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SHIP BRIDGE LIGHTING: RED OR WHITE

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ABSTRACT

Although the superiority of red lighting over white in terms of subsequent dark adaptation is well-documented, the operational significance of this superiority is difficult to quantify. More operationally relevant measures are required in order for the user to evaluate the relative advantages and disadvantages of each type of lighting. The present study provides data showing the advantage of red pre-adaptation in terms of visual detection range superiority for simulated-ship targets.

In addition, the merits of red lighting for the darken ship condition are discussed.

SHIP BRIDGE LIGHTING

This report outlines the work undertaken on DCIEM Task 15C20, Naval Ship Lighting Systems. The purpose of the work was to determine whether red or white night-lighting should be used at various work stations. The work involves two major areas: the lighting of bridge displays, both flood-lit and integrally lit; and the lighting for externally observable areas during "darken ship" conditions.

That red light is less detrimental to dark adaptation than light of other hues is an accepted fact --- it has been demonstrated many times. The detrimental effect on dark adaptation increases as the wavelength of the pre-adapting light shifts from the red end of the visible spectrum toward the centre and/or as the total luminous energy of the pre-adapting light is increased. This has led to the practice of making the lighting as red and as dim as possible if the visual task precedes another visual task requiring dark adaptation. At very low levels of pre-adapting luminance the difference in the effects of red and white lighting is measurable, but small. Red is still superior; but is the difference of practical consequence? Given appropriate visual performance data, this is a question which the operational user can best answer. However, the available visual performance data are from experiments using stimuli (small, high contrast lights) unlike some of those in an operational setting. A ship showing no lights, for example, is a relatively large, low or medium-contrast target against the sea or horizon. In addition, the data are not usually in a form, say visual range, which the user is familiar with. The major aim of this study, then, is to supply illustrative data which the user can relate more easily to the operational requirement.

PART I

RED OR WHITE LIGHTING FOR DISPLAYS

Four experiments were performed concerning the relative effects of viewing red and white displays on the subsequent detection of low/medium contrast targets which simulated ships on the night horizon. Three of the experiments involved flood-lit displays; one involved an integrally-lit display. Each of the four experiments, along with the results, will be briefly described. A general discussion of the results follows.

The pre-adaptation display consisted of a red or white flood-lit screen usually of about 0.1 ft.L. luminance, approximately one metre diameter and one metre from the subjects' eyes. This illumination was provided by a standard Kodak projector. The red filters used in these experiments had a 50% cut-off point at about 610 nm.

The targets for the post-adaptation detection task were presented by 35 mm slide projections on a gray wall about 4.2 metres from the observers' eyes. The top half of the slide was clear, the bottom half was opaque. The targets, (opaque rectangles with a length-to-height ratio of 10), were placed lengthwise on top of the "horizon". The observers' view, when dark-adapted, was that of a long "blob" outlined against a "sky" (0.0001 ft.L.) which occupied the top half (190 cm x 90 cm) of the normal projection area. A graded series of 10 target sizes, all with the same length- to-height ratio, was used. The projected images ranged in size from 5 cm long x 1/2 cm high to 40 cm x 4 cm. In all of the experiments presentation of the slides began immediately subsequent to the extinguishing of the pre-adapting light. Each slide was presented for five seconds. Four observers were used in each of the four experiments. All of the 14 observers (two observers served in two experiments) had normal, or corrected-to-normal vision. Their ages ranged from 22 to 37.

Experiment 1: Method

Each observer was tested individually during a five-day period. The first day consisted of familiarization with the experimental setup, training trials and determination of which size test object could be detected at the 75% level following dark adaptation. This size plus one size larger and one size smaller were used in the experimental sessions.

During the next four days the observers were exposed to twelve experimental sessions, three per day. Six sessions were used to determine the interfering effects of low level red light on detection following dark adaptation, and six to determine the effects of low level white light. Each of the three daily sessions required 45 minutes. Observers were given 15 minute breaks between each session. The colour conditions alternated between sessions and were order-balanced across subjects.

In each experimental session the observers were dark adapted for twenty minutes and then viewed the flood-lit screen (0.1 ft.L) for five minutes. The floodlight was extinguished and the detection task commenced. Eighteen slides were presented for five seconds each. Half of the slides contained test objects, half did not. The observers were required to respond verbally when an object was sighted. No feedback was given. After the eighteen slides were presented the observer viewed the flood-lit screen for five more minutes then performed the detection task again. The sequence was repeated a third time, then the observer rested for 15 minutes in lighted conditions. The observer then dark adapted and completed the same sequence of events as above (the second session), rested 15 minutes and completed a third session. This daily procedure required about three hours.

The order of presentation of the three sizes of test objects was balanced across all the sessions and equated for the red and white conditions. The order of slides within each session was randomized with the constraint that three sizes of test object were presented in each thirty second period.

Experiment 1: Results

After 5 minutes adaptation to red flood-lighting the four observers detected 512/648 (79%) of the targets presented in the subsequent 90 sec. After white adaptation they detected 443/648 (68%) of the targets, 11% less than after red adaptation. The false alarm rate, the rate of claiming a target detection when no target was present, was about 10% for red and 11% for white. The data were also analyzed in terms of visual range for a given level of detection, e.g., at what "simulated" range were targets detected 75% of the time under the two lighting conditions? From te data pooled for the four observers, the red pre-adaptation condition resulted in a visual range increase of 12% over the detection range after white pre-adaptation.

Experiment 2: Method

This experiment utilized the same stimuli and procedures as Experiment 1. The major difference between the two experiments was that following the initial dark adaptation period in each session, the observers were required to match the brightness of either the red or white adapting light with that of the other. For example, when the interfering effect of red light was being studied, the viewing screen was flooded with 0.15 ft.L. of white light for 30 seconds. When the white light was extinguished the observer attempted to reproduce this brightness with the red light by adjusting a rheostat. Two matches were made, one in a downward direction, one upwards. The white light was presented for another 30 seconds and another two matches attempted. The average brightness of the four matches was utilized for each adaptation period preceding the three subsequent detection sessions. This procedure is aimed at better simulating the situation in which the user is free to adjust the light level either by changing the height of a lamp or by means of a rheostat.

Another change toward better simulation from Experiment 1 was that a coastal chart was placed upon the viewing screen to provide some detail to assist in the observers' luminance matches.

Experiment 2: Results

On the average, the observers adjusted the pre-adapting floodlighting so that the red was about 15% higher in luminance in order to discriminate the same detail on the coastal chart. After five minutes adaptation to red flood-lighting the four subjects detected 425/648 (66%) of the targets presented in the subsequent 90 sec; after white adaptation, 377/648 (58%), or 8% fewer. The false alarm rate was 10% for the red condition and 12% for the white condition. In terms of visual range, the red condition showed a 17% advantage.

Experiment 3: Method

In this experiment four observers were again tested over a five-day period with the first day devoted to training and determination of detection levels. One difference between this experiment and the previous two was that a set of four consecutive sizes of test objects, with a mean detection level of 75%, was selected.

Another difference was that the effects of one minute exposures of low level light conditions on subsequent detection were investigated. This procedure was an attempt to simulate the situation in which the observer is alternating between a chart-table, or other flood-lit surfaces and looking outside for other ships. As in the other experiments each observer participated in 12 experimental sessions. The effects of red and white light were investigated in alternate sessions. Two subjects began with the white condition, two with the red. Three sessions were run per day. Each lasted about 45 minutes. There was a 15 minute break between sessions. The laboratory setup was the same as described for Experiments 1 and 2.

Each session began with 20 minutes of dark adaptation. The observers then viewed the flood-lit chart (0.1 ft. L). Following a one-minute adaptation period observers performed the detection task for one minute. During this period 12 slides were presented for five seconds each. Six of the slides contained test targets, six did not. On completion of the detection task subjects again viewed the chart for one minute, followed by a one-minute performance on the detection task. The sequence was completed ten times during each session. For the detection task the slides were presented in a balanced randomized order during each session. Six different session orders were utilized with the same order used for both the red and white conditions. Subjects were not informed of these ordering procedures.

Experiment 3: Results

The red pre-adapting condition showed superiority in terms of detection during the interposed one-minute periods, 798/1355 (59%) versus 707/1355 (52%) for the white pre-adapting condition. The false alarm rate for red was 16%, for white 18%. In terms of visual range, the advantage for the red condition is 13%.

Experiment 4: Method

The major difference between the following experiment and those described previously is the use of integral lighting during both the adaptation period and the detection task. The integral lighting display consisted of a light table covered with a positive transparency of an instrument panel (see Fig. 1). The light transmitted through the transparency was filtered to approximate an operational brightness level of 0.05 ft.L. The display was the only source of light present during the adaptation periods.

During each session observers adapted to the light panel for 20 minutes, followed by performance on the detection task. The observers again searched for test objects during five second slide presentations but following each presentation they returned their gaze to the instrument panel for five seconds. Thus throughout the remainder of the session the observers alternated their gaze between the horizon scene and the instrument panel. The session was concluded after 13 minutes of this procedure.

Each of the four observers participated in one session per day for four days. Each session took approximately 35 minutes to complete, excepting the first which also served as a familiarization and threshold determination session. It required about 90 minutes. Three different size test objects were used for the detection task, one size corresponded to the observers' 75% detection level, one size was larger and the other smaller. The number of slides containing test objects was approximately equal to the number of "blanks". The order was randomized with the constraint that each size test object was equally represented during each two minute portion of the task. The same order was used for each observer during each experimental session in which he participated. The observers were not informed of the randomization procedure, nor were they given feedback concerning their performance.

Experiment 4: Results

The observers detected 249/336 (74%) of the targets after red adaptation and 220/336 (65%) after white adaptation, a difference of 9%. The false alarm rate for red was 14%, for white 17%. In terms of visual range, the advantage for the red condition was 12%.

DISCUSSION

The results of the four experiments are given in Table 1. This table summarizes the performance of 14 different observers attempting to detect 5974 targets among twice that number of slide presentations after a variety of adaptation conditions. The advantage of red pre-adaptation is clear. Furthermore, given that the slight advantage of red in terms of the false alarm rate is reliable and that the usual positive correlation between deteotin rate and false alarm rate applies to our results, these results slightly underestimate the visual range advantage of red pre-adaptation. Whether this advantage is of operational consequence is, as mentioned previously, a matter for the user to decide.

Against this advantage of red lighting we have the well-known disadvantages, mainly, (a) loss of colour-coding, (b) potential focussing problems for older personnel, and (c) increased cost. Colour coding need not be lost however, a small flashlight could supply the necessary small area of white lighting for those occasions requiring the use of colour information, unless it was a requirement to have important, colour coded information available for viewing at all times. Another possible solution is that blue-filtered white lighting could be used. This comprise would result in better colour perception than with red lighting but would not provide the maximum detection ranges allowed by red lighting.

An additional point concerning the relative importance of the choice of red or white lighting is the relatively large individual differences in ability to perform detection following light adaptation. Figure 2 presents the data of two observers from the third experiment: the best observer, and an "average" observer. A pair of lines for each observer shows detection rate as a function of range for the two experimental conditions (red or white pre-adaptation). For a given observer the horizontal distance between the two lines is a measure of the detection range improvement afforded by red pre-adaptation. Note, however, the great difference in detection ranges between the two observers, a difference which is much greater than the red/white difference for either observer. It is clear, then, that the selection of the observer for the detection task can be of greater import for good performance than is the choice of the colour of the lighting. The relatively small advantage of red over white chart-lighting will not yield maximum detection ranges if bridge personnel are not properly selected.

PART II

DARKEN-SHIP

Luria and Kinney (1967) discuss the topic of red lighting and the concealment of ships. They state that, prior to WW II, U.S. Navy ships used blue light at night for illuminating work areas which might be detected by look-outs on enemy ships. It might have been the prominent visual physiologist, Selig Hecht (Anon., 1942) who provided the impetus for the changeover to red. The argument advanced was that if the same levels of blue and red light are used in order to perform photopic visual tasks aboard ship, the blue light will be about 1000 times more effective for scotopic vision; i.e., easier for an enemy lookout to detect. Thus, a dark-adapted look-out would be much more likely to detect a blue-lit ship at night. This conclusion is based upon laboratory work and does not take into account other factors which would be important in the real situation.

One of these factors is atmospheric spectral transmission, i.e. how well the intervening atmosphere transmits the various wavelengths of light. The clear sky is blue because air molecules scatter the shorter (blue) wavelengths of light more effectively than the longer (red) wavelengths. Increased scattering of a bundle of light rays means that the transmission of the bundle through the atmosphere from source to observer is decreased, leading to the possibility that differences in the atmospheric transmission of red and blue light might decrease the advantage of red light for darken-ship conditions. (i.e., blue light is scattered more, red light is transmitted more). Luria and Kinney point out that little was known about the transmission of the atmosphere in the 1940's and that only fifteen years or so prior to their own study was any sizeable amount of data collected. They cite the work of Gates (1966) and use his data to determine the joint effects of atmospheric spectral transmission and the spectral sensitivity of the dark-adapted eye to determine the relative detectability of various coloured lights at night. They show a spectral distribution of solar energy reaching the earth's surface for three different sun elevations (Fig. 3). As the elevation is decreased, the sun's rays pass through increasing amounts of the earth's atmosphere, thereby increasing any scattering and absorption which might occur. Since an enemy lookout would be viewing along a horizontal path (0 elevation), the curve which seems the most applicable is the 7 curve. From the three curves it can be seen that, as the sun's rays pass through increasing amounts of the earth's atmosphere, the red end of the spectrum becomes predominant in transmission. These data also imply that red and blue lights equated for visibility for a given elevation will not be equally visible along a path with a different elevation.

Returning to the original case, that of using the same levels of different hues to perform photopic visual tasks aboard ship at night, Luria and Kinney look at the relative visibilities of white and red lights for a dark- adapted observer. They calculate the visibility of white relative to red to be about 37, i.e., the level of red lighting could be raised by a factor of 37 before it became as visible to an enemy look-out as white lighting. Using Gates' data (7 elevation) to correct for the atmospheric spectral transmission, they find that the advantage is reduced to a factor of 19.

Luria and Kinney then consider the case of equal scotopic levels of light for darken-ship conditions. This might be the case in which light is necessary only to move about on deck and to be able to see fairly large objects. Neglecting atmospheric transmission, these lights would obviously be equally visible to a dark-adapted observer because they are set at the same level for scotopic vision. Because of its higher transmission, however, the red light would be more visible to a distant, dark-adapted observer. The calculated visibility of red relative to blue for this condition varies from 1.3 to 27, depending upon the exact spectral characteristics of the red and blue lighting and which of the spectral transmission curves of Fig. 3 is used. The highest relative visibility for real is found with the 7 elevation curve, the case which is presumed to be the most appropriate for our purposes.

Luria and Kinney conclude:

> "It would seem, then, that the use of blue light for nocturnal ship-board lighting has some basis in practical experience. Although better data are needed than seem to be currently available, the issue does not appear to be closed. The choice of the colour of light which will give the best chance of escaping detection is probably a function of the specific situation involved." (Luria and Kinney, 1967).

The "better data" required are presumably atmospheric spectral transmission data which are more clearly applicable to the ship-to-ship visibility case. We have been unable to locate any such data. There is reason to believe that the spectral transmission close to the sea surface would reflect the action of suspended water droplets (spray, mist) which would tend to scatter the visible wavelengths about equally. Gate's (1966) data were obtained with a fairly clear atmosphere. If red and blue are transmitted equally through a maritime atmosphere, the spectral sensitivity of the human eye determines the choice of hue --- red. The relative advantage of red over blue, then depends upon the lighting level (photopic or scotopic) and the characteristics of the atmosphere (clear or containing suspended water droplets) between the darkened ship and the observer.

Although red lighting appears to be the proper choice, appropriate spectral transmission data would be very useful in confirming this.

REFERENCES

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GATES, D.M.; Spectral distribution of solar radiation at the earth's surface, Science, 151, (3710), 4 Feb 66, pp. 523-529.

LURIA, S.M., and KINNEY, J.A.S.; Merits of red or white lighting for naval use. In AGARD Conference Proceedings No. 26, Aircraft instrument and cockpit lighting by red or white light, October, 1967.

FIGURE CAPTIONS

Table 1: A summary of the detection data from the four experiments.

Figure 1: Positive transparency of the instrument panel used in experiment 4.

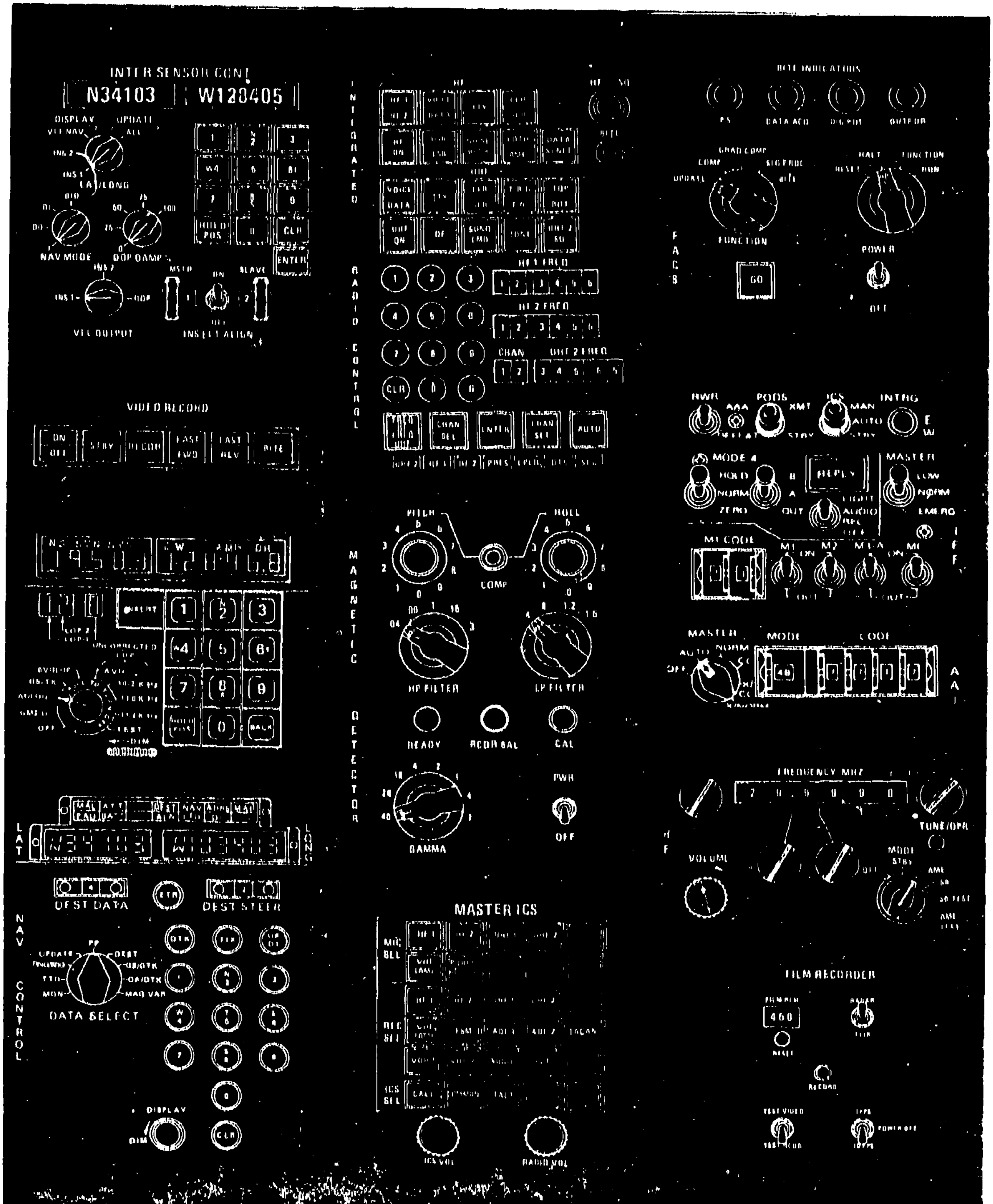
Figure 2: Detection performance as a function of range for two observers from experiment 3.

Figure 3: Spectral distribution of sun's energy reaching the earth's surface as a function of sun elevation (Gates, 1966).

APPENDICES

TABLE 1: A Summary of the Detection Data from the Four Experiments

			PERFORMANCE (%)				
			Detection Rate		False Alarm Rate		
Expt.	Adaptation Conditions	Task Duration	Red	White	Red	White	Range Advantage For Red
1	0.1 ft.L. screen for five minutes	one and a half minutes	79	68	10	11	12
2	(Subjective Matching) Coastal chart about 0.15 ft.L. for five minutes	one and a half minutes	66	58	10	12	17
3	0.1 ft.L coastal chart for one minute	one minute	59	52	16	18	13
4	Integrally-lit panel five seconds	five seconds	74	65	14	17	12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UPDATE
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VEL OUTPUT
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CLR
VIDEO RECORD
INTEGRATED
RADIO CONTROL
CHAN
MAGNETIC
DETECTOR
PITCH
ROLL
COMP
HP FILTER
LP FILTER
READY
RCDR BAL
CAL
GAMMA
PWR
OFF
MASTER ICS
ICS VOL
RADIO VOL
BITE INDICATIONS
FUNCTION
POWER
GO
REPLY
MODE 4
MASTER
MODE
CODE
FREQUENCY MHZ
VOLUME
TUNE/OPR
FILM RECORDER
460
DEST DATA
DEST STEER
DATA SELECT
NAV CONTROL
DISPLAY
DIM

Figure 1

Figure 2

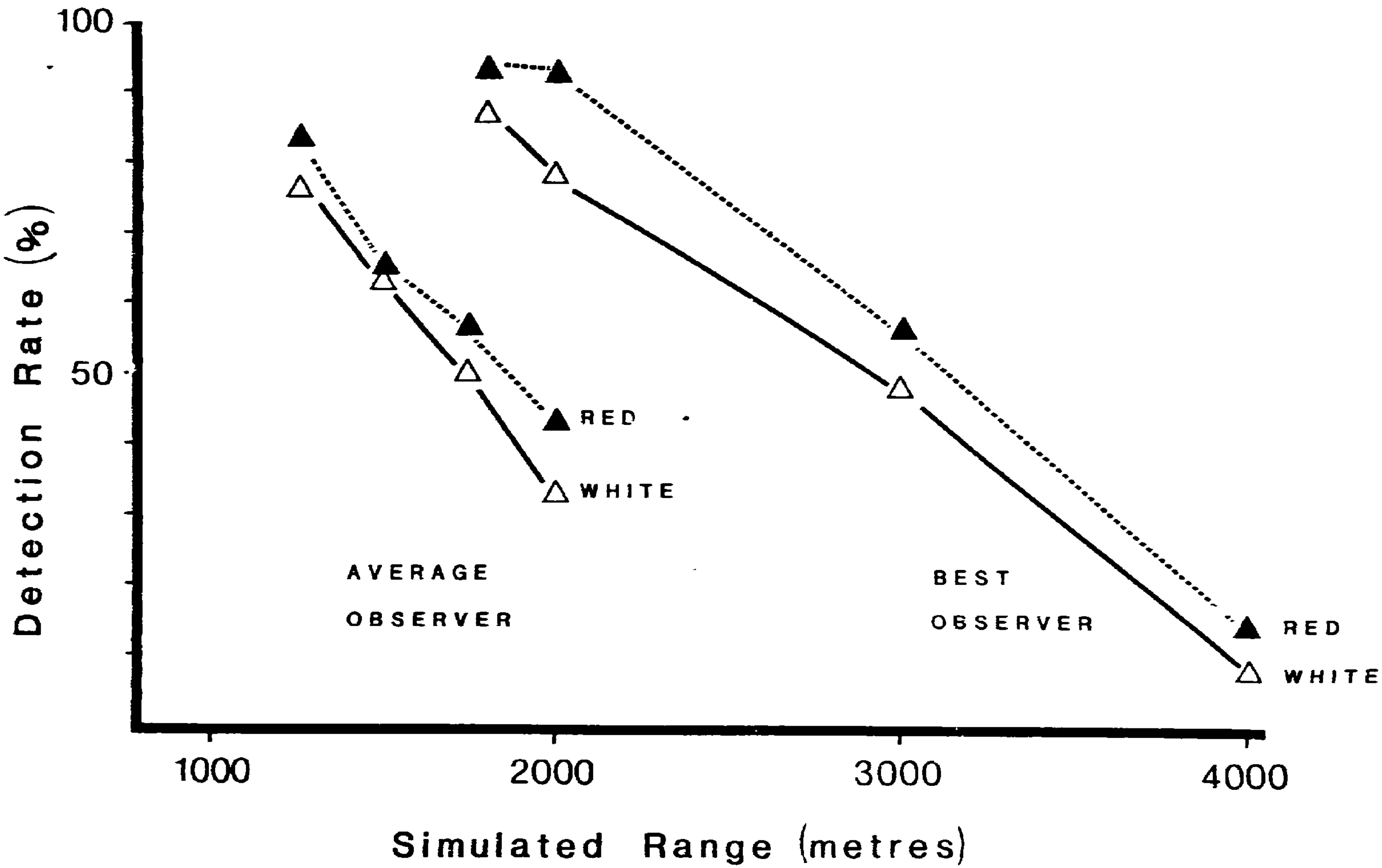
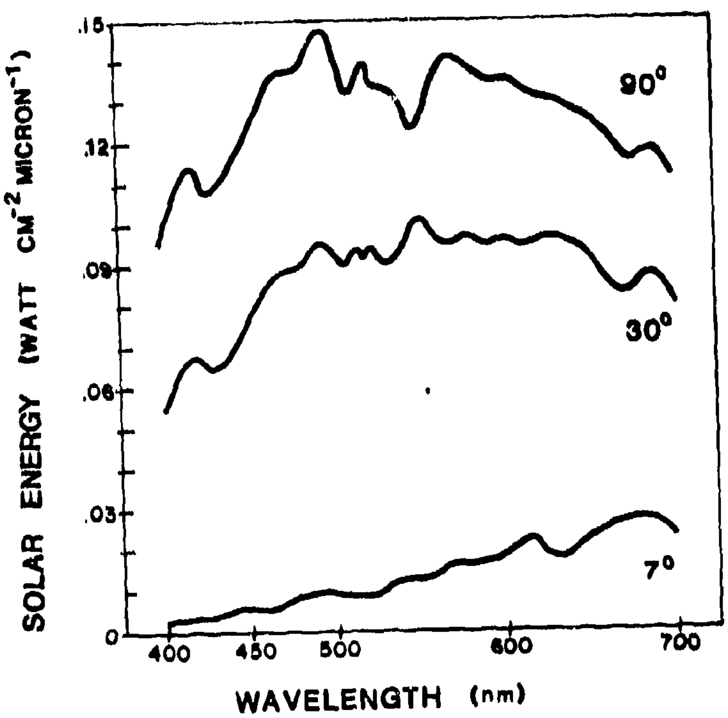

Detection Rate (%)
100
50
RED
WHITE
AVERAGE
OBSERVER
BEST
OBSERVER
RED
WHITE
1000
2000
3000
4000
Simulated Range (metres)

Figure 3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.03
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500
600
700
WAVELENGTH (nm)