NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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PERFORMANCE AND PREFERENCE ON A SONAR DETECTION TASK UNDER VARIOUS COLORS OF AMBIENT ILLUMINATION

by

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NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Research Project M0100.001-1019

Released by:

W. C. MILROY, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory
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SUMMARY PAGE

PROBLEM

To determine whether or not objectively measured performance on an actual sonar display, under lighting conditions identical to those at sea, and with appropriate controls, would show any performance differences under all of the possible lighting conditions -- red, blue, subdued white, bright white, and dark.

FINDINGS

When detection performance was tested under mesopic illumination conditions (colors) that were matched photopically, as they are at sea, significiant differences were found. The fastest detection times were under the subdued white condition, yet most observers chose red or blue illumination (the two worst for detection performance) as their preferred lighting to work under. There appears to be no correlation between preference and performance.

APPLICATIONS

The original suggestion made by two submarine crews of "enhanced" sonar detection capabilities under blue light was not supported. The subdued white lighting has been shown to enhance performance and is better than blue for fine acuity, color vision, and dark adaptation. Due to the additional advantages of subdued white illumination, it is recommended for use in sonar control rooms.

ADMINISTRATIVE INFORMATION

This investigation was undertaken under Naval Medical Research and Development Command Work Unit M0100.001-1019 - "Improvement of sonar performance through modification of sonar displays." This report was submitted for review on 30 March 1984, and approved for publication on 17 May 1984 . It has been designated as Naval Submarine Medical Research Laboratory Report Number 1023 .

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ABSTRACT

Twenty observers participated in a sonar detection task under three photopically matched colors, bright white light, and no ambient light conditions. All trials were run under mesopic conditions to simulate normal operations at sea. The subdued white and the no light conditions resulted in the shortest detection times, followed by the bright white, blue, and red conditions. Most subjects, however, preferred the red or blue illumination. There appears to be no correlation between preference and performance. Advantages of using the subdued white lighting in sonar control rooms are discussed.

PERFORMANCE AND PREFERENCE ON A SONAR DETECTION TASK UNDER VARIOUS COLORS OF AMBIENT ILLUMINATION

INTRODUCTION

In the past, sonar systems provided primarily auditory signals for the operator to use in the detection and classification of targets. Since the auditory modality was so much more important than the visual, lighting in the sonar shack was not carefully controlled. Sonarmen had the option of operating under red, white, or a no light condition. Red light was primarily used in order to maintain dark adaptation for the Officer of the Deck who needed to look through the periscope at night. The white and no-light conditions were employed in the sonar control room according to the preference of the sonarmen on duty. With the advent of the modern submarine, the red lighting system has been determined to be of little use (1). Not only does the submarine not go to periscope depth as often as it once did, but the Officer of the Deck can dark-adapt very effectively by wearing dark goggles or an eye patch. In addition, it has been found that the advantage that dim red light offers over dim white for dark adaptation amounts to only a few minutes, which may not be of great practical significance (2). Consequently, as early as 1970, recommendations were made to eliminate the dual, red-white lighting system (1). It was only recently, however, that red light in sonar shacks was actually eliminated. Amidst a rebirth of interest in sonar lighting, blue light has now emerged to replace the red (3).

This relatively recent increase in concern about optimal light level and the use of colored illumination in the sonar shack is a direct result of the increase in the number of visual displays. The change to blue, in particular, can be traced to the experience of a single submarine sonar crew which tried blue sleeves over the light bulbs in the sonar control room and reported enhanced detection capabilities (4). Similar opinions on other submarines led to a suggestion that all sonar shacks be rigged for blue illumination (5).

Investigations by this Laboratory have examined several different hypotheses for the popularity of blue light, ranging from psychological effects to actual improvements in visual function. There was no evidence for any difference in contrast sensitivity between red, white, and blue light (6), no difference in detection ranges with red and blue light (7), and no difference in performance on a simulated sonar display under red, white and blue light (8). As expected, there was some evidence of visual fatigue on the simulated display for far-sighted subjects under the red light. Also, there was a general preference for blue light over red in this study, consistent with the earlier, anecdotal evidence.

All the previous studies matched the levels of red, blue, and white light photopically, i.e. for a light-adapted eye. The filters that are presently used aboard submarines are approximately matched photopically. However, as Kinney (9) has pointed out, for the range of illumination found in the sonar shack, the blue light is 2 to 10 times more visually effective than the red. This key finding might help account for the preference for blue. It is probably based both on the greater amount of illumination under blue in conditions where the lights are photopically matched, and on psychological factors as well, many of which are detailed by Luria and Kobus (10). The higher brightness level with blue enables operators to see large objects and room outlines better. However, acuity is not proportionally enhanced. This would explain the lack of a demonstrated performance advantage under blue light on sonar-type tasks requiring acuity.

Most recently, Luria and Kobus (10) tested preferences and performance under blue and subdued white light when the illumination levels were matched mesopically -- that is, for an eye adapted to the dim light level of a typical sonar shack. In contrast to the previous studies, they found that a reduced white light, equated in visual effectiveness to the blue, may have been better for operating certain equipment, resulting in faster detection and classification of targets. However, two-thirds of the men tested still preferred the blue light in the sonar trainer. Yet, when the lights were later tested at sea, four out of five crews preferred subdued white, including two that originally preferred blue in the trainer.

There, thus, remain questions about the effectiveness of the blue lighting at sea, particularly about the reports of the "enhancement" of detection capabilities under blue light. Standard visual tests do not support the employment of blue lighting, yet the preference among sonarmen evidently remains. It thus remains to be determined whether or not objectively measured performance on an actual sonar display, under lighting conditions identical to those at sea, and with appropriate controls, would show any performance differences under all of the possible lighting conditions -- red, blue, subdued white, bright white, and no light. In this experiment, performance on actual sonar equipment was monitored in an attempt to clearly separate performance and preference.

METHOD

Subjects

Twenty male volunteers served as subjects, 10 laboratory staff and 10 students at the Naval Submarine School. Those who ordinarily wore corrective lenses did so during the experiment.

Apparatus

Stimuli were presented on the CRT display of a sonar system (AN/BQR-20) set at eye-level at a distance of 30 inches from the subject. The system provides a spectrographic display of any input signals. Frequency is represented along the x-axis and time along the y-axis, with continual "waterfall" updating. New information is presented every 500 ms in the form of a horizontal line across the top of the display, and it is pushed down as successive lines appear. It takes 16 seconds for a new line to reach the bottom of the display, where it disappears.

The display was configured such that the center frequency on the x-axis corresponded to 500 hz with the left and right edges corresponding to approximately 250 and 750 hz, respectively. Along the x-axis was a scale with labels every 50 hz. Frequencies in the input signal detected by the system appear as lighted dots at their appropriate hz value along the X dimension. The amplitude of a particular frequency is coded by the brightness of the dot. The overall intensity of the screen was adjusted so that the display was at a fairly dim level -- similar to the levels observed aboard submarines. Figure 1 is a photograph of a typical display.

Stimuli

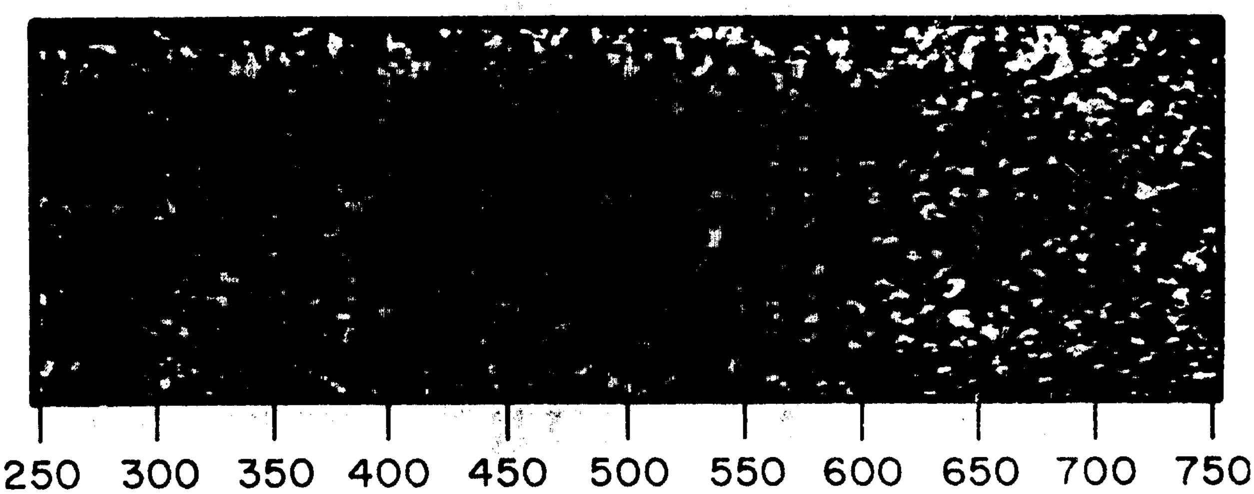
The stimuli consisted of a background "noise" pattern and a sine wave "target" signal displayed on the CRT screen. The background noise was produced by playing a tape of ambient sounds recorded by the sonar equipment of a submarine at sea on a Hewlett-Packard model 3964A instrumentation recorder. The output of the recorder was fed to the sonar processor for analysis. The resultant display revealed a multitude of signals at frequencies throughout the 250-750 hz range, appearing as the stippled pattern in Figure 1.

The target stimulus was a sine wave signal produced by a Wavetek model 130 function generator and input to the processor unit. The frequency of the signal could be varied from 300 to 750 hz in 50 hz steps, resulting in 10 possible stimuli. The amplitude of the signal was controlled by a Hewlett-Packard model 350D dB attenuator. The unattenuated target appeared as a bright vertical line, at the appropriate frequency, beginning at the top of the display and extending toward the bottom over time. Figure 1 shows a target present at 400 hz.

Lighting Conditions

All subjects performed under five separate lighting conditions: white, subdued white, red, blue, and no light. The illumination was provided by two Cool White flourescent bulbs situated

FIGURE 1: Typical display with a target beginning to appear at 400 hz.



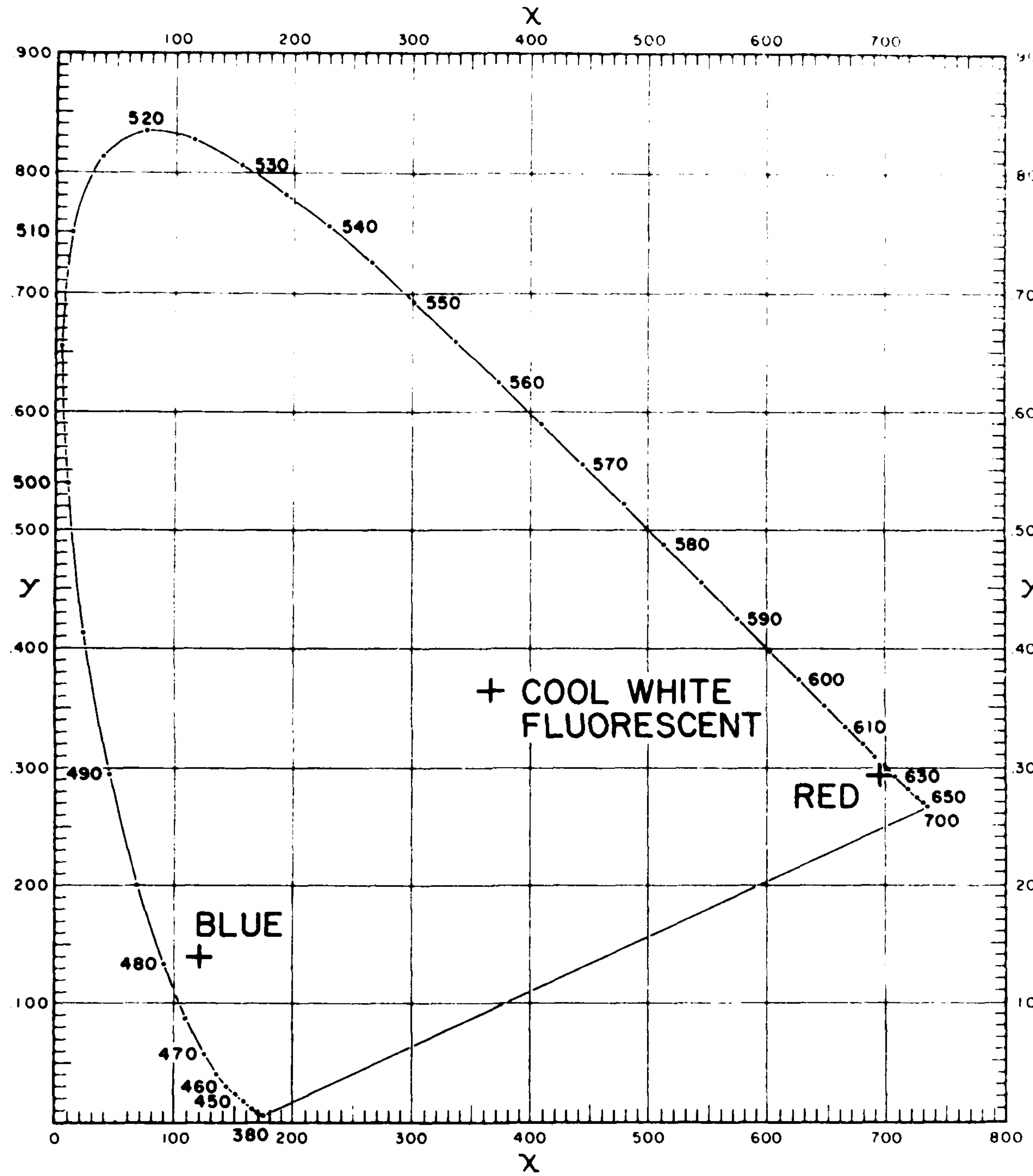


FIGURE 2: The CIE chromaticity coordinates of the red and blue filters used with cool white flourescent lamps, and of the lamps alone.

above and behind the subject. In the white condition, the bulbs were uncovered, resulting in 14.5 foot-candles (fc) of photopic illumination falling on the CRT screen. The subdued white, red, and blue conditions were matched photopically for .2 fc on the screen. This value was chosen because it falls within the range of illumination measured in submarine sonar shacks (11). The subdued white was obtained by placing neutral density filters over the bulbs. The red and blue conditions were obtained by placing red or blue plastic sleeves over the bulbs. The blue condition required a small amount of additional neutral density filter material to obtain an exact match. The sleeves are those used in sonar shacks to provide colored lighting and are available from the GSA catalog. The transmittances of the red and blue sleeves are .019 and .023, respectively. The chromaticities of the Cool White lights alone and the lights covered by red or blue sleeves are shown in Figure 2. The ambient illumination was turned off in the no light condition.

Procedure

The 20 subjects were randomly assigned to one of five groups, placing four subjects into a group. All subjects performed under all five lighting conditions, but each group used a different order of presentation. The five orders were counterbalanced so that each lighting condition appeared in each position.

Subjects first adapted for 2-3 minutes to the white or colored lights, five minutes to the no light condition. The sonar tape was played, producing background noise on the display. The sine wave target signal was then introduced at one of the 10 possible frequencies at an amplitude well below threshold. The starting amplitude was the same for all subjects for each session. Every 15 seconds the experimenter would increase the signal level by 1 dB until the subject successfully reported its frequency. The time required to detect the signal was recorded using a digital stop watch. Subjects were discouraged from guessing, but no penalty was given for misses. This process was repeated with stimuli presented at the remaining nine frequencies. The order of presentation of frequency was randomized across sessions. Thus 10 detection durations under each of five lighting conditions were recorded for each subject, yielding 50 trials per subject. For each session the sonar tape was started from the same position so that the pattern of background noise over time was similar across all sessions. At the completion of all sessions, 17 of the subjects ranked the five lighting conditions in order of preference.

RESULTS

Performance Data

The detection time data initially contained one missing value under the blue illumination condition. Yates' approximation procedure was used to replace the missing datum (12). Figure 3 shows the mean detection times and standard errors of the mean for each illumination condition. Mean detection time was lowest under the subdued white and no light conditions, followed by the white, blue, and red conditions.

A two-way repeated measures ANOVA [Group x (Illumination Color x Subject)] on the detection data revealed a

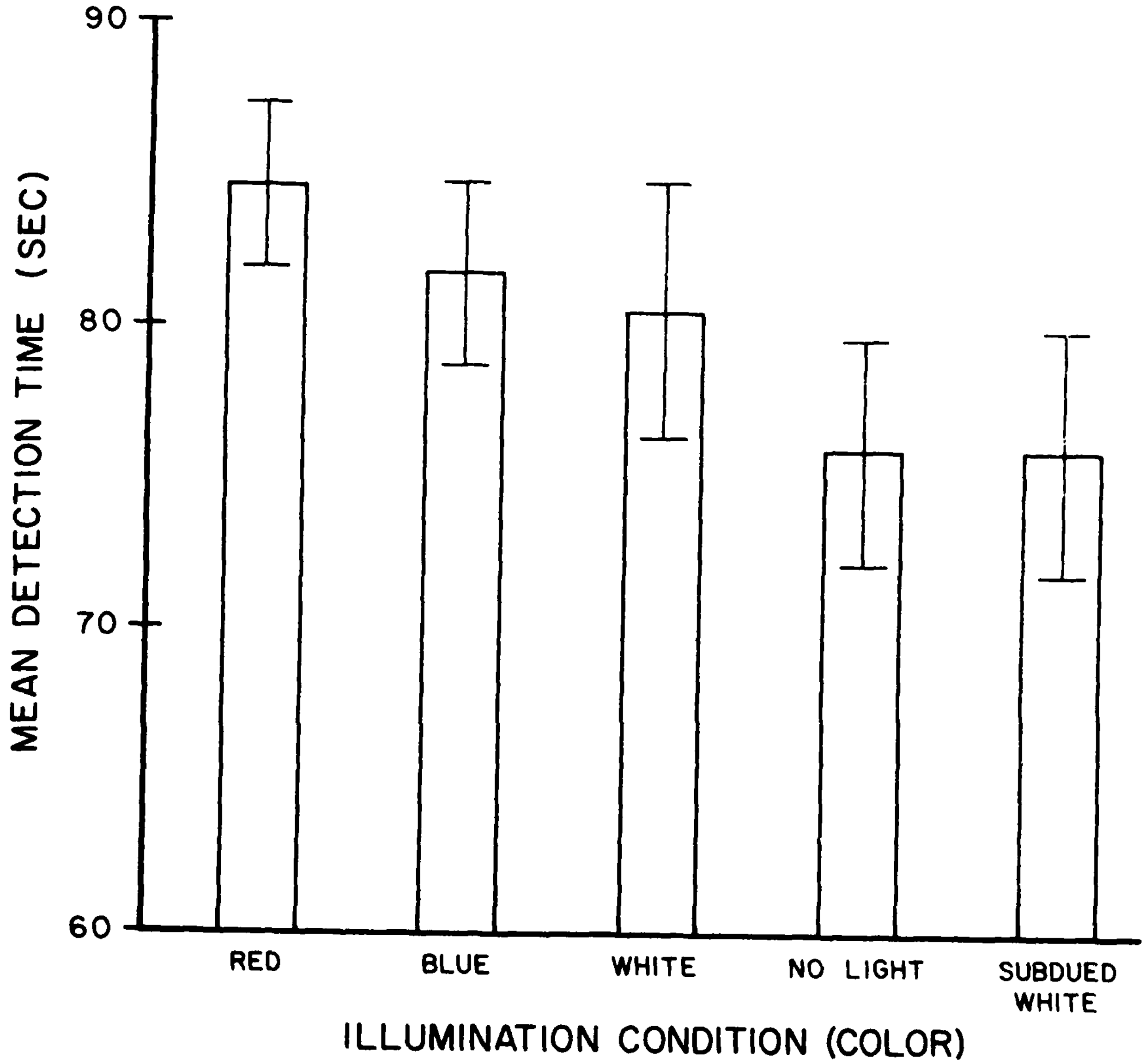


FIGURE 3: Mean detection time for all subjects under each illumination condition (color). Error bars represent ± 1 S.E.M.

significant interaction between group and illumination color ($F(16,60) = 3.30$, $p < .01$). This implies that the groups were affected differently under each lighting condition. An analysis of this effect indicated that two of the groups showed a slight decrease in detection time from their first to last session. This practice effect was not present for the other three groups, and further analysir indicated that there were no significant performance differences between the groups. In addition, there was a significant effect of illumination color ($F(4,60) = 3.09$, $p < .05$). In other words, the performance of all groups was significantly effected by the ambient illumination condition. The Newman-Keuls test was performed to determine which color comparisons were responsible for this finding. The results show that the subdued white and no light conditions provided significantly faster detection times than the red condition. No other comparisons reached significance. Table I shows a summary of all comparisons.

Preference Data

Seventeen of the subjects ranked the five illumination conditions in order of preference. Numbers were assigned to each subject's rankings, beginning with "1" for the most preferred through "5" for the least preferred. Table II shows the mean preference ranking for each illumination condition. The most preferred color was red with a mean of 2.29, while the least preferred color was white with a mean ranking of 4.18. The Kendall Coefficient of Concordance demonstrated substantial agreement of opinion about the lighting conditions by the 17 subjects ($W = .25$, $p < .01$).

Not only was there a high degree of agreement between subjects, but a Friedman Two-Way Analysis of Variance by Ranks (Illumination Color x Subject) indicated that the differences among the mean ranks was significant ($\chi_r^2 = 17.18$, $p < .05$). Table III shows the results of Nemenyi's Test of Order Data (13) which was used to evaluate the individual color comparisons and expose those

TABLE I. Differences in detection time (secs) between lighting conditions. Significance of the differences was tested with the Newman-Keuls procedure.

	Subdued White	None	White	Blue	Red
Subdued White	----	.02	4.49	5.86	8.66*
None			4.47	5.84	8.64*
White				1.27	4.17
Blue					2.80
Red					----

*p < .05

TABLE II. Mean rank and standard deviation for each illumination condition. Rank of 1 signifies most preferred. (N = 17 subjects)

Illumination	Mean Ranking	S. D.
Red	2.29	1.26
Blue	2.35	1.50
Subdued White	2.77	1.09
No Light	3.41	1.23
White	4.18	1.18

TABLE III. Differences in mean preferences for the different lighting conditions. Significance of the differences was tested with Nemenyi's procedure.

	Red	Blue	Subdued White	None	White
Red	---	.06	.47	1.12	1.89*
Blue			.41	1.06	1.83*
Subdued White				.65	1.42
None					.77
White					

*p < .05

responsible for this finding. Significant differences in preference were found between the two most preferred colors (red and blue) and the least preferred color (white).

Correlation Analysis

Finally, in order to uncover any relationship between preference and performance, the detection times under each lighting condition were ranked for each subject and correlated with his preference rankings. None of the 17 Spearman Rank Correlation Coefficients reached significance, indicating no consistent relationship between performance and preference. The overall performance ranks (from Figure 3) were correlated with the overall preference ranks (Table III). The result ($r = -.60$, n.s.) shows no significant relationship between the two, although it is interesting to note that it is negative. In other words, those lighting conditions that resulted in the shortest detection times showed a tendency to be less preferred.

DISCUSSION

Past research has demonstrated that the type of lighting used in sonar control rooms may affect detection and classification of targets (10). Since sonar is increasingly becoming more of a visual task, it is important that we become more concerned with the conditions that may affect visual performance. The present investigation is the first to show differences in detection times for sonar signals under different photopically matched illumination colors. It was found that performance differed significantly under the various colors and that the pattern of performance depended on the order of presentation of the colors. Specifically, a practice effect was found for two groups which demonstrated noticeably faster detection times from their first session to their fifth. However, because order of presentation was counterbalanced across subject groups, it is worth looking past this interaction at the main effect of room color.

The post hoc analysis showed a significant, 8.7 sec, advantage for the subdued white and no light conditions relative to the red. The strong showing for the subdued white is in general agreement with other tests involving this and other lighting conditions matched mesopically (10). It should also be noted that, although the subdued white-blue difference did not reach statistical significance, it still amounted to just under 6 secs on average. The no light condition was equally as effective as the subdued white but its operational usefulness is in doubt because of the difficulty in reading or writing, which is sometimes necessary.

Subjects in the present study once again showed a preference for the colored (red and blue) illumination. It is interesting to note that the most preferred illumination conditions resulted in the poorest performance. Once again, as in a similar study (10), preference and performance under various illumination colors are not positively related.

Since all but one of the subjects who participated in this study had no previous experience in detecting targets on a spectrographic display, it is not surprising that a practice effect was found. This might not have occurred had trained sonar observers been used. Further testing on actual or simulated sonar displays, employing trained sonar operators, would further isolate performance from unwanted sources of variability.

CONCLUSIONS

This study indicates some enhancement of performance under no light and subdued white illumination versus bright white, red, and the presently used blue lighting. It has not been determined if these results are of significant operational importance. Although the no light condition was virtually equal to the subdued white in performance, it has some disadvantages, such as inhibiting the operators' ability to read and write. The additional advantages of working under the subdued white lighting make it an obvious choice over the other conditions, including the blue that is presently used. As Kinney (9) has noted, the added amount of light with the blue does not enhance fine acuity and therefore is not advantageous in a task which requires the detection of fine detail. Also, use of any color of illumination reduces the effects of color coding. This may become of particular importance with the future use of color CRT's. Unless reasons for the preference of blue illumination are determined and are linked to performance, all available evidence points to the subdued white lighting as being the appropriate choice. Subdued white is better than the currently employed blue for fine acuity, color vision, and dark adaptation. In addition, subdued white light has been shown to be significantly better for the detection of a sonar target signal than blue (10), and now red illumination.

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