Naval Submarine Medical Research Laboratory

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THE RELATIVE EFFECTIVENESS OF FOUR COLOR CODING TECHNIQUES FOR INTENSITY CODING ON SIMULATED ADVANCED MINE DETECTION SYSTEM (AMDS) DISPLAYS

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Naval Medical Research and Development Command
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SUMMARY PAGE

THE PROBLEM

To determine which of four color schemes would be most effective for coding the eight intensity levels of sonar signals on CRT displays for the Advanced Mine Detection System (AMDS).

FINDINGS

The ability of observers to detect and identify sonar targets on simulated AMDS displays was measured for one existing and three proposed color coding schemes at several target signal strengths. One proposed color coding scheme was found to afford significantly superior performance, especially at lower signal-to-noise ratios.

APPLICATION

Colorimetric specifications of the coding scheme shown to provide enhanced target detection are provided, for implementation on the AMDS.

ADMINISTRATIVE INFORMATION

This study was conducted at the Naval Submarine Medical Research Laboratory under Naval Medical Research and Development Command Research Work Unit No. 65856N M0100.001-5003, Enhanced performance with visual sonar displays. The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of the Navy, the Department of Defense, or the United States Government. The manuscript was approved for publication on 10 September 1993 and designated as NSMRL Report No. 1189.

Abstract

Four methods of color coding the intensity levels of sonar returns on the Advanced Mine Detection System displays, currently under development, were studied to determine how the added use of color could enhance operability. The target detection and identification performance of seven experienced observers was measured using the following schemes for coding signal intensity into eight discrete steps: levels of green (the original coding method), levels of white, colors approximating specifications supplied by the Naval Undersea Warfare Center (NUWC), and colors arranged according to lightness, from dark to light. A portion of a static AMDS display 726 pixels wide by 323 pixels high was simulated on a computer controlled color display system. A single target, simulating six sonar pings, or histories, was six pixels wide (10.2 arc min visual angle) by one pixel high, and was present on 50% of the trials. It could be located anywhere in the background. Four target signal strengths were used. The randomized distributions of the background noise levels and the target levels were specified by NUWC and considered to be representative of those expected at sea. Each observer ran on two 100-trial sessions of each of the 16 conditions, combinations of one of the four target strengths and one of the four color coding schemes. In a signal detection paradigm, for each trial the observer signalled, by key press, confidence in the presence or absence of a target on a four-point scale, and indicated the location of the target, when present, by means of a trackball cursor. The hit rates (percentage of trials on which the observer correctly declared the presence of a target), false alarm rates (percentage of trials on which the observer incorrectly declared the presence of a target), and percentage of correct target identification (location) were computed. Results showed that for the two strongest target levels, the four color coding schemes all produced uniformly high performance. For the two weakest target levels, at a false alarm rate of 5%, analyses of variance showed that the color scheme specified by NUWC was superior to the other three in both hit rate and target identification. This superiority became more evident as target strength (i.e., signal to noise ratio) decreased. This color scheme uses highly saturated colors with the representation of signal intensity directly related to both luminance and to the wavelength of the visible spectrum. Colorimetric specifications of the color schemes tested are provided.

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THE RELATIVE EFFECTIVENESS OF FOUR COLOR CODING TECHNIQUES FOR INTENSITY CODING ON SIMULATED ADVANCED MINE DETECTION SYSTEM (AMDS) DISPLAYS

Typical CRT display screens of submarine systems in the past have been monochrome. Specifications for coding signals in many current sonar display systems are therefore written in terms of intensity levels on monochrome displays. Current technology, however, now permits color CRT displays of high reliability and resolution, and these are being incorporated into the latest shipboard systems. The question arises, then, of how best to make use of this color capability in these systems. It would be beneficial to know whether the use of color could enhance the operability of the display, and if so, how.

Of concern in this study is coding the intensity levels of sonar returns on the display for the Advanced Mine Detection System (AMDS) being developed by IBM under the direction of the Naval Undersea Warfare Center (NUWC), New London Detachment, Code 2123. This system uses active sonar to detect small underwater objects such as mines, displaying bearing along the horizontal axis and range along the vertical axis. The intensity of the sonar return is coded in the initial version of the system as proportional to pixel luminance on the green phosphor display screen. Intensity is coded using a three-bit scheme into one of eight luminance steps, from zero (same as the dark screen background) to the brightest green available (maximum green gun value for the CRT). In such displays, the target, on the average, gives a more intense signal return than the background noise and is thus perceived as a brightened area. With the proposed use of a color CRT for this display, NUWC raised the question of how alternative color coding techniques would compare with intensity coding of only the green phosphor for detection and identification (localization on the screen) of a significant signal. For example, combining values from the red and blue guns with that from the green to make white would add to the luminance of that pixel. The range of luminance from the zero background to the maximum white would therefore be greater than the luminance range of only the green gun, thus permitting a greater amount of luminance change between the intervening adjacent steps. This might afford better distinguishability among the levels and enable the operator to discern signals more easily.

Another alternative would be to code the signal intensity as different colors and luminances on the screen, with the same goals as above. This approach has been tried before, with various results. In a study by Butler and McKemie (1974), performance was compared using seven different color codes and one gray-scale code for displaying seven or eight intensity levels on simulated sonar displays. Observers signalled the presence of targets on displays containing noise backgrounds. The probability of detection, or hit rate (percentage of trials in which the observer said a target was present when it in fact was), and false alarm rate (percentage of trials in which the observer said a target was present and it was not) were measured. Results showed differences in probability of detection among the seven color codes, and that all color codes were superior to the admittedly non-optimum gray-scale code over the range of 10 signal to noise ratios tested. The false alarm rate was low and essentially constant across all conditions. The authors concluded that the best codes were those in which the colors were linearly related to a predetermined subjective measure of conspicuousness, which was highly correlated with luminance. It was apparent that these codes were also most broadly distributed over the available chromaticity space.

In a somewhat different task, French (1978) found no difference in pattern detectability thresholds between three gray scales and three color coding scales, each having 8, 16, or 60 levels of hue and luminance coding combinations.

A study by Kraiss and Küttelwesch (1984) compared signal detection performance on simulated sonar displays using seven coding schemes at three combinations of background noise variance and signal to noise ratio. Two of the codes were white on a black background and the reverse. The other five used from three to 12 colors at various luminance coding schemes. Two of the color codes showed superior performance at a low signal to noise ratio with zero background noise variance. As noise variance increased, however, these codes showed significantly poorer performance than the other codes. The authors concluded that there was no evidence that color can facilitate the signal detection task.

In a more recent study (Salafia, DaRos, & Boivin, 1988; Salafia, 1990), performance on a simulated sonar detection task was compared for one monochrome green-scale code and three color codes of seven signal intensity levels. Two of the color codes used only two hues and the third used four. For all codes the four highest signal intensity levels were encoded as increasing luminance of the same hue. No differences were found among the four codes, either for probability of detection, probability of false alarms, or minimum detection level at any of the seven signal to noise ratios tested.

Using color schemes similar to those used by Salafia, et al. (1988, 1990), Douglas (1988) found that observers generally subjectively preferred using monochrome green over colors for target detection, but collected no performance data.

Another study also failed to show a beneficial effect of color coding in a sonar detection/classification task (Glenn, Zaklad, Ryder, & Goodman, 1991). Response times were compared for finding targets using each of three color codes, a standard monochrome encoding, a color code that had been chosen by the group of subjects for preferred brightness and color in a previous signal detection experiment, and an adjustable color code in which the subjects could vary the colors to suit their preference. Response times were slightly but significantly faster for the monochrome scale than for either of the two color coding schemes. The authors concluded that the effectiveness of color coding sonar detection displays is still an open question and that further exploration of color codes is required.

Given the lack of clear and concise human factors recommendations on this issue, the present research was conducted to compare alternative coding schemes in order to provide NUWC with recommendations for the AMDS display. In this study, we simulated a portion of a static AMDS display and compared operators' detection and identification performance using four coding schemes: levels of green, levels of white, colors approximating NUWC specifications, and colors arranged in order of lightness, from dark to light.

Method

Observers

Seven females 21 to 32 years old (mean = 29.6 years) were paid for observing. All had normal or corrected vision for the viewing distance, and all had prior experience with visual psychophysics experiments.

Experimental Design

A two-factor (four levels of target strength x four color coding schemes) within subjects (repeated measures) design was used. All observers were given two 100-trial sessions under each of the 16 conditions of target strength and color coding scheme. The order of the experimental conditions was randomized for each observer.

Apparatus

The sonar displays were simulated on a Ramtek 9400 high resolution color display system controlled by a DEC VAX minicomputer. Observers responded using a standard computer terminal keyboard and a Ramtek trackball. The terminal display was used to give the observer informational prompts and knowledge of results, as described below. The experimental room was dimly and indirectly illuminated by a fluorescent desk lamp located behind the display monitor.

Sonar Displays

For each trial, a display consisting of simulated randomized background noise was presented on the screen 726 pixels wide by 323 pixels high, measuring 19.6 cm wide by 7.9 cm high. At the typical viewing distance of 57 cm, this subtended a viewing angle of 19.6^{o} wide by 7.9^{o} high. The distribution of the background noise levels was considered by NUWC to be representative of that expected at sea, and is given in Table 1. The preponderance of the noise background is displayed as display Level 0, or black, for all color schemes investigated here. Percentage of the background noise pixels illuminated then rapidly decreases with increasing display level, approaching zero at Levels 6 and 7. In fact, no background pixels representing Levels 6 and 7 were illuminated, due to computer constraints in representing infinitesimal probabilities. A different pattern of random noise was used for each trial.

Table 1
Percentages for Simulated Background Noise by Display Level

Level	Percent
0	83.89
1	12.36
2	3.18
3	0.51
4	0.056
5	0.004
6	0
7	0

A target, simulating six sonar pings, or histories, was six pixels (1.7 mm, or 10.2 minutes of arc) wide by one pixel high. A target, when present, could be located anywhere within the background. Four target signal strengths were used, from weak (No. 1) to strong (No. 4). They were assigned to intensity levels in the four color schemes according to the algorithm shown in Table 2, as specified by Code 2123, NUWC, in accordance with the type of data expected from actual targets at sea. The highest signal strength (No. 5) was not used because pilot experiments indicated that the task in that case was too easy and therefore no worthwhile data would be collected. This meant that only coding of Levels 0 through 6 were used in this experiment; Level 7 was never displayed.

Table 2
Algorithm for Determining Target Intensity Levels for Five Target Signal Strengths

1. For each target define:

Target Signal Strength	Shift	Variability
1	1	3
2	1	5
3	3	2
4	3	3
5	4	4

2. Generate a uniform number (X) between 0 and 1.
3. Compute display level directly as follows based on values defined above:

   Intensity Level = Shift + X * Variability.
   If Intensity Level > 7, set Intensity Level = 7.

4. Repeat for each history.

Note. In these experiments only Target Signal Strengths of 1 through 4 were used, so Intensity Level never exceeded 6.

Color Schemes

Green. The display that encoded signal intensity in luminance levels of green was defined first, with Level 0 being black, that is, having gun values of zero, and Level 7 having the maximum green gun value. The six intervening values were psychophysically scaled to approximate equal brightness steps between the two extremes. The colorimetric specifications are given in Table 3. Successive levels of green had a luminance increase over its preceding level by an average factor of $\sqrt{1.73}$. A factor of $\sqrt{2}$, typically used for scaling intensity on actual sonar displays, was not achievable due to limitations of display system. All colorimetric measurements were made using a PR-703A/PC SpectraScan fast

Table 3
Colorimetric Specifications of CRT Stimuli for Signal Level Coded by Luminance of Green

Level & Nominal Color	Luminance (cd/m^2)	x	y	u'	v'	Dominant Wavelength (nm)	Excitation Purity (%)
1 Green	08.7	.284	.605	.117	.562	523	46.6
2	11.1	.284	.606	.117	.562	523	46.7
3	15.6	.284	.606	.117	.562	523	46.9
4	22.0	.284	.607	.117	.562	523	47.1
5	29.1	.284	.607	.117	.562	523	47.1
6	35.4	.283	.607	.117	.562	523	47.1
7	44.4	.283	.607	.117	.562	523	47.1

Note. The x and y values are the chromaticity coordinates on the CIE 1931 chromaticity diagram. The u' and v' values are the coordinates on the CIE 1976 Uniform Chromaticity Scale diagram.

Table 4
Colorimetric Specifications of CRT Stimuli for Signal Level Coded by Luminance of White

Level & Nominal Color	Luminance (cd/m²)	x	y	u'	v'	Dominant Wavelength (nm)	Excitation Purity (%)
1 White	12.9	.295	.294	.199	.445	481	42.7
2	16.1	.296	.297	.198	.448	481	42.1
3	23.2	.299	.297	.201	.448	481	41.4
4	32.7	.302	.296	.203	.448	480	40.7
5	44.2	.299	.292	.202	.445	480	41.2
6	55.9	.299	.289	.204	.443	479	42.0
7	65.3	.295	.287	.202	.441	479	43.1

Note. The x and y values are the chromaticity coordinates on the CIE 1931 chromaticity diagram. The u' and v' values are the coordinates on the CIE 1976 Uniform Chromaticity Scale diagram.

spectral scanning system (Photo Research Div., Kollmorgen Corp.). CRT gun values are not given because of the vast differences in display systems and CRT screens.

White. The next display specified was the "white" encoded scheme. For each of the gun values specified for the green display, appropriate amounts of red and blue were added to make an acceptable white, resulting in a display of eight levels from black to the brightest white available on the CRT display, again in approximately equal steps. The luminance of each step (except Level 0, which was black) averaged 50% greater than the corresponding level on the green display, and so the steps between each level as well as the total luminance range of the white display were 50% greater than those of the green display. Again, the successive levels of white increased by an average factor of $\sqrt{1.73}$. The specifications for this display are given in Table 4.

NUWC. The color coded display specified by NUWC Code 2123 using CRT gun

Table 5
Colorimetric Specifications of CRT Stimuli for Signal Level Coded by NUWC-Specified Colors

Level & Nominal Color	Luminance (cd/m²)	x	y	u'	v'	Dominant Wavelength (nm)	Excitation Purity (%)
1 Dk Blue	00.8	.185	.211	.143	.368	481	73.2
2 Blue	05.9	.168	.132	.158	.279	474	83.7
3 Dk Green	22.7	.251	.473	.123	.521	501	44.7
4 Green	40.6	.266	.537	.120	.542	508	41.3
5 Orange	50.5	.505	.439	.279	.544	584	61.8
6 Yellow	65.8	.465	.470	.241	.549	575	55.4
7 Red	26.9	.576	.320	.405	.507	508[a]	53.3

Notes. The x and y values are the chromaticity coordinates on the CIE 1931 chromaticity diagram. The u' and v' values are the coordinates on the CIE 1976 Uniform Chromaticity Scale diagram.

[a] This is an extraspectral hue, between red and violet, plotted on the CIE 1931 chromaticity diagram as complementary to the given wavelength.

values for a given display system was visually approximated on NSMRL's Ramtek system. This code of eight levels was an approximate subset of 16 colors recommended to NUWC by the Applied Research Laboratory at the University of Texas (ARL/UT). The latter code had Level 0 as black, four increasing levels of blue, five increasing levels of green, four increasing levels of yellow, one level of red, and the highest level as white. The eight colorimetric values used in the present study are given in Table 5.

Lightness. An additional color coded display scheme was designed by the authors at NSMRL based on order of lightness of color, with Level 1 a dark blue and Level 7 white. This scheme was chosen for test for several reasons. First, it was another approximate subset of the 16 colors recommended by ARL/UT. Second, both this and the NUWC specified code had luminance highly correlated with signal intensity level, found to be effective by Butler and McKemie (1974). Third, as also true of the NUWC code, it used colors widely spaced in chromaticity, shown to be effective in the Butler and McKemie (1974) study. Finally, it had the intuitive appeal of lighter colors indicating greater signal intensity. The specifications are given in Table 6, where one can see that with the exception of red (Level 4), luminance of the colors increases with their lightness.

Procedure

The experiment was self paced. Observers were told to work accurately and that there were no time limits, and that a target would be present on only 50% of the trials. The observer pressed the Enter key to start each trial. The display then took approximately 2 s to appear line by line on the screen. A signal detection paradigm (Swets, Green, Getty, & Swets, 1978) was employed, in which the observer first scanned the display and decided upon the presence or absence of a target. She then keyed in a confidence rating of her judgment, as follows: 1 - certain there is no target; 2 - somewhat sure there is no target; 3 - somewhat sure that there is a target; and 4 - certain that there is a target. The terminal screen then indicated to the observer the

Table 6
Colorimetric Specifications of CRT Stimuli for Signal Level Coded by Order of Lightness of Color.

Level & Nominal Color	Luminance (cd/m^2)	x	y	u'	v'	Dominant Wavelength (nm)	Excitation Purity (%)
1 Violet	10.0	.197	.097	.209	.231	460	82.5
2 Blue	17.5	.154	.070	.175	.178	467	93.1
3 Green	42.4	.266	.533	.120	.541	508	41.4
4 Red	26.6	.576	.321	.404	.507	507[a]	53.1
5 Orange	51.0	.504	.440	.277	.545	584	61.8
6 Yellow	66.3	.463	.471	.240	.549	575	54.7
7 White	68.6	.277	.257	.202	.418	477	49.2

Note. The x and y values are the chromaticity coordinates on the CIE 1931 chromaticity diagram. The u' and v' values are the coordinates on the CIE 1976 Uniform Chromaticity Scale diagram.

[a] This is an extraspectral hue, between red and violet, plotted on the CIE 1931 chromaticity diagram as complementary to the given wavelength.

correctness of her choice, that is, whether there actually was a target in the display or not. If a target was present, the observer was prompted to place a trackball cursor over it and press Enter on the keyboard, to determine if the target was correctly located, or "identified." The computer terminal then gave a message as to the correctness of the location and recorded the observer's performance for each trial. The observer continued until the 100 trials for that session were completed. Before the experiment, the observer was given a brief practice session with each of the four color schemes. Each session took from 25 to 50 minutes to complete, depending upon the difficulty of finding the target.

Results

A confidence rating scale of 1 through 4 generates three points on the observer's Receiver Operating Characteristic (ROC) curve (Swets, et al., 1978), which is a plot of false alarm rate on the x-axis versus hit rate on the y-axis. As customary, these rates were converted to *z*-scores prior to further analyses. For each observer a line was fit through these points, plotted in terms of *z*-scores, by the least squares method with slope and intercept as free parameters. A hit rate that corresponded to a false alarm rate of 5% ($z = -1.65$) was then determined. This false alarm rate was chosen due to its being an operationally meaningful level of performance. In a similar fashion, the rating technique yields three points in the false alarm rate by percentage correct identification (PCI) space (with false alarm rate on the x-axis and PCI on the y-axis). For each observer, a best fitting line was determined and the PCI for a false alarm rate of 5% was computed.

For the two strongest target levels, very little difference among the four color coding schemes was seen. All produced uniformly high levels of performance.

For the two weakest or most difficult to detect target levels, significant differences were found among color coding schemes. The data for the hit rates and for the correct identification percentages for the false alarm rate of 5% were subjected to separate repeated measures analyses of variance (ANOVAs). For hit rate, the difference between the two target levels was highly significant, $F(1, 6) = 340.2, p < .001$, with, as expected, the stronger of the two being much easier to detect. The mean hit rate for Target Level 1 was 15.3% and for Target Level 2, 59.5%. The interaction between Target Level and Color Code did not approach significance, as the difference between the two target levels was nearly the same for all four color codes. The effect of color coding scheme was also highly significant, $F(3, 18) = 10.4, p < .001$. The

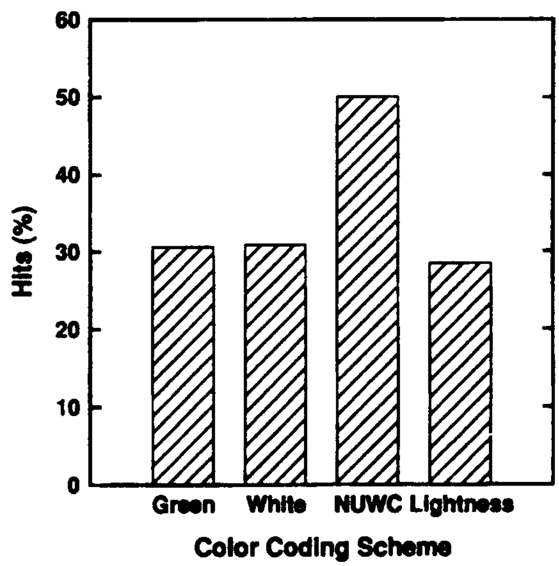

Figure 1. Mean percentage Hits for the two most difficult target levels combined, at a False Alarm Rate of 5% for the four color coding schemes.

percentage of hits for both target levels combined are shown for the four color coding schemes in Figure 1. A post hoc Newman-Keuls test showed that the NUWC color coding s. eme was significantly different from the other three schemes, $p < .01$, which were not significantly different from each other, $p > .05$.

For percentage correct identification, again target level was significant $F(1, 6) = 31.6$, $p < .005$, and a significant difference was found for color coding scheme, $F(3, 18) = 5.6$, $p < .01$. The percentages for each color coding scheme are shown in Figure 2. A Newman-Keuls test showed that the NUWC colors were significantly different from the lightness color code, $p < .01$ and the green code, $p < .05$, but not significantly different from the white code, $p > .05$. The green, white, and lightness color codes were not

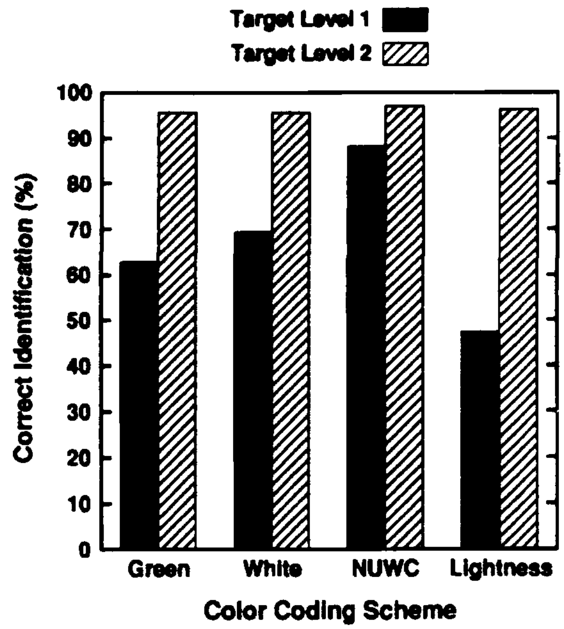

Figure 3. Mean percentage Correct Identification for Target Levels 1 and 2 at a False Alarm Rate of 5% for the four color coding schemes.

significantly different from each other. The interaction between color code and target level was also significant, $F(3, 18) = 7.5$, $p < .005$. At Level 2, the four codes yield similar PICs, whereas at the weakest level, Level 1, the NUWC code is far superior to the other three (Figure 3).

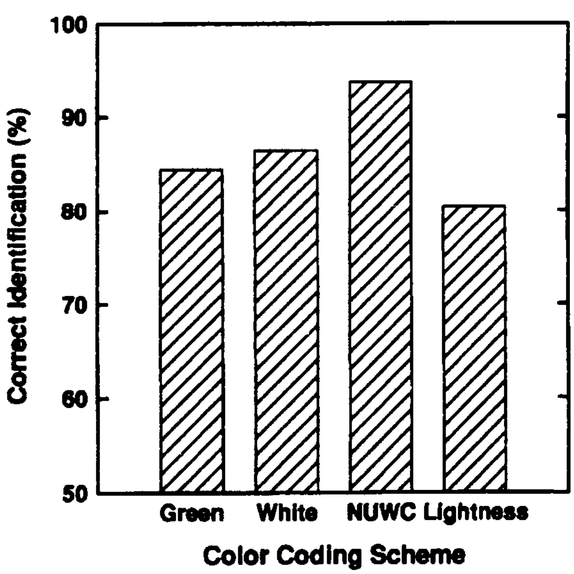

Figure 2. Mean percentage Correct Identification of target for the two most difficult target levels combined, at a False Alarm Rate of 5% for the four color coding schemes.

Discussion and Conclusions

For the AMDS displays as simulated here, for both detection of a six-pixel wide target and identification of its location within a display of background noise, the color coding scheme as specified by NUWC has been shown to be superior to coding by intensities of green, white, or by an alternative color coding scheme tested here. This superiority becomes more evident as target strength (i.e., signal to noise ratio) decreases.

These results confirm those of previous research that, when properly chosen for the particular set of display conditions, a color coding scheme can prove superior to a monochrome intensity scale (Butler & McKemie, 1974), but in other cases may not enhance performance over monochrome schemes (Glenn, et al., 1991; Salafia, 1990; Salafia, et al., 1988).

Why the NUWC color code proved effective here remains a question. The colors were well separated in chromaticity space and their luminances were highly correlated with coded intensity level (except for the highest level, which was red), as suggested to be most effective by the Butler and McKemie (1974) study. On the other hand, the color code was redundant with luminance, which as discussed by Salafia, et al. (1988) might be ignored by the operator and not enhance performance at all. In addition, the alternative color scheme (Lightness) also tested here had very similar characteristics to the NUWC scheme, yet proved no more effective than the two monochrome schemes. These two color schemes looked quite different on the display due to the mapping onto the intensity distribution of the background noise. As shown in Table 1, the preponderance (99.43%) of the background noise pixels were coded at intensity Levels 0, 1, and 2, with Level 0 being black in all cases. Levels 1 and 2, however, totalled over 15% of the background. For the NUWC scheme, Levels 1 and 2 were coded into dark blue and blue of low luminances (see Table 5), whereas the Lightness scheme coded these levels into violet and blue of much higher luminances (Table 6). The effect of this was to make the Lightness display look generally much brighter than the NUWC display, and perhaps this caused the bright targets to be more difficult to detect.

Another issue, which Salafia, et al. (1988) have suggested, is that the signal intensity level correlates with the spectral order of dominant wavelength. If signal intensity were additionally coded by increasing levels of luminance, as both the NUWC and the Lightness color codes roughly were, color coding would be redundant, as discussed in the previous paragraph, and may not add to the overall effectiveness of the display. Salafia's point, here, however is that the redundant coding would at least not present conflicting scales of the same information and thus would not interfere with operator performance. The correlation coefficients of signal intensity level with luminance and with dominant wavelength for both the NUWC code and the Lightness code were calculated. The correlation of intensity with luminance is reasonably high for both codes, $r = .74$ for the NUWC code and $r = .94$ for the Lightness code, despite the non-monotonicity due to the red in each scheme (see Tables 5 and 6). The correlation of intensity with dominant wavelength for the NUWC code is $r = .90$, however, while that for the Lightness code is $r = .30$. It must be concluded that order according to dominant wavelength is indeed a powerful determinant of a color code's effectiveness.

An additional conclusion of the Butler and McKemie (1974) study was that displays whose colors were rated as harmonious afforded better performance than those whose colors were judged as being unpleasant, a factor that may have entered into the present study. The colors in the NUWC scheme, especially at Levels 0 through 2 may have been more harmonious or so dark that they did not appear unpleasant, whereas the Lightness scheme may not have had this subjective advantage. A related issue discussed by Kraiss and Küttelwesch (1984) and Salafia (1988), and perhaps more to the point, is chromatic noise, or colored "snow" on the display screen, in which color could add to the masking effect on the target by the amplitude noise already inherent in the display. The more uniform background brightness of the Lightness display may have hindered detection performance relative to the NUWC display scheme.

The results of this research provide evidence that to the extent the at-sea conditions of background noise and target signal strength were accurately simulated, the color coding scheme as specified in Table 5 would be highly appropriate for use on the AMDS display. This coding scheme can be generally characterized as having the representation of signal intensity directly related to both luminance and to the wavelength of the visible spectrum, while having the colors lie at the outermost parts of the chromaticity space so as to present the most saturated colors (highest excitation purity) available on the display system.

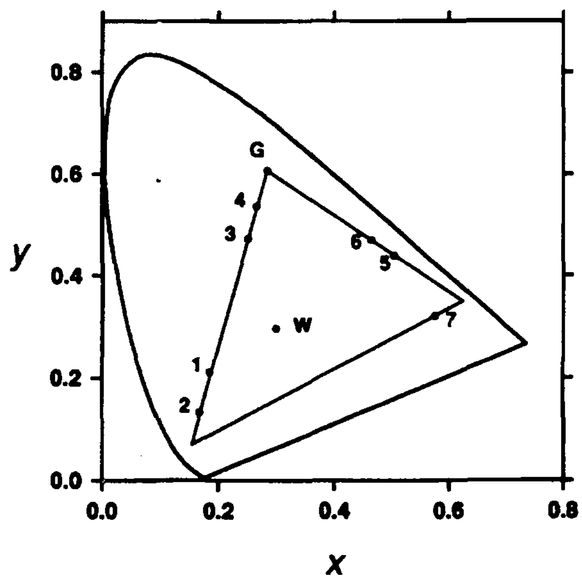

Figure 4. Coordinates of the Green (G), White (W), and NUWC (1-7) color coding schemes on the CIE 1931 chromaticity diagram. The triangle is the boundary of chromaticities available on the display system used in this study.

Figure 4 shows the locations on the chromaticity diagram of the NUWC code colors and the green and white scales, as well as the chromaticity boundaries of the phosphors on the display monitor used in this study. One can see that the NUWC colors lie at the boundary of the most saturated colors available. Spectral order proceeds from blue through green to yellow and red, with colors 1 and 2 transposed, and colors 5 and 6 transposed. (For color 7, a small amount of blue was added to the red to make it look less orange. This also added very slightly to its brightness.) If achievable on a display, a possibly better coding scheme would have highly saturated colors completely in spectral order, perhaps spaced further apart perceptually, while at the same time having their respective luminances increase from a very low level to the maximum. The concept of combining high saturation and spectral order that is correlated with luminance may well prove to be the basis for color coding schemes for the types of displays studied here that have applicability under a wide range of situations, including number of intensity levels.

As Butler and McKemie (1974) pointed out, however, the choice of a color coding scheme must depend on such factors as the characteristics of the signal and the noise, the color and resolution characteristics of the display system, and the operator's task. Only some of the nearly infinite number of color coding schemes apparently are effective for a given set of conditions. The authors mentioned above, and ourselves, agree that more systematic studies of coding in the color space are required.

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Four methods of color coding the intensity levels of sonar returns on the Advanced Mine Detection System displays, currently under development, were studied to determine how the added use of color could enhance operability. The target detection and identification performance of seven experienced observers was measured using the following schemes for coding signal intensity into eight discrete steps: levels of green (the original coding method), levels of white, colors approximating specifications supplied by the Naval Undersea Warfare Center (NUWC), and colors arranged according to lightness, from dark to light. A portion of a static AMDS display 726 pixels wide by 323 pixels high was simulated on a computer controlled color display system. A single target, simulating six sonar pings, or histories, was six pixels wide (10.2 arc min visual angle) by one pixel high, and was present on 50% of the trials. It could be located anywhere in the background. Four target signal strengths were used. The randomized distributions of the background noise levels and the target levels were specified by NUWC and considered to be representative of those expected at sea. Each observer ran on two 100-trial sessions of each of the 16 conditions, combinations of one of the four target strengths and one of the four color coding schemes. In a signal detection paradigm, for each trial the observer signalled, by key press, confidence in the presence or absence of a target on a four-point scale, and indicated the location of the target, when present, by means of a trackball cursor. The hit rates (percentage of trials

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on which the observer correctly declared the presence of a target), false alarm rates (percentage of trials on which the observer incorrectly declared the presence of a target), and percentage of correct target identification (location) were computed. Results showed that for the two strongest target levels, the four color coding schemes all produced uniformly high performance. For the two weakest target levels, at a false alarm rate of 5%, analyses of variance showed that the color scheme specified by NUWC was superior to the other three in both hit rate and target identification. This superiority became more evident as target strength (i.e., signal to noise ratio) decreased. This color scheme uses highly saturated colors with the representation of signal intensity directly related to both luminance and to the wavelength of the visible spectrum. Colorimetric specifications of the color schemes tested are provided.