45	.073	4	5.90	.073
PH	0	1.70	.090	2	2.40	.087	3	3.40	.083	3	3.67	.112
	Md # of rings missed	Mean Reaction Time (rings)	Mean Tracking Error	(same as 5cps)			(same as 5cps)			(same as under 5cps)		
	1.23	2.66	.087	2.23	4.69	.078	3.75	4.98	.078	4.67	4.76	.086

TABLE IV

PHYSICAL BRIGHTNESS
Criterion Measures (high level)

Subj.	5 cps			15 cps			30 cps			D. C.		
	# Miss on L. rings	Md. Re-action time on rings	Mean Track'g Error	# Miss on L. rings	Md. Re-action time on rings	Mean Track'g Error	# Miss on L. rings	Md. Re-action time on rings	Mean Track'g Error	# Miss on L. rings	Md. Re-action time on rings	Mean Track'g Error
NS	0	3.45	.076	0	3.60	.068	0	2.22	.082	0	2.54	.053
RF	0	1.90	.066	0	1.90	.047	0	2.45	.053	0	2.54	.057
PH	0	1.30	.084	0	1.54	.077	0	1.45	.062	0	1.90	.064
B	0	1.75	.096	0	2.90	.072	0	1.90	.092	0	3.30	.087
BL	0	1.75	.081	0	1.90	.064	0	1.90	.061	0	3.90	.059
AK	0	1.90	.073	0	1.30	.063	0	0.68	.085	0	1.54	.083
EB	0	1.90	.076	1	1.75	.064	0	4.45	.074	0	2.90	.071
JR	0	1.60	.130	0	2.30	.126	0	1.45	.112	0	1.90	.088
	Md. # Miss	Mean Re-act.time	Mean Track'g error	(same	as under	5cps)	(same	as under	5cps)	(same	as under	5cps)
	.45	1.94	.085	.51	2.15	.073	.45	2.06	.078	.45	2.57	.070

TABLE V

APPARENT BRIGHTNESS CRITERION MEASURES

(LOW LEVEL)

Subj.	5 cps			15 cps			30 cps			D.C.		
	# Miss/6 on L. rings	Median React. Time (Rings)	Mean Track'g Error	(same as under 5cps)			(same as under 5 cps)			(same as under 5cps)		
NS	0	2.15	.063	0	3.22	.065	1	3.23	.060	1	3.45	.055
RF	0	1.54	.074	0	1.90	.043	0	1.90	.061	0	1.90	.042
PH	0	0.450	.071	0	1.36	.090	0	0.54	.077	0	1.67	.070
B	0	1.45	.093	0	2.45	.087	0	2.30	.076	0	3.90	.089
BL	0	1.75	.090	2	3.12	.073	1	2.70	.062	3	8.90	.071
AK	1	1.68	.114	0	4.36	.100	3	6.22	.096	6	0.0	.095
EB	0	2.54	.082	1	3.68	.075	1	2.75	.082	0	5.45	.098
JR	0	1.36	.130	0	1.68	.091	1	1.68	.100	2	2.90	.130
	Md # of rings missed	Mean Reaction time (rings)	Mean Track'g Error	(same as under 5cps)			(same as under 5cps)			(same as under 5cps)		
	.60	1.62	.090	.60	2.72	.078	1.22	2.67	.077	.90	4.02	.081

TABLE VI

APPARENT BRIGHTNESS CRITERION MEASURES

(HIGH LEVEL)

	APPARENT BRIGHTNESS (low level)	APPARENT BRIGHTNESS (high level)	PHYSICAL BRIGHTNESS (low level)	PHYSICAL BRIGHTNESS (high level)
Landolt rings missed across 4 strobed conditions	$\chi^2 = 0.22$	$\chi^2 = 4.16$	$\chi^2 = 1.61$	$\chi^2 = 12.60$**
Response latency across 4 strobed conditions	$\chi^2 = 6.19$	$\chi^2 = 21.0$***	$\chi^2 = 7.92$*	$\chi^2 = 9.24$*
Tracking error across 4 strobed conditions	Analysis Variance F = 2.41	Analysis Variance F = 0.78	$\chi^2 = 4.72$	$\chi^2 = 1.88$
	Analysis of variance of tracking error across all 4 conditions F = 1.40			

*Significant at .05
**Significant at .01
***Significant at .001

TABLE VII

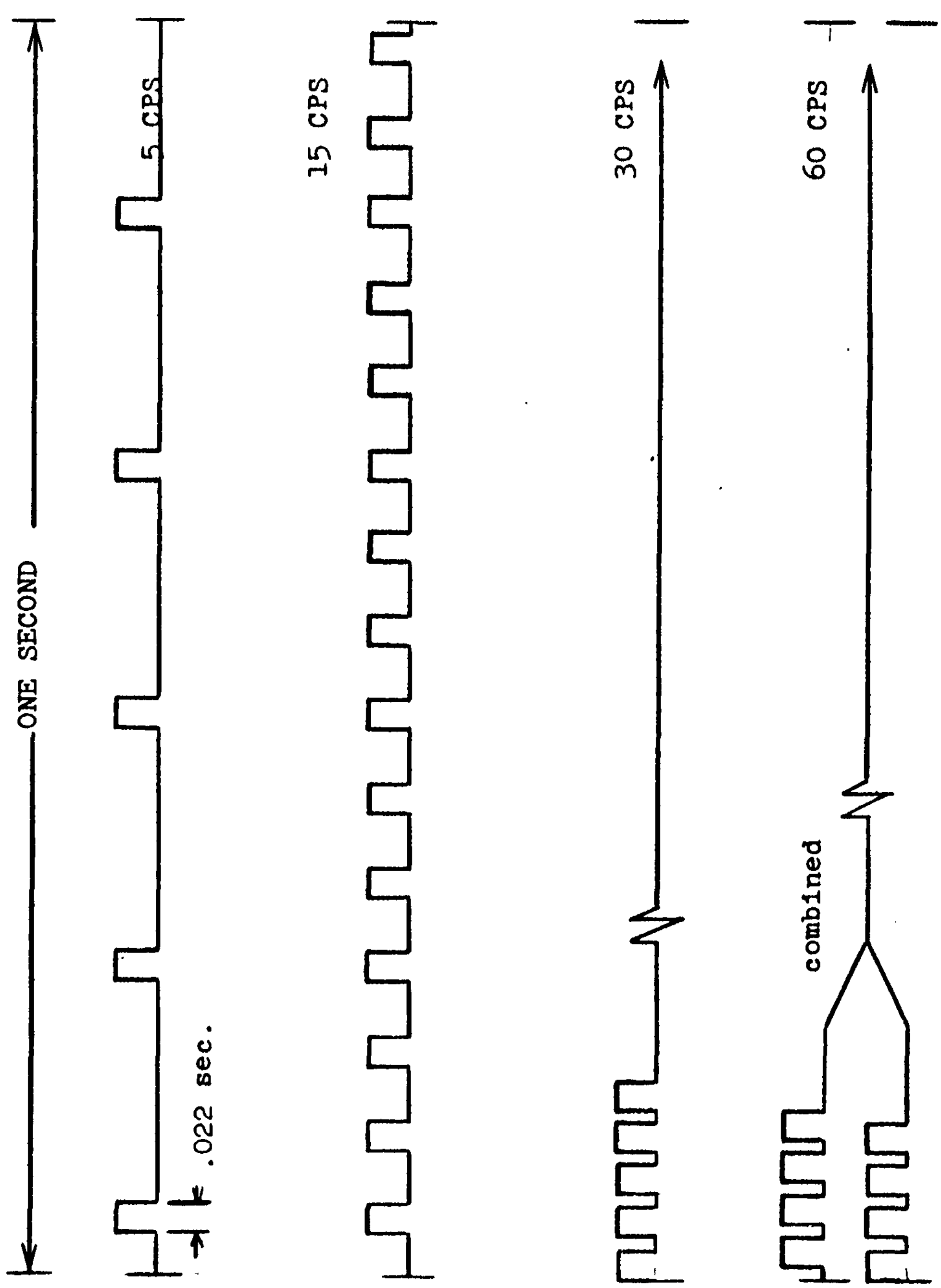
Tabulation of treated data. All χ^2 (Chi Square) obtained through the use of Friedman Two-way Analysis of Variance

APPENDICES

APPENDIX A

VISUAL ANGLES OF COMPONENTS IN TEST FIELDS

Component	Visual Angle
Immediate surround	
Horizontal (11.0")	18° 22'
Vertical (8.0")	13° 26'
Between tracking needle and middle of outer row of Landolt rings	10° 6'
Between tracking needle and inner row of Landolt rings	7° 4'
Landolt-ring pattern	
Horizontal	2° 19'
Vertical	3° 41'
Landolt ring	1° 40'
Landolt ring gap or break	12'
Tracking needle at rest (9 o'clock)	
Horizontal	51'
Vertical	6'
Tracking needle (oscillating field)	1° 1'



Appendix B Wave forms of various experimental light pulses. Flash duration constant at .022 sec.

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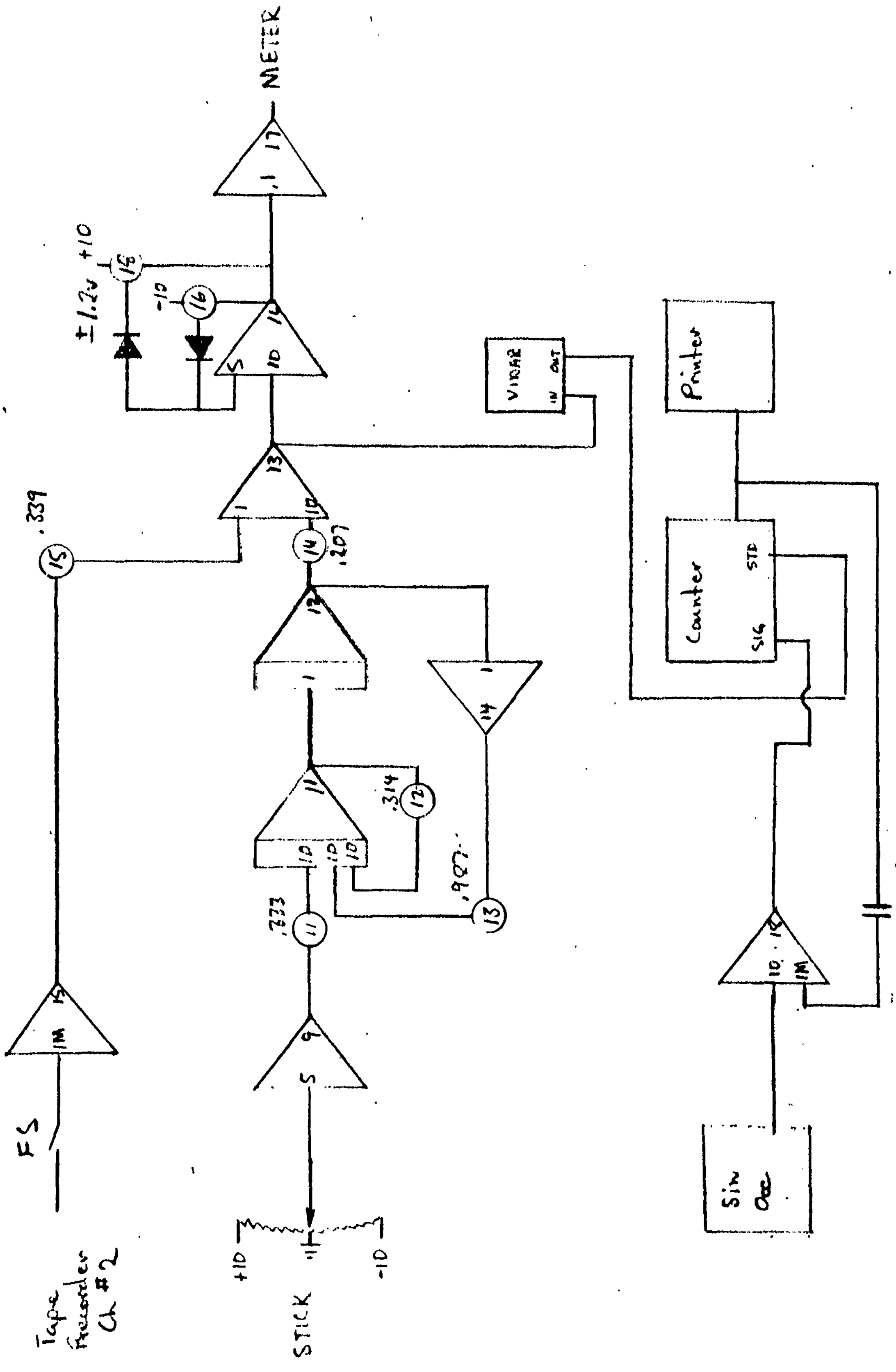

APPENDIX C. TRACKING EXPERIMENT IN PITCH

L. Sommers

APPENDIX D

ACUITY AND COLOR TESTS

Subject	Right Eye	Left Eye	AO H-R-R Color Plates
E.B.	20/15	20/20	normal
P.H.	20/20	20/20	normal
B.T.	20/30	20/20	red-green
D.F.	20/30	20/50 30	normal
J.R.	20/20	20/20	normal
N.S.	20/30	20/30	normal
B.L.	20/20	20/20	normal

APPENDIX E

INSTRUCTIONS TO SUBJECTS

This is a study on dark adaptation. You know that when you first enter a darkened movie theater, it takes a little while before your eyes become used to the dark. After you've spent 5-10 minutes in the dark, you suddenly begin to see people and things around you that you didn't see when you first came in.

In this experiment, we are trying to find the effects of different kinds of lighting on dark adaptation. We want to find out whether or not a pilot could take his eyes off a display and yet look almost immediately into the night sky.

Your first task will be that of tracking a needle. Look through the scope now and you will see a needle going up and down. Your task is to keep the needle level or at 9 o'clock. This you can do by moving the control stick by your side. Will you try tracking now?

After asymptote:

The tracking task is the most important job as far as you are concerned. Whether or not you crash your aircraft depends on your careful tracking of the needle. At all times during the experiment, when the needle is on, your primary job is to track the needle. We will ask you to do other tasks during the experiment, but the most important thing is the tracking. Your tracking response is being recorded outside this booth.

Do you have any questions? If not, we will proceed with the experiment.

APPENDIX F

COMPENSATORY INCREASES IN INTENSITY FOR VARIOUS CONDITIONS ACCORDING TO TALBOT'S LAW

1.0 Ft-L

CON-dition	increase req'd	increase instituted	increase req'd	increase instituted
A 5 cps	93%	1.93 Ft-L	93%	5.79 Ft-L
B 15 cps	78%	1.78	78	5.34
C 30 cps	57	1.57	57	4.71
D 60 cps	0	1.00	0	3.00

For the apparent luminance experiment, the same magnitude in increase as above was followed. The McBeth Illuminometer was directed at the test field with the corrected apparent foot-candle held constant at the index. The variable density filter was adjusted until an optical balance was achieved in the illuminometer. The mean readings at the filter are as follows:

Con-dition	1.0 apparent Ft-candle	3.0 apparent Ft-candle
A 5 cps	5.4	4.0
B 15 cps	6.0	4.5
C 30 cps	6.6	5.0
D 60 cps	6.9	5.7

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