NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

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THE EFFECT OF CONTRAST ON TARGET DETECTION IN PBB DISPLAYS

by

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Naval Medical Research and Development Command
Research Work Unit M0100.001-1022

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SUMMARY PAGE

PROBLEM

Increasing the number of luminance levels in a sonar waterfall display increases the target contrast and target detection. This study tested whether the improved performance is due to the increased contrast or the increased number of luminance levels.

FINDINGS

In a display in which the number of luminance levels ia held constant at eight, increasing the contrast ratio of target to background had no effect on target detection.

APPLICATION

In designing sonar displays target detection will be improved more by increasing the number of luminance levels than by simply increasing the target contrast.

ADMINISTRATIVE INFORMATION

This research was conducted under Naval Medical Research and Development Command Work Unit M0100.001-1022 --"Enhanced performance with visual sonar displays." It was submitted for review on 22 January 1986, approved for publication on 27 June 1986, and designated as NAVSUBMEDRSCHLAB Rep. No. 1078.

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ABSTRACT

If the number of luminance levels in the PBB display is increased, target detectability is enhanced. One possible explanation of this enhancement is that the target's contrast ratio is increased as the number of luminance levels in the display is increased. In order to test this directly, the number of luminance levels in a PBB display was held constant and the target's contrast ratio was increased by increasing the range of the luminance levels. Under these conditions, there was no enhancement of target detectability, i. e., observers performed equally well on high and low contrast displays. Thus, the improvement in performance obtained when the number of luminance levels is increased must be attributed to other perceptual factors.

INTRODUCTION

Several investigators have experimented with target detectibility in Passive Broadband (PBB) displays with the hope of improving operator performance, i.e. lowering the operator's threshold of detection [1]. In these displays, bearing is represented along the horizontal axis, time along the vertical axis and the amplitude of the signal is encoded by pixel intensity. The displays are currently monochromatic, and signal strength is mapped onto one of eight luminance levels [2]. As yet, no one has attempted to specify the critical stimulus attributes of the PBB display that underlie target detection, or propose a model as to how the visual system is capable of detecting targets.

Typically in these experiments, the target's signal to noise ratio (SNR) is increased until the target is detected. One of the problems in this approach is that SNR does not accurately specify those stimulus features of the visual display that may be essential to target detection. Rather, SNR maps onto stimulus attributes in a probabilistic manner. Thus, as the target's SNR is systematically increased, the critical stimulus features essential to target detection may erratically vary. From a psychophysical viewpoint, SNR imprecisely specifies the target stimulus.

Three stimulus attributes which may be essential for target detection are marking density, contrast ratio of target to background, and grouping of similar brightnesses [3].

Marking density is the percentage of the target's signal that maps onto a luminance level greater than screen black. As a target's signal strength increases, its marking density increases beyond that of the background noise.

Contrast ratio is the ratio of the average luminance of those pixels associated with the target to that of the background. As target strength increases, the average luminance of the target relative to that of the background increases.

Grouping of similar brightnesses refers to the visual system's ability to group similar luminance levels in order to perceive a form. As target strength increases, the number of bright pixels associated with the target increases relative to the background. These bright pixels may be grouped together for target detection.

These stimulus features may be quantized (in a probabilistic manner) for targets whose signal strength is measured in SNR [3]. The research in this report is part of a project to systematically investigate stimulus attributes in the PBB display in order to determine their relative importance in target detection. Once those stimulus attributes essential to target detection are known, the PBB display format may be modified so as to enhance them, thereby increasing target detectibility.

The investigations in this report concern the effect of increasing the contrast ratio of target to background on target detection. It may be demonstrated that increasing the number of intensities used to map signal level to luminance level increases the contrast ratio of target to background for a target with a given signal strength 3. However, increasing the number of luminance levels in the display may also affect the visual system's ability to group luminance levels of similar brightnesses. In order to evaluate the effect of increasing the contrast ratio on target detection independent of the grouping by similar brightnesses factor, it is desirable to keep the number of luminance levels in the display constant while still increasing the contrast ratio for a given signal strength. This may be achieved by increasing the range of the luminance levels employed in the display.

For example, consider a PBB display composed of only two levels. A target with a signal strength of -6.02 db has a predicted marking density of 60%. That is, 60% of the target's signal should map onto a luminance level greater than screen black as opposed to 50% of the background noise. If the luminance levels employed in a low contrast display are .125 Fl (screen off) and .177 Fl (screen on), the predicted contrast ratio of target to background is 1.03 i.e.:

$$(.177*.6 + .125*.4)/(.177*.5 + .125*.5).$$

However in a high contrast display utilizing luminance levels of .125 Fl and 1.14 Fl the contrast ratio is 1.17 i.e.:

$$(1.14*.6 + .125*.4)/(1.14*.5 + .125*.5)$$

Thus, if target detection is solely a function of contrast ratio -- that is if sonar operators detect targets when they have reached a given contrast--the signal strength necessary for target detection will be lower for a high contrast display as opposed to a low contrast display, because a weaker target in the high contrast display generates a contrast ratio comparable to a stronger target in the low contrast display. In our example, the contrast ratio of 1.03 is achieved with an SNR of -6.02 in the low contrast display but with the much lower SNR of -13.01 db in the high contrast display.

This analysis may be extended to a display of eight luminance levels. One simply computes a weighted average luminance of the target and background by taking into account the predicted percentage of each of the luminance levels.

To conclude, if target detection is solely a function of contrast ratio, then the threshold to detect targets should be lower for the high contrast display. However, if contrast ratio has no effect on target detection, then increasing the ratio should not alter the threshold for target detectibility.

METHOD

Subjects

Twelve Submarine school students participated in the experiment.

Apparatus

An AED 512 color graphics terminal and a PDP 1104 were used to generate the displays. The addressibility of the monitor was 512 x 484 lines (48 pixels per inch horizontally and 62 pixels per inch vertically). The C.I.E. chromaticity coordinates (x,y) of the phosphors were .603, .340 for red, .296, .580 for green, and .152, .065 for blue. Only the red and green phosphors were utilized in the display.

A Spectra Pritchard Photometer model number 1980 A was used to measure luminance values of target and background.

The Display

The sonar display simulated one depression-elevation sector of a spherical array passive broadband (SAPBB) short term averaging (STA) display with bearing represented along the horizontal axis, time along the vertical axis and amplitude of signal encoded by the intensity of the pixel. The display was 150 pixels in the horizontal dimension by 200 pixels in the vertical dimension, 2.25 x 2.75 in. The subject viewed the display at a distance of approximately 2 ft. At this distance the display subtended 5.3 x 6.5 deg visual angle. A target was modeled as being fixed in bearing and one pixel in width.

The displays were monochromatic with only the green phospher utilized to generate the luminance values. Eight luminance levels for pixel encoding were used, the same employed on actual sonar displays. The ambient illumination falling on the screen was set at .5 foot-candles (fc), and was provided by two fluorescent bulbs covered by neutral density filters. The lowest level, screen black, is defined as the luminance value at which the display portion of the screen has the same brightness as the nondisplay edges of the screen.

The contrast ratio of target to background is a function of the distribution of luminance levels in both target and background. The distribution of luminance levels was based on displays utilized in previous experimentation at Naval Underwater System Center. Sea noise may be modeled by a Gaussian with a mean of 0 and a standard deviation (SD) of 1, and it may be simulated by randomly generating numbers between plus and minus infinity. The probability that a randomly selected number will fall in any given interval is represented by the area under the Gaussian within that interval. The mapping of noise to luminance levels entails an arbitrary assignment of intervals of numbers to luminance levels. Numbers less than or equal to 0 are mapped onto luminance level zero or screen black. The seven luminance levels above screen black correspond to successive deviations from the mean in increments of one third SD as illustrated in Figure 1. In this manner the theoretical distribution of luminance levels in the display may be computed from the area under the curve between these successive deviations.

The display may be conceptualized as a 150 by 200 pixel matrix. In creating the display, the probability of the appearance of each luminance level was calculated for the noise. For each cell of the matrix, a random number between 0 and 1 was generated, and this number was mapped onto luminance levels in accordance with the underlying probabilities.

In a similar manner, the distribution of luminance levels which composed the target may be computed. The signal level of the target was modeled by the equation 2:

$$\text{Signal Level} = \text{Noise} + 10\,(\text{target SNR}/10.0) \qquad (1)$$

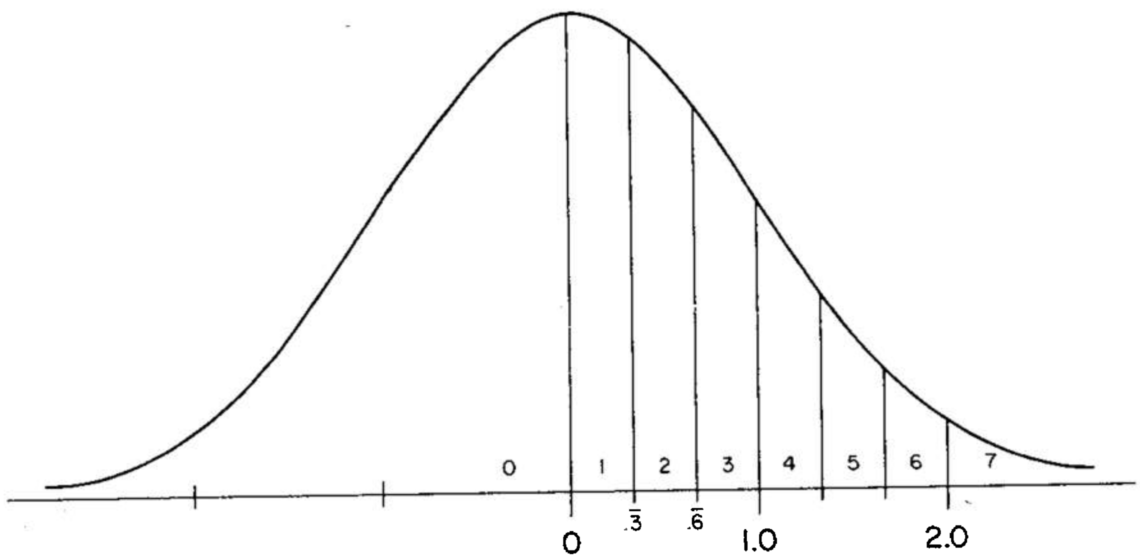

Figure 1: Sea noise is represented as being distributed along a normal curve. The areas between the 1/3 SD intervals correspond to the percentages of the various luminance levels in a PBB display composed entirely of noise and categorized into 8 luminance (or energy) levels.

In the experiment, the targets were constant in both bearing and strength per 200 lines of data. Target strength (i.e. signal level) increased per 200 lines of data such that the mean of the target's signal level corresponded to an increase in marking density of two percent. For example, illustrated in Figure 2 is a distribution of luminance levels associated with a target whose mean signal level deviates from the mean level of the noise by .25 SD. The expected marking density of this mean signal level is 60% and the target's SNR is -6.02 db. In Table 1, the relationships between marking density, signal level and SNR are given. These values are derivable from equation 1.

The underlying distribution of luminance levels for the target is of course different from that of the noise. The distribution for each mean signal level represents the distribution of luminance levels one should observe in the long run. For example, if we keep SNR constant and randomly select numbers between 0 and 1, mapping these numbers in accordance with the underlying probabilities of the occurrence of luminance levels associated with the target, the actual distribution of levels, as well as the actual marking density and contrast ratio of target to background, would vary per 200 lines of data. Thus in an experiment, if SNR was systematically increased, marking density and contrast ratio may not systematically increase although in the long run one would expect them to do so. There are two possible solutions to this problem:

1) Over the course of the experiment, run a large number of trials at each of the SNR'S tested.

2) Compute the expected distribution of luminance levels in the long run for each mean signal level to be tested in the experiment (from which marking density and contrast ratio can be derived) and present targets whose distributions of luminance levels accurately reflect those distributions across 200 lines of data at a particular bearing. In this manner, when SNR is systematically increased, marking density and contrast ratio also systematically increase.

Due to the long computation time needed to create these displays with the equipment at hand, the latter solution was employed in the experiment. This method also has another advantage: The average luminance of the target can be directly computed and compared to obtained measurements from a photometer.

The displays were first computed, generated and stored

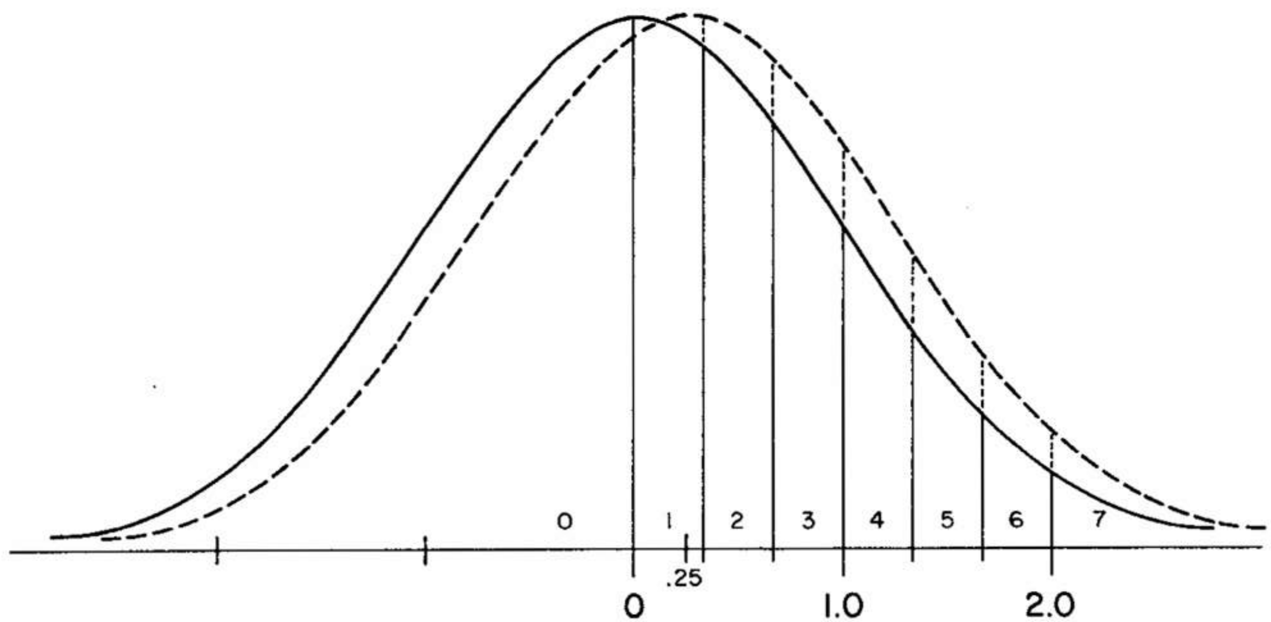

Figure 2: The distribution of signal levels associated with a target (-6.02 db) (broken line) superimposed upon the distribution of noise (solid line). The areas under the target's distribution between the 1/3 SD intervals correspond to the percentage of each luminance in the PBB display that maps to the target.

TABLE I: The relationship between Signal to Noise Ratio (SNR), Signal level and predicted Marking Density.

SNR (db)	Signal Level	Marking Density(%)
-10.0	.10	54
-8.24	.15	56
-6.99	.20	58
-6.02	.25	60
-5.15	.305	62
-4.50	.355	64
-3.87	.41	66
-3.33	.465	68
-2.84	.52	70
-2.37	.58	72
-1.92	.643	74
-1.53	.703	76
-1.14	.77	78
-0.76	.84	80
-0.39	.915	82
-0.02	.995	84
0.33	1.08	86
0.70	1.175	88
1.07	1.28	90

to disk. This method was expeditious in that it made it possible to waterfall the display at a realistic rate for Short Term Averaging (STA), i.e. at approximately 200 lines of data in 15 sec. Through the use of software it was possible to present the exact same data either with the low or high contrast range of luminance levels.

Measuring The Contrast Ratio

Two ranges of luminance levels were employed. In the low contrast display, each luminance level represented an increase in luminance by a factor of the square root of two over the preceeding level (a relationship employed on actual sonar displays). These luminance values were: .125, .177, .25, .35, .5, .71, 1.0, 1.4 fL. In the high contrast display, the first two luminance values were the same as those utilized in the low contrast display, but the subsequent levels marked an increase in luminance by a factor of two over the preceding value i.e.: .125, .177, .35, .71, 1.4, 2.83, 5.66, 11.32 fL. These values were obtained by measuring the green color dot of a single pixel. Originally it was desired to utilize a factor of two between successive luminance levels in the high contrast display; however, the luminance required exceeded the output of the CRT. For a more detailed discussion of these matters the interested reader is referred to the Appendix.

To measure luminance, the target was presented at one bearing, and the photometer, with a 2 min aperture, was placed approximately 2 ft from the display screen. At this distance, the aperture of the photometer covered a circular area composed of a single color dot and the black area of the screen around it (see the Appendix). A one second delay was introduced between successive updates of the display in order to stabilize the photometric readings. The analog output from the photometer was sent to an analog to Digital converter, and the digitalized readings were stored on a PDP 1104. Thus the sequence of events was as follows: the display updated and then paused for one second after which a reading was taken; this reading was digitalized and stored and the process was repeated. The target's signal level was constant for 200 lines; thus 200 readings were taken and averaged for each signal level tested. A "target" whose distribution of luminance levels exactly reflected the long run predicted distribution of levels for the noise was generated and measured. The average luminance of this target served as the average luminance of the background when the contrast ratio of the targets was computed. In Figure 3 the increase in contrast ratio for the low and high contrast displays is plotted as a function of marking density. Also

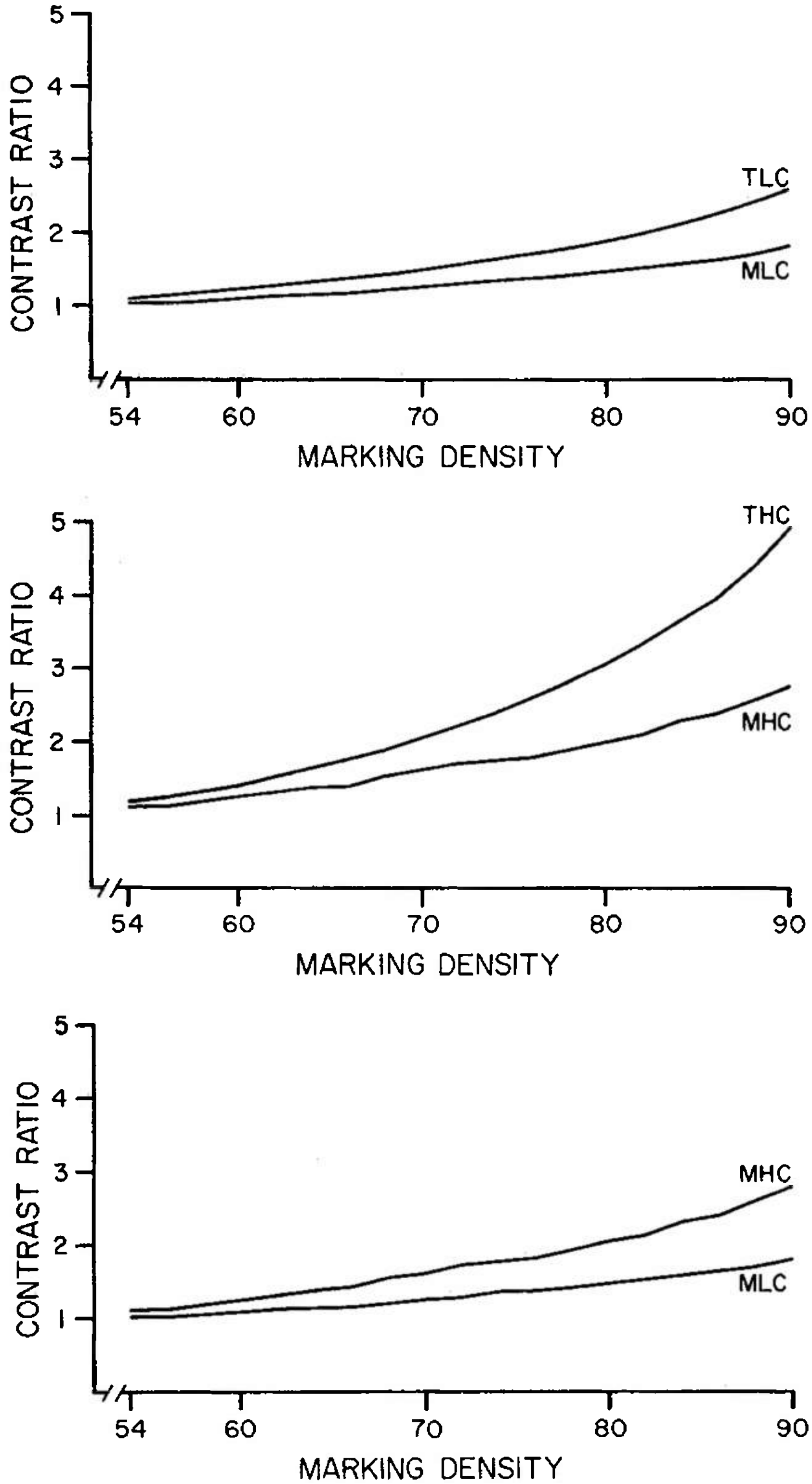

Figure 3: Contrast ratio as a function of marking density. (A) the theoretical and measured contrast ratios for the low contrast display. (B) theoretical vs measured contrast ratios for the high contrast display. (C) the high and low contrast ratios measured in the experiment.

plotted in Figure 3 is the predicted contrast ratios for the high and low contrast displays. The obtained values were in accordance with the predicted values; although, the measured values were consistently lower than the predicted contrast ratios. The reason for the discrepancy between the two is discussed in the Appendix.

As illustrated in Figure 3, the range of contrast ratios for the low and high contrast display was sufficient to register a change in the threshold of detectability when detectibilty is measured in terms of marking density. For example, suppose that the contrast ratio is critical to target detection, and that the threshold contrast ratio necessary for detection is 1.3. In the high contrast display this ratio is obtained with a marking density of only 62%, which corresponds to an SNR of -5.15 db. However in the low contrast display this contrast ratio is not achieved until the target's strength obtains a marking density of 72%, i.e. an SNR of -2.37 db. Thus we should expect much better performance on the high contrast display if contrast ratio is a critical stimulus feature of target detection.

Procedure

The subject searched for a single target at a time. The target was presented at a constant bearing for 200 display lines. The display "waterfalled" 200 lines of information in approximately 15 seconds and then stopped. A crosshair appeared which the subject was instructed to position with a joystick over the column which he believed contained the target. The degree of position error tolerated for a correct response was 5 pixels in width (approximatley 1/8 in) centered around the target column. A column was one pixel in width. There was no time limit for this response. When the subject made his decision, he informed the experimenter, who entered the response in the computer. The display then waterfalled for another 200 lines with a new target, at a new bearing, and at an increased signal strength as described above. This procedure was repeated until the subject correctly detected three targets in a row. The marking density of the first of these targets was scored as the subject's threshold.

Each subject was tested on both the high and low contrast display. Across subjects, the order of presentations of the displays was counterbalanced. The high and low contrast displays presented the exact same data. Thus the order and bearing of the targets were the same for the two displays.

RESULTS

The results, listed in Table II, show that with the low contrast display the average threshold marking density was 69.33%, whereas with the high contrast display the average marking density was 70.83%. These values are not significantly different ($t=1.91$, $p<.05$). Thus, increasing the contrast ratio of target to background had no effect on target detectibility.

DISCUSSION

Increasing the number of luminance levels in a PBB display increases the target contrast with a given signal strength. We have already demonstrated [4] that increasing the number of luminance levels also increases operator performance, i.e. lowers the threshold of target detectibility. The current experiment stemmed from the question, is this increase in performance wholly attributable to the increase in contrast ratio. The present results show that this is not the case. As the target contrast was increased while holding the number of luminance levels in the display contant, performance did not improve. Thus the increase in performance when the number of luminance levels is increased must be attributable to other factors such as grouping by similar brightnesses or changes in the connectivity of similar luminance levels.

The range of the luminance values can play a role in target detection insofar as the range of luminance levels may interact with the number of effectively different luminance levels. For example, if the range of luminance levels is so small that several adjacent levels are treated as equivalent by the visual system, then this would be tantamont to decreasing the number of levels in the display. Likewise, the ambient illumination falling on the screen, if too bright, may decrease the number of luminance levels in the display that can be distinguished from one another. In this situation, the range of luminance levels interacts with the ambient illumination. In the high contrast display, for example, the display can withstand higher levels of ambient illumination before the range of eight luminance levels collapses into a smaller range.

TABLE II: Percent marking density thresholds on high and low contrast for each subject.

Subject	High Contrast	Low Contrast
1	70	70
2	70	68
3	70	70
4	70	68
5	68	68
6	70	70
7	72	72
8	70	70
9	68	68
10	76	68
11	76	70
12	70	70
MEAN	70.83	69.33
SD	2.62	1.30

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APPENDIX

Several limitations with our equipment and characteristic problems with shadow mask CRT screens in general made measurment of the average luminance of the target difficult.

The first problem arises in trying to measure the luminance of a single green color dot. (A pixel is composed of a three color dots: red, green, and blue. In our displays, only the green color dot was utilized.) On the one hand, the 2 min aperture of the photometer is larger in diameter than a single color dot, thus the instrument is measuring both the luminance of the color dot and the surrounding black area of the screen. On the other hand, due to the misconvergence of the electron gun, if a single color dot is turned on, surrounding color dots may also be illuminated (to a lesser extent). Insofar as the photometer's aperture partially covers a neighboring illuminated color dot, the measurement consists of an average of the luminance of the color dot being measured, neighboring color dots some of which are on some off, and the black regions of the screen between adjacent color dots. The situation is illustrated in Figure 4.

However, accurately measuring the luminance of a single color dot is not critical, because the observer cannot resolve individual dots on the screen. The 2 min aperture thus integrates luminance over an area which is more in accordance with the observer's visual resolution of the display.

What did prove critical to the measurement of the average luminance of the target and background was the misconvergence of the electron gun. When trying to illuminate only a single color dot, a few surrounding color dots were also dimly illuminated; however, when measuring the average luminance of the background and target, a large number of surrounding color dots were illuminated. For each dot there was some degree of misconvergence: thus a considerable amount of light was added to the background and the target. The measured contrast ratios for the high and low contrast displays were less than the predicted ratios beacause of this "stray" illumination. The situation is analagous to adding a "veiling luminance" of light to a target and surround. To demonstrate the magnitude of the attenuation of contrast, the luminance of a black target, i.e. screen off, was generated on the PBB display and measured. The average luminance for this target was 2.33 fL and 1.37 fL for the high and low contrast display respectively. This marks an increase in luminance by a magnitude of ten over the luminance of screen black (.125 fL) when the entire screen is off.

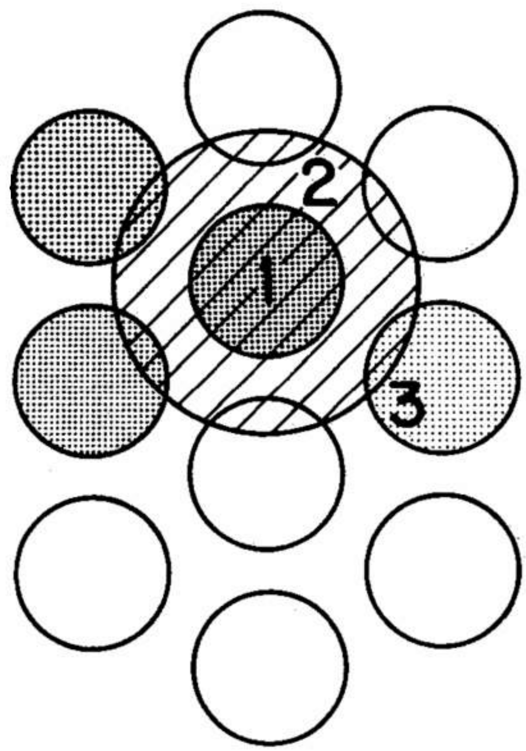

Figure 4: Measuring the luminance of a color dot. The photometer measures an area which includes: 1) The color dot of interest, 2) its black surround, 3) the edges of adjacent color dots. The large circle is the aperture of the photometer. The small circles are the color dots. The degree of shading represents brightness (the denser the shading the brighter the pixel). When one dot is illuminated, several adjacent dots are also illuminated, to a lesser degree, due to misconvergence.

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If the number of luminance levels in the PBB display is increased, target detectibility is enhanced. One possible explanation of this enhancement is that the target's contrast ratio is increased as the number of luminance levels in the display is increased. In order to test this directly, the number of luminance levels in a PBB display was held constant and the target's contrast ratio was

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increased by increasing the range of the luminance levels. Under these conditions, there was no enhancement of target detectibility, i.e., observers performed equally well on high and low contrast displays. Thus, the improvement in performance obtained when the number of luminance levels is increased must be attributed to other perceptual factors.