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AN INVESTIGATION OF THE RED ILLUMINATION
OF THE SUBMARINE CONNING TOWER.

Interval Report No. 1
of Bureau of Medicine and Surgery
Project X-519(Lv-273-p)

Prepared by:

Lt.(jg) W. S. Verplanck, H(S) USNR

15 March 1946

APPROVED: C. W. SHILLING, CAPTAIN (MC) USN, MC-in-C.

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"A Study of the Illumination of the Submarine Conning Tower"

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C O N T E N T S

SUMMARY

Although many studies of red illumination have been made, and theoretical findings used to establish optimum illumination of working spaces where night vision must be maintained, few of these have been practically evaluated in terms of the night vision performance required in or near that space.

This report describes experiments designed to provide such practical evaluation of the red illumination of the conning tower of a submarine. The visual performance simulated that of an officer at the periscope, and the illumination conditions, which determined the state of dark adaptation of the subjects employed, included:

(a) Complete absence of lights in the conning tower.
(b) Full illumination of all night lights, and of all instruments, in a conning tower painted black.
(c) Full illumination of all night lights, and of all instruments, in a conning tower painted flat white.

The results clearly indicate that, without respect to the interior paint finish, the red light provided in the conning tower by two 50-watt red steam-tight fixtures, although sufficient to permit casual reading and chartwork, is not sufficient to impair to any measurable extent practical night visual performance of personnel working in such a space.

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Note: The results of this investigation were transmitted to the Bureau of Ships on 28 April 1945 in a preliminary report. Further reports were transmitted verbally two weeks later.

AN INVESTIGATION OF THE RED ILLUMINATION OF THE SUBMARINE CONNING TOWER.

A. INTRODUCTION

The Medical Research Department, U. S. Submarine Base, has undertaken a series of experiments on conning tower illumination at the request of the Bureau of Ships. These were designed to determine the extent to which laboratory findings on the effect of dim red light upon night vision may be duplicated in a practical situation.

Such experiments were considered necessary not only because available data on dark adaptation indicated that some decrement in night vision performance might be expected, but also because in a series of carefully controlled experiments conducted at NMRI*, such a decrement, although small, has been found in the absolute visual threshold.

This decrement, experimentally induced by a uniformly illuminated field, and measured by a precise technique, might be expected to appear in a non-uniformly illuminated space such as a conning tower, when the performance in question is one which is affected by many other factors than the state of the adaptation of the retina. It is the present problem to determine whether or not it does.

A performance simulating the visual task of an officer at the periscope was therefore measured under three conditions of conning tower illumination. This performance was the detection of the position of a target in the dimly illuminated field of a simulated periscope. A similar measure has proven useful in previous studies of dark adaptation as a function of illumination.**

The tests were conducted in the Mark IV Attack Trainer of the Submarine School, which was made available for this purpose by Captain F. E. Warder, USN, Officer-in-Charge of the Submarine School. This trainer is a replica of the conning tower of a submarine, with

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* Lee, R.H. Instrument Lighting and Low Level Illumination in Submarine Conning Towers. Naval Medical Research Institute, Bethesda, Maryland, 1/17/45.

** Bromer, J.A. An Experimental Comparison of Ultra-Violet and Indirect Red Illumination Systems for Aircraft Instrument Panels. Aero-Medical Department, Naval Air Experimental Station and the Franklin Institute.

a nearly complete set of the instruments found in fleet-type submarines, with night lighting, and with a Number Two periscope which may be raised for observation of targets on a model seascape, seen against an evenly illuminated sky.

B. EXPERIMENTAL DESIGN

1. Night Visual Performance and Basic Procedure:

The experimental procedure was established after a month's series of preliminary experiments. Basic difficulties were uncovered during this period, and were eliminated from the procedure finally developed. This final procedure was followed through all three of the experiments reported herein.

The performance utilized was the detection of a target in the field of a dummy periscope. This target appeared in any one of five positions in the field - "center", "left", "right", "far left" and "far right", from the observer's point of view.

Subjects were run in teams of three, each taking his turn in an experimental series of 20 trials per man. Each team ran four such series during an experimental session.

On each trial, a team of subjects was posted at the Dead Reckoning Tracer, which is located just aft of the hatch against the starboard bulkhead. A "ready" signal was given, then "Go!". On the word "go", a stopwatch was started, and the first subject proceeded to the periscope as rapidly as possible. As soon as he had oriented himself to the periscope field and had detected the horizon, he called, "Mark". At this time, the first stopwatch was stopped and a second started. The second stopwatch was stopped when the subject reported the correct location of the target. The subject then returned to his starting place to await his next trial, and the next member of the team was run. The two time measures obtained have been termed "periscope time" and "pick-up time" respectively.

All experimental sessions were held at night between 0000 and 0700, this being the only time at which the Attack Trainer was available. Subjects modified their regimen of sleep, so that five nights of work were possible in any week.

Approximately one and one half hours intervened between the starts of successive experimental series. Between series, subjects always wore red goggles and waited in a room illuminated with ordinary incandescent light to a level of approximately 3-4 foot candles at the working height. At least 10 and usually 15 minutes before the beginning of an experimental series, the subjects adapted themselves to the condition of illumination of that series by going

into the conning tower and remaining there under the appropriate lighting conditions. No restrictions were imposed on their movements during this final adaptation period.

Of the four series of trials run on each night, two were made in complete darkness (B), and two under red (R) conditions of illumination. The order of these was varied systematically, BRRB, RBBR, RBBR and BRRB, from night to night.

2. Experimental Variations of Illumination:

The two conditions of illumination employed were no illumination whatever ("black") and "red". Under "black" conditions, the conning tower was completely blacked out. The only lights visible to the dark-adapted eye were the faint glow of a covered-over radium-illuminated instrument dial which could not be completely obscured, and an electron tube filament which could be seen at a distance through the conning tower entrance.

Under "red" conditions, the night-lighting circuits of the conning tower were illuminated. This included the following items:

(a) Lighting fixtures:

Two steam-tight lighting fixtures, one located forward and to the port side, just in front of the illumination switch panel, and one located aft and to the port, just above the TDC, were illuminated. Each of these was fitted with a 50 watt GE red incandescent light bulb.*

(b) Instruments:

The following instruments were also illuminated at their highest brightness:

(1) Torpedo Data Computer, Mark IV. (Sylvania Lighting)
(2) Underwater Sound Equipment (Sylvania Lighting); Range Dial lacking.
(3) Periscope Azimuth Circle Illumination, SL-1021.
(4) Dead Reckoning Tracer (red-dipped incandescent bulbs).
(5) Engine Order Telegraph.
(6) Rudder Angle Indicator.
(7) Pit Log.
(8) Depth Gauge (Radium).

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* Such relatively high illumination would not be employed during a night approach or when a submarine is surfaced at night. It was used, however, in order to test the red lighting under conditions which should surely show an operationally meaningful loss of night vision if this were possible to demonstrate.

Other instruments, e.g., the radar, were not operational, and consequently could not be illuminated. None of these, however, would contribute significantly to the illumination of the working space, and none would be visible to the eye of an individual working in that space.

A series of brightness measurements was made, employing a Macbeth Illuminometer modified for the measurement of red light, These measurements were taken at several points within the conning tower, selected as typifying the brightnesses exposed to the eye. (Table IA, Appendix). Measurements of illumination in white and red were made at the same time, and are presented in Tables IIA and IIB of the Appendix.

It should be noted that throughout the first two experiments the bulkheads of the conning tower were painted black. This produced suppression of reflection, so that all sources of reflection were decidedly high-lights.

C. FIRST EXPERIMENT

The first experiment, which took place on the nights of March 5, 6, 7 and 8, 1945, employed the periscope of the conning tower and the illuminated seascape provided in the Mark IV Trainer.

1. Periscope:

The periscope of the Mark IV Attack Trainer is a modification of a standard Kohlmorgen instrument, designed to suit the special needs of the Trainer. The real field, in low power, is 20° in diameter, and is bisected horizontally by a simulated horizon produced by a Kodachrome artificial seascape placed in the position of a reticle in the optical path.

This periscope, when raised, may be trained around an artificial skyscape. This "sky", a panorama backdrop some 17 feet in radius, is very evenly illuminated by a series of 19 150 W Mazda projector floodlamps, equipped with a Pyrex HR Mitchell color filter #1923, "Rich Blue". Against this sky, ship models may be observed. These are mounted on crabs, which are concealed from the view of the man using the periscope by the sea-foreground reticle mentioned above.

2. Sky Brightness:

Since the transmission of the periscope was unknown, it was considered advisable to begin with a fixed amount of light on the

seascape seen through the periscope and to vary the difficulty of the test by variation of the target size. Brightness of the skyscape was set approximately at 5.50 log micromicrolamberts. Constancy was achieved effectively by use of a rheostat and voltmeter. Each night, measurements were made by at least two individuals at the beginning, in the middle, and at the termination of the experimental session. These measurements yielded throughout the full course of the experiment, 5.51 ±.02 log uul as the value of the "sky" brightness. The whole panorama of the skyscape observed through the periscope was of uniform brightness within the error of measurement.

Owing to the complexity of the optical system, the light transmission of this periscope is low, and the visual stimulus is well within the starlight range of brightness.

3. Target:

During preliminary trials, a series of targets of high contrast which gave pick-up times in the desired range were tried. The target finally selected on the basis of these preliminary runs was a 1:500 scale model of the U.S.S. ESSEX, at zero angle-on-the-bow, viewed through the low power objective at a simulated range of approximately 2100 yards. This yielded a rectangular target subtending a solid angle of 0.75 square degrees at the retina.

4. Control of Target Positions:

The position on the horizon of the target in the periscope field was varied by control of the position of the entrance pupil of the periscope. This was achieved mechanically and optically without movement of the exit pupil of the periscope or of the target. The lower end of the periscope in the conning tower, then, always remained in the same position, trained at relative bearing 000 and the target was never shifted. It was made to appear at the relative bearings 353, 356, 000, 004 and 008 in the 20° periscope field for "far left", "left", "center", "right" and "far right" respectively, giving 6° intervals between positions in the 30° apparent field. Balanced series were used, so that the target appeared the same number of times in each position for each subject in each series. Positioning was performed by a petty officer who worked at the control panel of the Attack Trainer.

5. Timing:

Measurement of periscope time was made by an operator in the conning tower. This man was responsible for giving all signals, and controlling the activity of subjects during a series. Measurements of pick-up times were made by the control panel operator. An IVC system provided efficient communication.

6. Correction of Responses:

Each subject's response was immediately called "right" or "wrong" by the control panel operator. In the latter instance, search of the periscope field continued until the target was correctly located, and the timer stopped only when the correct response had been given.

7. Subjects:

Three subjects, Mi, Zi, and Kr, all Seamen, were employed in the first experiment. All were normal with respect to scotopic sensitivity, their terminal rod thresholds being determined (Hecht-Shlaer Model III Adaptometer) at 2.3, 2.3 and 2.2 log uul respectively. All were thoroughly trained during the exploratory experimentation, and had reached a stable level of performance. All were cooperative, and understood the importance of the work. Under instruction to report the target on "hunch", they did so, and refrained from guessing. Statistical analysis of errors indicates that they were successful in avoiding the tendency to guess in order to give shorter times.

8. Results:

Periscope times were not extensively treated statistically, inasmuch as they were extremely short (average: 3 seconds), very consistent, and represented exclusively the time required to move to the periscope, and to adjust the head to the eyepiece. All statistical analysis has therefore been devoted to the pick-up time.

Since the distribution of pick-up time was geometric, geometric means were computed. Table I gives these mean values for all trials of the pick-up time under conditions of red illumination, under conditions of no illumination, and for both, together with the ratio of pick-up time under red illumination to pick-up time under no illumination.

Similar values are given for each of the four nightly series, for each of the four nights, and for each of the three subjects. Only among the latter do stable differences appear, and there is no important indication of systematic differences among series and nights.

It is evident that there is no reliable deterioration or improvement of performance in the absence of illumination, and statistical analysis shows that the apparent better performance under red illumination is not reliable, and might have occurred by chance. A more extensive statement of the statistical treatment, together with complete data on each subject, is given in the Appendix, in Tables III, IV, V and VI.

9. Errors:

It will be remembered that if a subject made an error, he was so informed, and search continued until the correct response was given. The time was measured as usual and included in the data. Three reasons led to the adoption of this procedure. First, it was desired to determine if red light led to a greater number of erroneous locations, possibly by the production of misleading after-images. Second, erroneous reports characterize performance in the region of the visual thresholds, and are valid factors in contributing to long scanning times. Finally, a check of erroneous reports permits analysis of all the data to determine the effect of guessing on this performance.

Table II gives the number of trials under each condition of illumination on which one or more erroneous reports of the location of the target were made. It includes the value of chi-square, based on the assumption that an equal number of errors should be made in a like number of trials, and the probability that the departure from this hypothesis is attributable to a systematic factor, rather than to the procedure of sampling. For two subjects, there is a probability at the 5% level that fewer errors are made in the presence of red illumination. This value of "p" is such that no final conclusions may be drawn.

Analysis of the number of errors made on each trial indicates clearly that at no time were the subjects guessing systematically on the location of the target, but that in reporting the location of a target they were "playing their hunches", or "reporting on suspicion" as they had been instructed. Thus, on approximately 2/3 of all trials for each man, the first report was correct. After one error had been made, each subject located the target correctly on the next report better than 50% of the time. This holds true progressively. At no time does the number of correct responses fall to the chance expectancy level. The conclusion that guessing is not a factor in performance is also borne out by the fact that occasionally a subject would make more than 4 errors - that is, he would repeat a report which he had already made, and which had been called wrong. This was done, according to the subject, from his belief, based on what he thought he saw, that the operator's response of "Wrong" to a report might have been in error.

10. Discussion:

The data seems to indicate that red light, of the intensities reached in the present experiment -- which were deliberately chosen on the basis of preliminary experimentation to show an effect -- does not interfere with a "practical" visual performance.

Several objections might readily be raised to such a conclusion on the basis of the present experiment.

TABLE I.

Exp. I: Mean*Pick-up Times Under Red Illumination and Under No Illumination.

	Both Conditions	Red Light	No Illumination	Ratio R/B
All Trials (All Subjects All Nights)	3.8	3.5	4.1	.85
Series 1	3.5	3.6	3.2	1.13
Series 2	4.5	4.0	5.3	.76
Series 3	3.7	3.8	3.7	1.03
Series 4	3.6	2.8	4.6	.64
(All Subjects All Series)				
Night 1	5.6	5.6	5.7	.98
Night 2	4.1	3.3	4.9	.68
Night 3	2.6	2.6	2.6	.98
Night 4	3.5	3.1	4.0	.78
(All Nights, All Series)				
Each Subject:				
Kr	2.0	1.6	2.4	.69
Mi	4.7	4.2	5.4	.78
Zi	5.7	6.2	5.4	1.15

Mean = Geometric Mean; Pick-up Time in seconds.

* Value will not necessarily correspond with a simple average of "red" and "black"(no illumination) times.

TABLE II.

Experiment I: Errors (N = Number of trials on which one or more errors occurred)

Subject	N.Black	N.Red	Chi Square	p(%)
Zi	52	61	.62	less than 50, more than 30.
Mi	50	31	4.46	less than 5, more than 1.
Kr	45	27	4.50	less than 5, more than 1.

(1) The small exit-pupil of the periscope may have served as an artificial pupil and obscured the effect on visual performance of pupillary contraction effected by the red illumination.

(2) Other subjects might not show this negligible effect. More subjects should be run.

(3) The variability of the performance is such that random errors, arising from the relatively uncontrolled situation, might obscure the effort completely. They might equally well obscure <u>any</u> effect.

A second experiment, following the plan of the first, was therefore undertaken to meet these objections insofar as time, facilities, and personnel permitted.

D. SECOND EXPERIMENT.

1. Periscope:

A new dummy periscope was designed and built. Optically, it consisted of one barrel of a 7 x 50 binocular, with an extension between the eyepiece and the prism system to permit focusing at a distance of 109.5 cm.

This monocular was mounted on the front of an elongated black box which had, as in a periscope, a false eye-cup in the correct position. The eyepiece of the monocular was at the same height above the deck as that of the periscope, and the box was fitted with handles similar to those of a periscope.

At the other end of this light-tight box was mounted an NDRC Model III Adaptometer, placed at such a distance from the monocular that its circular field duplicated that of the Type 4 periscope. The rotatable T and its controls were removed from the adaptometer, so that a clear visual field was obtained. The use of this instrument permitted accurate control of illumination.

Immediately in front of this illuminated field was placed a movable slide made of four sheets of neutral filter of .10 l.u. density, cemented between two sheets of glass, and duplicating a typical sky-sea brightness ratio. The top of this slide bisected horizontally the field of the monocular to produce an effective sea-foreground and horizon line.

A comparison of the specifications of this device with those of the Type 4 Periscope shows the similarity of those specifications significant to the visual task.

	Type 4 Periscope		Mock-Up Periscope
	High Power	Low Power	
Power	6.0x	1.5	7.0x
Entrance pupil	42.0 mm	10.5	50.0 mm
Exit pupil	7.0 mm	7.0	7.14 mm
Transmission	50.9 %	43.6 %	55.0 %
Real field	8o	3.2°	6.8°
Apparent field	48o	48o	47.5°

2. Sky Brightness:

Since the transmission of the monocular is known, it was possible to fix the brightness of the visual field on a basis other than arbitrary. It was decided to select a "sky brightness" comparable to that of a moonless night. The NDRC instrument was accordingly adjusted so that the field brightness was approximately 4.90 log uul. Measurement at this set level at the beginning and at the end of the experiment, gave a value of 4.91 ±.02 log uul.

3. Target:

The target employed consisted of a small thickness of the same filter as the sea-foreground, cemented on the horizon slide. This piece measured 6 mm in height by 1.5 mm in width. Two mm. of the target extended above the horizon. This 1.5 x 2 mm rectangle protruding above the horizon was backed by a second piece of filter of the same size, making the density of the target above the horizon .20 l.u. in all. The area of this part of the target subtended .40 square degrees at the retina, and that of the area below 1.20 square degrees. Contrasts were respectively .38 and .22. The total area, 1.60 square degrees, may be compared with the 0.75 degrees of the target in Experiment I. In all probability, it was only that part of the target extending above the "horizon" which was effective. Its retinal area corresponds to that yielded by an aircraft carrier at 13,300 yards and zero angle-on-the-bow, which may be compared with the 2,100 yards of the target of Experiment I.

4. Control of Target Position:

The position of the target was varied by lateral movement of the horizon slide. Shifts through steps of 2.1 cm have a separation at the retina of 7.7° for the five positions, slightly greater than that of Experiment I (6°). As before, balanced series were used.

5. Timing:

The same time measurements were obtained as in the previous experiment. They were made, however, by a member of the team of subjects not being run at the time. This necessarily increased the timing error, which is difficult to eliminate, but it was unavoidable.

6. Error Correction:

As before, search continued until the correct position of the target was reported. However, in this experiment, as soon as the correct position was reported, the target was illuminated briefly by a flashlight bulb to enable the subject to see the target easily. The bulb, located in the middle of the interior top surface of the NDRC Adaptometer, and operated by a switch on the side of the box, made it possible to illuminate the periscope field to a brightness of 7.80 log uul, permitting easy location of the target when desired. Verbal evidence from another laboratory has indicated that this procedure might decrease the variability of performance. The brightness and duration were such that complete recovery from the slight light adaptation produced was effected before the subject's next trial began.

7. Subjects:

Six subjects were employed. Three of these, forming Team A, had been employed in the previous experiment; the three additional subjects, Ma, Mc, and Ba, forming Team B, were all quartermaster strikers, and were found to be normal with respect to scotopic sensitivity. (Terminal rod thresholds were measured at 2.3, 2.1 and 2.1 log uul respectively.)

All six men were thoroughly trained on the present instrument in ten nights of exploratory and training experimentation, until a stable level of performance had been reached. As before, all subjects were cooperative, all tried to perform as well as possible, and all refrained from irresponsible guessing, as the data show.

8. Experimental Series:

Data were collected on four experimental nights, April 11, 12, 18 and 19. Each team of subjects made runs at intervals of $1\frac{1}{2}$ hours as before. The two teams of subjects alternated in running on the periscope, and in measuring the periscope time of the other team. Order of "red" and "black" series also alternated between the two teams, Team A running R-B-B-R, B-R-R-B, R-B-B-R and B-R-R-B; and Team B running B-R-R-B, R-B-B-R, B-R-R-B and R-B-B-R respectively, on the four nights of experimentation.

9. Results:

Table III gives mean pick-up times for all men under each condition of illumination in this experiment. Complete results are given in Tables VIII, IX, X, XI, XII and XIII of the Appendix. The faster times shown by two of the three subjects also employed in Experiment I indicate that this task is perhaps an easier one than the former. The difference may be considered due largely to differences in brightness. However, the times obtained are all of the same order of magnitude.

On the pooled results, an average delay of .3 seconds appeared, which is barely significant statistically".* On no one night, or on any series, or for any one subject is the difference statistically significant.

For 5 of the 6 subjects, a difference appears between mean "red" and "black" pick-up times, the former being longer by some 15%, although the difference is not a reliable one in any case. Thus, it may take, on the average, 8 seconds to see a target after being exposed to the red illumination of the black-painted conning tower, when that target could be made out in 7 seconds by a man who is completely dark-adapted. The operational importance of this difference cannot be judged on the basis of these data alone.

No reason can be adduced from the relatively slower performance of Team B compared to Team A other than their shorter training at the task.

10. Error:

The same analysis of errors which was performed on the data of Experiment I was again performed. The results, shown in Table IV, are similar to the earlier set, but indicate that the apparent tendency to make fewer errors in red light was a spurious one. The correction technique, it appears, had little effect on the number of errors made.

11. Brightness Variations:

Earlier in this report, it was suggested that the objection might be raised that the present experimental method was not sensitive to variations in the experimental procedure and consequently not suited to the production of reliable data. As a check, on one night, five subjects were run on three series of trials with no external illumination, but with variation in the periscope field brightness. The results are presented in Table V, and, in greater detail, in Table XIV of the Appendix.

In this series, statistically significant and systematic variation of performance occurs in as little as 20 trials.

At the time that these series were run, the subjects were not informed of any differences in field brightness. However, all subjects commented immediately on the increased difficulty or ease of the first run, and asked what had been done. Ordinarily comments

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* That is, a difference of this size would have occurred fewer than once in twenty possible times by chance. It is therefore presumed to be due to the action of an experimental variable.

TABLE III.

Experiment II: Mean* Pick-up Times Under Red Illumination and Under No Illumination.

	Both Conditions	Red Light	No Illumination	Ratio R/B
All Trials (All Subjects All Nights)	4.1	4.4	3.8	1.15
Series 1	4.5	4.9	4.1	1.21
Series 2	3.8	4.0	3.6	1.10
Series 3	3.9	4.2	3.7	1.12
Series 4	4.1	4.4	3.8	1.17
(All Subjects All Series				
Night 1	4.9	5.1	4.7	1.10
Night 2	4.2	4.4	4.0	1.10
Night 3	3.9	4.3	3.5	1.21
Night 4	3.3	3.6	3.1	1.15
(All Nights All Series) Each Subject:				
Mi	2.9	3.3	2.6	1.29
Kr	3.2	3.5	3.0	1.15
Ba	3.6	3.8	3.5	1.10
Zi	3.7	3.6	3.8	0.95
Ma	5.0	5.6	4.4	1.29
Mc	6.9	7.4	6.6	1.13

Mean = Geometric Mean ; Pick-up Time in Seconds.

* Value will not necessarily correspond with a simple average of "red" and "no illumination" times.

TABLE IV.

Experiment II: Errors
(N = number of trials on which one or more errors occurred)

Subject	N.Black	N.Red	Chi Square	p(%)
Zi	57	47	.96	less than 50, more than 30.
Mi	46	68	4.25	less than 5, more than 1.
Kr	49	51	.04	less than 95, more than 50.
Mc	34	49	2.71	less than 10, more than 5.
Ma	44	45	.01	less than 95, more than 50.
Ba	48	40	.72	less than 50, more than 30.

TABLE V.

Experiment II: Mean Pick-up Times Produced at Three Field Brightnesses.

Subject	Field Brightness 5.33 log uul	Field Brightness 4.91 log uul	Field Brightness 4.67 log uul
	(Geometric Mean - Seconds)		
Mi	2.0	2.7	4.3
Zi	2.5	2.8	5.1
Ma	1.9	3.0	5.1
Mc	2.6	4.2	8.9
Ba	3.0	3.9	7.4

were restricted to "I'm doing well tonight" or "that was a bad series". None ever volunteered any remarks about better performance under conditions of complete darkness.

12. Sources of Error:

The greatest source of error in the present experiment lies in the timing procedure. Times were measured to the nearest even second so that the recorded time in each trial contains two sources of error (1) that produced by the reaction time of the timer, and (2) that produced by dropping fractions of a second, which may become subject to individual differences among the timers. Because of the use of the geometric mean, this source of error, although quite unimportant for longer times, may become serious where times are uniformly short.

There are two possible courses to take, once it is admitted that a source of error exists and cannot be avoided within the framework of the experiment, and the conditions of personnel and time in which it must be performed: (1) increase the number of trials, vary the timers (if more than one must be used), and so reduce the variable error, or (2) obtain an estimate of the individual difference between timers.

The first solution is reasonably ensured by the large number of trials. It was possible to obtain some rough estimate of individual differences by having two men make the same measurements on a series of 80 trials run by one subject.

Discrepancies occurred on 17 of the 80 trials, and exceeded one second only once. The effect of these errors is evident in the second series, in which nine one-second errors occurred; it is negligent in the remainder of the data and produces no systematic effect. This source of error, then, will not produce misleading results if a sufficiently large number of trials is run.

E. THIRD EXPERIMENT

1. Purpose:

A third experiment, duplicating the second in all but one factor was run to determine the effect of altering greatly the reflectance of the interior bulkheads of the submarine. This was considered desirable inasmuch as many submarines have abandoned the conventional flat-black interior finish for more liveable colors. The use of white paint ensured that tests would be run with paint of the highest reflectance apt to be encountered.

The second purpose of this experiment was to duplicate, if possible, the barely reliable finding of a very slight slowing-up

of performance under the red illumination, which was found in the preceding experiment.

2. Procedure:

No alterations in procedure, method, subjects or lighting were introduced except that the periscope field brightness was increased to 5.01 log uul. The original adjustment of the adaptometer unit was inadvertently altered, and it was considered wiser not to attempt a readjustment in the time available. Brightness and illumination measures made in the white painted conning tower are presented in Tables IB and IIB of the Appendix. It should be noted that the alteration in brightness produced varies strikingly from region to region of the working space. The experiment was run on the nights of May 8, 9, 10 and 11.

3. Results:

Table VI gives the pick-up times for all men under each condition of illumination in this experiment. Individual results are given in Tables XV, XVI, XVII, XVIII, XIX, XX and XXI of the Appendix.

The slightly lower means may be compared with the results presented in Table III. They doubtless reflect the minor change in brightness noted above.

No significant differences in pick-up time appear between the two conditions of illumination, red and no illumination.

F. AUXILIARY EXPERIMENTS.

In order to evaluate the results obtained with the mock-up periscope, a series of measurements was made of the absolute terminal threshold. Two methods were employed, and both gave results in keeping with those obtained on the first, second and third experiments.

1. Procedure:

In both methods, the Hecht-Shlaer Model III Adaptometer (RCN) was employed. Conditions of dark adaptation and pre-adaptation were uniform with those employed in the periscope tests. All tests were run in the white painted conning tower.

Method I: At various intervals, measurements of the absolute terminal threshold were made using the standard method of limits throughout the months of April and May. Ten ascending series alternated with ten descending series in steps of .10 log units.

TABLE VI.

*

Experiment III: Mean Pick-up Times Under Red Illumination and Under No Illumination.

	Both Conditions	Red Light	No Illumination	Ratio R/B
All Trials	3.5	3.4	3.5	.98
(All Subjects All Nights)				
Series 1	3.4	3.4	3.3	1.02
Series 2	3.5	3.5	3.5	1.00
Series 3	3.5	3.5	3.4	1.02
Series 4	3.5	3.2	3.6	.89
(All Subjects All Series)				
Night 1	3.4	3.5	3.2	1.10
Night 2	3.2	3.2	3.2	1.02
Night 3	3.8	3.4	4.2	.81
Night 4	3.4	3.5	3.3	1.07
(All Nights All Series)				
Each Subject:				
Kr	2.8	2.8	2.7	1.03
Ba	3.0	2.9	3.2	.89
Ma	3.2	3.5	3.0	1.28
Mi	3.8	3.6	3.9	1.08
Zi	3.8	3.7	3.9	.96
Mc	4.5	4.7	4.4	1.08

Mean = Geometric Mean ; Pick-up time in seconds.

* Value will not necessarily correspond with a simple average of "red" and "no illumination" times.

TABLE VII. Absolute Terminal Thresholds Obtained on Six Subjects Under Two Conditions of Illumination.

Subjects	No Illum. (Mean) No.of Meas.	Abs.Thr. (log uul)	SD	Red (Mean) No.of Meas.	Abs.Thr. (log uul)	SD	Diff.
Ba	8	2.28	.06	5	2.34	.12	0.06
Kr	9	2.25	.09	5	2.26	.21	0.01
Mi	8	2.23	.35	4	2.21	.15	-0.02
Zi	8	2.20	.11	5	2.15	.15	-0.05
Ma	5	2.19	.10	4	2.20	.14	0.01
Mc	8	2.16	.15	5	2.22	.25	0.06

TABLE VIII. Absolute Terminal Threshold - Constant Method First 5 vs Second 5: Red and No.Illum.

SUBJECTS	Red First Five	Red Second Five	No Illumination First Five	No Illumination Second Five
Ba	2.30	2.30	2.30	2.25
Kr	2.25	2.15	2.25	2.20
Mi	2.25	2.20	2.25	2.25
Zi	2.30	2.30	2.30	2.30

In measurements under red illumination, the subject looked around the red illuminated conning tower between each ascending and descending series. No special shield other than that provided with the adaptometer shielded the subject from the red illumination during the measurements.

Method II: In Method II, the subject received five series of ten stimulations at each of five brightness levels. The stimuli were presented at ten second intervals. Between each series, the subjects looked about the red illuminated conning tower for 20 seconds. It was anticipated that if the red illumination produced a measurable deficit in dark adaptation, the frequency of seeing should be greater for the last five stimuli of each series, than for the first.

2. Results:

Method I: Table VII presents the mean absolute terminal threshold of each subject under each illumination together with the difference. Only one difference is close to significant and that one is in the wrong direction, i.e., the subject performs better under red illumination.

Method II: Results on the four subjects employed on Method II are presented in Table VIII. There seems to be a tendency for a lowering of threshold in the latter half of the series. However, any difference which exists is slight and inconsistent.

G. GENERAL DISCUSSION AND CONCLUSIONS

The findings of the experiments herein reported answer without equivocation the question initially placed. For all practical purposes, present standards of red illumination of the conning tower are entirely adequate for the purpose of inducing and preserving dark adaptation.

These levels of illumination are, moreover, adequate for casual reading, and for chartwork, even though they will not sustain such use of the eyes for protracted periods of time without fatigue. Nor does it follow that further improvement may not be made in the light fixtures which are the source of illumination. Although they do not seriously interfere with the dark-adaptation of the eye when it is free to glance about the whole space, they do yield bothersome highlights and provide sources of distraction which may be found uncomfortable.

Many factors operate to render practical night visual performance relatively insensitive to minor shifts in the state of retinal adaptation. First, the practical performances involved are complex, and depend not merely on the state of the retina, but

also, and to a greater extent, on the efficiency and habits of the whole individual. Fatigue, motivation, skill in the use of the eyes, familiarity with the situation affect performance greatly under both conditions of illumination, and easily obscure the effects of the slight decrement in retinal adaptation induced by dim red light.

No untoward effects on night vision, then, may be expected from use of as many as two 50-watt red steam-tight fixtures in the conning tower, or from instruments red-illuminated as they are now produced.

APPENDIX

APPENDIX

STATISTICAL TREATMENT OF DATA

The distribution of pick-up times obtained in the preliminary experiments were clearly geometric, so that the statistics of the normal probability curve could not be directly applied. For that reason, each time measurement was converted into logarithms, and means and standard deviations of log pick-up times (seconds) completed. This is a straightforward and simple method of handling such skewed data, and yields distributions closely approximating the normal.

When such mean log times are converted back into an arithmetic scale, the geometric mean time in seconds is obtained, i.e.

$$M_g = \left(X_1 \cdot X_2 \cdot X_3 \ldots X_n\right)^{1/n}$$

The standard deviation so derived is a factor which establishes the limits about the mean within which the measurements may be expected to carry. Thus, when we have

Mean (log pick-up time) = 1.00
Standard Deviation log pick-up time = 0.30

it is interpreted as follows:

Geometric mean (log pick-up time) = 10 sec.

and 68% of all measures will fall between 1/2 x 10 seconds and 2 x 10 seconds, or between 5 and 20 seconds.

The <u>differences</u> between mean log pick-up times also became, on conversion to the arithmetic scale, factors expressing the relative lengths of pick-up time under red illumination to pick-up time under no illumination. This value, termed in the tables in the body of this report the Red/Black Ratio, expresses the results most succinctly. Values over 1.00, of course, indicate a

decrement under red illumination, and values under that indicate that the mean pick-up times are shorter under red light.

The significance of the difference was computed for the log values. All differences occurring under varying illuminations which are significant at the 5% level, are indicated by asterisks.

The values have been computed not only for varying conditions of illumination, but for each series, each night, and each subject. No systematic variations appear, although there is some indication that the performance of all is better on the third and fourth nights of each experiment, perhaps because of a motivational variation.

TABLE IA.

Brightness of Surfaces Exposed to the Eye, under Illumination by Two 50-Watt Red Lamps in Steam Tight Fixtures, and with All Instruments Illuminated. (foot lamberts)

SURFACE	BLACK PAINTED INTERIOR (fl)
Forward Port Corner	.03
TDC Frame	.01
Deck	.001
Switchboard	.02
Region of ladder to bridge	.001
Overhead near fixture	.06
DRT (general)	.04
DRT (bright spot)	1.9
Fixtures, TDC	.06
Figures, Sound Dial	.06
Steamtight Fixture Direct	100.

TABLE IB.

Brightness of Surfaces Exposed to the Eye, under Illumination by Two 50-Watt Red Lamps in Steam Tight Fixtures, and with All Instruments Illuminated (Foot Lamberts).

SURFACE	WHITE PAINTED INTERIOR (fl)
Forward Port Corner	.07
TDC Frame	.02
Deck	.004
Switchboard	.02
Region of ladder to bridge	.08
Overhead near fixture	1.6
DRT (general)	-
DRT (bright spot)	-
Figures, TDC	-
Figures, Sound Dial	-
Steamtight fixture direct	-

TABLE IIA.

Intensity of Illumination Under Illumination by Two 50-Watt Red Lamps in Steam Tight Fixtures and with All Instruments Illuminated. (Ft. Candles)

Location in Conning Tower	Illumination (foot candles)
Eye level, at TDC	.11
Eye level, below port fixture	.40
Eye level at forward hatch	.13
Eye level, at rudder angle indicator	.50
On radar scope	.02

TABLE IIB.

Intensity of Illumination Under Illumination by Four 50-watt White Lamps in Steam Tight Fixtures and with All Instruments Illuminated. (Ft. candles)

Location in Conning Tower	Illumination (foot candles)
Eye level, at TDC	2.6
Eye level, below port fixture	12.5
Eye level, at forward hatch	1.8
Eye level, at rudder angle indicator	9.5
On radar scope	3.5

TABLE III.

Experiment 1: Summary for All Subjects of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Trials (All Nights)	.58	.47	.54	.45	.61	.48	-.07	.85
B. (All Subjects All Nights)								
Series 1	.54	.44	.56	.43	.51	.46	.05	1.13
Series 2	.65	.46	.60	.46	.72	.46	-.12	.76
Series 3	.57	.49	.58	.49	.57	.49	.01	1.03
Series 4	.56	.45	.45	.44	.66	.47	-.19	.64*
C. (All Subjects All Series)								
Night 1	.75	.48	.75	.49	.76	.47	-.01	.98
Night 2	.61	.49	.52	.44	.69	.47	-.17	.68
Night 3	.41	.40	.41	.39	.42	.40	-.01	.98
Night 4	.54	.42	.49	.41	.60	.43	-.11	.78
D. (All Nights All Series)								
Subject Kr	.30	.37	.22	.32	.38	.40	-.16	.69
Subject Mi	.67	.42	.62	.36	.73	.47	-.11	.78
Subject Zi	.76	.46	.79	.45	.73	.47	.06	1.15

M = Mean log pick-up time (log sec.)

SD = Standard Deviation

TABLE IV.

Experiment 1: Summary for Subject Kr of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.30	.37	.22	.32	.38	.40	-.16	.69
B. Series 1	.25	.35	.24	.36	.25	.34	-.01	.98
Series 2	.68	.33	.82	.33	.45	.34	-.13	.74
Series 3	.25	.36	.22	.34	.27	.38	-.05	.89
Series 4	.32	.42	.10	.20	.54	.46	-.44	.56*
C. Night 1	.46	.41	.37	.32	.54	.46	-.17	.68
Night 2	.25	.32	.16	.24	.34	.37	-.18	.66
Night 3	.21	.33	.17	.32	.25	.34	-.08	.83
Night 4	.28	.37	.17	.35	.38	.37	-.21	.62

TABLE V.

Experiment 1: Summary for Subject Mi of Mean and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.67	.42	.62	.36	.73	.47	-.11	.78
B. Series 1	.65	.39	.66	.35	.64	.43	.02	1.05
Series 2	.76	.43	.62	.35	.90	.45	-.28	.52
Series 3	.66	.42	.66	.41	.65	.44	.01	1.03
Series 4	.63	.46	.53	.33	.74	.50	-.21	.62
C. Night 1	.45	.40	.35	.32	.54	.46	-.19	.65
Night 2	.25	.32	.16	.24	.34	.37	-.17	.68
Night 3	.21	.33	.17	.32	.25	.35	-.08	.83
Night 4	.28	.38	.18	.35	.38	.37	-.20	.63

TABLE VI.

Experiment 1: Summary for Subject Zi of Mean and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.76	.46	.79	.45	.73	.47	.06	1.15
B. Series 1	.71	.43	.79	.34	.64	.48	.15	1.41
Series 2	.81	.49	.82	.52	.80	.45	.02	1.05
Series 3	.80	.49	.84	.48	.77	.50	.07	1.18
Series 4	.71	.42	.72	.40	.71	.44	.01	1.03
C. Night 1	1.02	.44	1.14	.40	.90	.44	.24	1.74
Night 2	.79	.46	.76	.41	.82	.50	-.06	.87
Night 3	.48	.37	.52	.39	.44	.36	.08	1.20
Night 4	.75	.41	.75	.36	.75	.45	.00	1.00

TABLE VII.

Experiment II: Summary for All Subjects of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Trials (All Nights)	.61	.39	.64	.39	.58	.39	.06	1.15 *
B. (All Subjects, All Nights)								
Series 1	.65	.39	.69	.38	.61	.40	.08	1.21
Series 2	.58	.40	.60	.41	.56	.38	.04	1.10
Series 3	.59	.40	.62	.41	.57	.39	.05	1.12
Series 4	.61	.38	.64	.37	.58	.38	.06	1.17
C. (All Subjects, All Series)								
Night 1	.69	.40	.71	.40	.67	.40	.04	1.10
Night 2	.62	.40	.64	.41	.60	.40	.04	1.10
Night 3	.59	.37	.63	.36	.55	.37	.08	1.21
Night 4	.52	.38	.55	.38	.49	.37	.06	1.15
D. (All Nights, All Series)								
Subject Mi	.46	.36	.52	.38	.41	.34	.11	1.29
Subject Kr	.51	.39	.54	.39	.48	.38	.06	1.15
Subject Ba	.56	.39	.58	.40	.54	.39	.04	1.10
Subject Zi	.57	.38	.56	.37	.58	.40	-.02	.95
Subject Ma	.70	.41	.75	.38	.64	.43	.11	1.29
Subject Mc	.84	.28	.87	.30	.82	.26	.05	1.13

TABLE VIII.

Experiment II. Summary for Subject Mi of Mean and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights.	.46	.36	.52	.38	.41	.34	.11	1.29
B. Series 1	.45	.38	.52	.41	.37	.33	.15	1.42
Series 2	.44	.35	.46	.33	.43	.45	.03	1.08
Series 3	.51	.37	.52	.40	.50	.34	.02	1.05
Series 4	.46	.35	.58	.36	.34	.30	.14	1.39
C. Night 1	.56	.38	.51	.40	.51	.36	.00	1.00
Night 2	.38	.36	.45	.38	.32	.33	.13	1.35
Night 3	.45	.37	.49	.37	.42	.36	.07	1.18
Night 4	.46	.32	.53	.34	.40	.29	.13	1.35

TABLE IX.

Experiment II. Summary for Subject Kr of Mean and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.51	.39	.54	.39	.48	.38	.06	1.15
B. Series 1	.61	.37	.68	.38	.54	.35	.14	1.39
Series 2	.49	.41	.45	.40	.54	.42	-.09	.81
Series 3	.48	.38	.45	.40	.50	.30	-.05	.89
Series 4	.46	.37	.60	.33	.32	.34	.27	1.87*
C. Night 1	.61	.40	.70	.37	.52	.32	.18	1.52
Night 2	.49	.41	.52	.43	.45	.39	.07	1.18
Night 3	.55	.35	.58	.34	.53	.37	.05	1.13
Night 4	.39	.35	.38	.35	.40	.33	-.02	.96

TABLE X.

Experiment II. Summary for Subject Ba of Mean and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights.	.56	.39	.58	.40	.54	.39	.04	1.10
B. Series 1	.58	.41	.62	.42	.53	.40	.09	1.24
Series 2	.53	.38	.55	.39	.51	.37	.02	1.05
Series 3	.52	.41	.61	.38	.43	.41	.18	1.52
Series 4	.62	.37	.55	.41	.70	.30	-.15	.71
C. Night 1	.70	.38	.65	.42	.76	.32	-.06	.87
Night 2	.57	.41	.64	.42	.51	.40	.13	1.35
Night 3	.49	.34	.52	.34	.47	.34	.05	1.13
Night 4	.48	.42	.53	.41	.43	.38	.10	1.26

TABLE XI.

Experiment II. Summary for Subject Zi of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.57	.38	.56	.37	.58	.40	-.02	.76
B. Series 1	.62	.37	.63	.32	.61	.41	.02	1.05
Series 2	.51	.37	.46	.35	.56	.39	-.10	.80
Series 3	.53	.40	.53	.41	.53	.40	.00	1.00
Series 4	.63	.38	.61	.38	.65	.38	-.04	.91
C. Night 1	.59	.43	.58	.42	.59	.43	-.01	.98
Night 2	.62	.40	.53	.37	.71	.40	-.18	.66
Night 3	.57	.31	.66	.26	.49	.33	-.17	.68
Night 4	.50	.39	.45	.38	.55	.38	-.10	.80

TABLE XII.

Experiment II. Summary for Subject Ma of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series All Nights	.70	.41	.75	.38	.64	.43	.11	1.29
B. Series 1	.78	.41	.77	.40	.78	.42	-.01	.98
Series 2	.68	.35	.82	.37	.58	.42	.24	1.74
Series 3	.69	.41	.80	.37	.58	.42	.22	1.66
Series 4	.62	.38	.60	.33	.64	.41	-.04	.91
C. Night 1	.82	.40	.86	.36	.79	.43	.07	1.18
Night 2	.75	.35	.78	.33	.72	.36	.06	1.15
Night 3	.70	.40	.76	.37	.63	.41	.13	1.35
Night 4	.52	.42	.59	.39	.44	.42	.15	1.42

TABLE XIII.

Experiment II. Summary for Subject Mc of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.84	.28	.87	.30	.82	.26	.05	1.13
B. Series 1	.85	.26	.89	.25	.81	.26	.07	1.18
Series 2	.82	.31	.88	.34	.76	.26	.06	1.15
Series 3	.84	.28	.81	.33	.87	.20	-.06	.87
Series 4	.85	.28	.88	.26	.83	.30	.05	1.13
C. Night 1	.87	.30	.90	.31	.85	.29	.05	1.13
Night 2	.91	.23	.95	.25	.87	.19	.08	1.21
Night 3	.79	.32	.80	.36	.79	.26	.01	1.03
Night 4	.78	.25	.82	.23	.75	.26	.07	1.18

TABLE XIV.

Performance on Three Field Brightnesses

N (each series) = 20.

SUBJECT	Field Brightness 5.33 log uul			Field Brightness 4.91 log uul			Field Brightness 4.67 log uul		
	Mean	SD	D	Mean	SD	D	Mean	SD	D
Mi	.29	.48	.14	.43	.46	.20	.63	.49	.34
Zi	.39	.38	.01	.38	.38	.33	.71	.46	.34
Ma	.27	.34	.21	.48	.46	.23	.71	.50	.44
Mc	.41	.45	.21	.62	.30	.33	.95	.31	.54
Ba	.47	.60	.12	.59	.33	.28	.87	.40	.40

TABLE XV.

Experiment III. Summary for All Subjects of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Trials (All Nights)	.54	.36	.53	.35	.54	.37	-.01	.98
B. (All Subjects All Nights)								
Series 1	.53	.36	.53	.36	.52	.36	.01	1.02
Series 2	.55	.36	.55	.36	.55	.36	.00	1.00
Series 3	.54	.35	.54	.34	.53	.35	.01	1.02
Series 4	.54	.37	.51	.34	.56	.39	-.05	.89
C. (All Subjects All Series)								
Night 1	.53	.34	.55	.35	.51	.33	.04	1.10
Night 2	.51	.38	.50	.37	.51	.40	.01	1.02
Night 3	.58	.36	.53	.33	.62	.37	-.09	.81*
Night 4	.53	.34	.55	.34	.52	.34	.03	1.07
D. (All Nights All Series)								
Subject Kr	.44	.38	.44	.37	.43	.39	.01	1.03
Subject Ba	.48	.31	.46	.28	.51	.32	-.05	.89
Subject Ma	.51	.34	.55	.34	.47	.35	.08	1.28
Subject Mi	.58	.39	.56	.40	.59	.39	.03	1.08
Subject Zi	.58	.36	.57	.35	.59	.38	-.02	.96
Subject Mc	.65	.32	.67	.33	.64	.31	.03	1.08

TABLE XVI

Experiment III. Summary for Subject Kr of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.44	.38	.44	.37	.43	.39	.01	1.03
B. Series 1	.44	.37	.45	.35	.43	.39	.02	1.05
Series 2	.51	.41	.52	.42	.50	.41	.02	1.05
Series 3	.44	.39	.43	.34	.44	.43	-.01	.98
Series 4	.36	.35	.37	.37	.36	.34	.01	1.03
C. Night 1	.43	.36	.48	.37	.39	.34	.09	1.25
Night 2	.52	.43	.51	.41	.54	.46	-.03	.93
Night 3	.36	.32	.31	.27	.41	.36	-.10	.80
Night 4	.44	.39	.47	.40	.40	.38	.07	1.18

TABLE XVII.

Experiment III. Summary for Subject Ba of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.48	.31	.46	.28	.51	.32	-.05	.89
B. Series 1	.41	.30	.40	.29	.42	.31	-.02	.96
Series 2	.49	.29	.49	.30	.50	.27	-.01	.98
Series 3	.40	.28	.39	.25	.41	.30	-.02	.96
Series 4	.63	.30	.56	.25	.70	.33	-.14	.73
C. Night 1	.48	.26	.51	.25	.45	.25	.06	1.15
Night 2	.45	.32	.38	.26	.53	.35	-.15	.71
Night 3	.55	.33	.51	.29	.60	.35	-.09	.81
Night 4	.45	.31	.44	.29	.46	.32	-.02	.96

TABLE XVIII.

Experiment III. Summary for Subject Ma of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series All Nights	.51	.34	.55	.34	.47	.35	.08	1.20
B. Series 1	.51	.36	.57	.34	.45	.34	.12	1.31
Series 2	.44	.32	.43	.33	.44	.36	-.01	.98
Series 3	.50	.30	.45	.32	.54	.31	-.09	.81
Series 4	.48	.36	.49	.33	.46	.38	.03	1.07
C. Night 1	.50	.35	.50	.36	.49	.36	.01	1.03
Night 2	.36	.35	.39	.33	.34	.36	--.01	.98
Night 3	.54	.34	.50	.32	.57	.35	-.07	.85
Night 4	.53	.30	.56	.31	.49	.27	.07	1.18

TABLE XIX.

Experiment III. Summary for Subject Mi of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both.		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.58	.39	.56	.40	.59	.39	.03	1.08
B. Series 1	.58	.37	.58	.40	.57	.31	.01	1.03
Series 2	.61	.42	.55	.40	.67	.42	-.12	.76
Series 3	.59	.37	.60	.38	.58	.36	.02	1.05
Series 4	.54	.41	.50	.40	.57	.42	-.07	.85
C. Night 1	.60	.40	.64	.40	.55	.40	.09	1.24
Night 2	.49	.40	.45	.40	.52	.40	-.07	.85
Night 3	.68	.37	.63	.38	.72	.36	-.09	.81
Night 4	.54	.37	.50	.37	.58	.36	-.08	.83

TABLE XX.

Experiment III. Summary for Subject Zi of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.58	.36	.57	.35	.59	.38	-.02	.96
B. Series 1	.53	.36	.53	.40	.54	.32	.01	1.03
Series 2	.60	.37	.59	.37	.62	.40	-.03	.93
Series 3	.60	.36	.63	.32	.60	.40	.03	1.08
Series 4	.57	.36	.52	.32	.62	.32	-.10	.80
C. Night 1	.56	.34	.55	.35	.57	.34	-.02	.96
Night 2	.57	.40	.54	.40	.60	.41	-.06	.87
Night 3	.55	.36	.51	.33	.59	.39	-.08	.83
Night 4	.62	.34	.67	.30	.58	.38	.09	1.24

TABLE XXI.

Experiment III. Summary for Subject Mc of Means and Standard Deviations of Log Pick-up Times together with Differences and R/B Ratios.

	Both		Red		Black			
	M	SD	M	SD	M	SD	Diff.	R/B Ratio
A. All Series, All Nights	.65	.32	.67	.33	.64	.31	.03	1.08
B. Series 1	.68	.30	.67	.27	.70	.33	-.03	.93
Series 2	.65	.27	.71	.25	.59	.26	.12	1.32
Series 3	.69	.28	.76	.26	.61	.27	.15	1.42
Series 4	.60	.40	.53	.27	.67	.35	-.14	.72
C. Night 1	.58	.28	.67	.25	.62	.25	-.08	.83
Night 2	.64	.33	.74	.28	.58	.34	.16	1.45
Night 3	.78	.26	.72	.23	.83	.27	-.11	.78
Night 4	.62	.29	.66	.29	.58	.29	.08	1.21