COLOR AND CONTRAST PERCEPTION IN MONOCHROME MEDICAL IMAGING FLAT-PANEL DISPLAYS

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ABSTRACT

The interpretation of diagnostic grayscale images by human beings relies on luminance discrimination at photopic levels. The observer in his search for abnormality relies on luminance modulation. If this hypothesis is valid, then the color of a monochrome presentation should not affect diagnostic performance when the image luminance is equivalent to grayscale levels. Does observer preference for a particular tint influence his performance defining an ideally colored grayscale? In this paper, we studied the variations in supra-threshold contrast perception when using different colored scales to display psychophysics targets on uniform background. We used targets with six different colored scales based upon the hue and saturation levels, while maintaining a constant luminosity. The six colored scales and the "white" grayscale constituted our set of seven colored scales used in a two-alternative forced choice scheme with random presentation and eighteen observers. All image targets contained the same degree of physical contrast and the same luminance values. We computed the degree of preference for all possible combinations of two colored scales. In spite of large inter-observer variability, we found that green and blue scales result in higher perceived contrast.

Keyword List: contrast perception, achromatic contrast, flat-panel display, medical display.

1. INTRODUCTION

High-resolution active-matrix polymer light-emitting displays (AM-OLEDs) have demonstrated potential to achieve extremely high image quality. Having small pixels (50 μm) and high luminance (greater than 1,000 cd/m^2), AM-OLEDs can provide image quality that would surpass the visual system capabilities, offering all the information recorded in the image raw data to the human observer. However, the spectral emission of organic polymers suited for AM-OLED devices is narrow (high color saturation). The wavelength distribution of light generated by carrier recombination within the organic thin-films typically corresponds to a single peak with a full-width at half-maximum of about 120 nm. Particularly in the case of active-matrix displays based on OLEDs, full-color devices are more technologically involved than monochrome devices. To obtain a full-color device, three different polymers with emissions along the RGB primaries are deposited either by advanced printing techniques or by successive deposition steps. An approach to obtain a white display with small organic light-emitting molecules involves the stack of multiple layers with different color emission causing a significant decrease in luminance. However, a monochrome device can be obtained spin-coating a single polymer layer on top of the substrate with the active-matrix circuits. In Table 1, we show the CIE chromaticity coordinates for organic light-emitting materials used in our laboratory, along with data for typical phosphors used in medical imaging monochrome cathode-ray tube monitors (P45 and P104).

An additional element that motivates this study is the known preference of some radiologists to using tinted bases in radiographic films. Even among currently available monochrome display devices, noticeable variations in the color coordinates of their gray-scale can be seen. It has also been proved that undesired color reflections from ambient illuminance can shift the sensitivity of the human observer in a non-reproducible fashion.[1]

In this work, we address the following question: does observer preference or increased sensitivity to a particular color scale influence its performance in visual detection tasks defining an ideally colored gray-scale? This study aims at understanding the effect of the color of monochrome presentations on the perception of contrast by the human vision and ultimately on diagnostic performance. In this paper, we report on the effect of the monochromatic scale

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Image Perception and Performance, Elizabeth A. Krupinski,
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Emitter	CIE 1931 coordinates	
	x	y
University of Michigan red polymer	0.679	0.319
University of Michigan green polymer	0.433	0.551
P45 (single crystal)	0.280	0.304
P104 (blended phosphor)	0.257	0.319

Table 1. Color coordinates according to the 1931 CIE standard for organic light-emitting materials and cathode-ray tube monochrome phosphors used in medical imaging monitors.

color on the perception of supra-threshold contrast using human observers. We constrained our study to luminance-based achromatic contrast perception by using colored monochromatic scales having different color coordinates at the state of maximum luminance from a common black state. No color contrast is therefore present in the patterns. In a previous study, the performance of spectral scales that rely on chromatic contrast was found poor compared to the grayscale mode.[2]

2. METHODS

We generated low-contrast sinusoidal gratings within circular targets with a diameter of 100 pixels and a frequency of 0.05 lp/pixel (about 0.25 lp/mm) above the visibility threshold for a grayscale mode (see Fig. 1). A mid-gray uniform field of 400 by 400 pixels surrounded the targets. Using an iterative process of adjusting the color and luminance, we modified the targets to obtain a collection of six different colored scales based upon the hue and saturation levels, while maintaining a constant luminance map. The six colored scales and the "white" grayscale constituted the seven colored scales used in the observer study.

Figure 1. Supra-threshold contrast test pattern with sinusoidal grating used in this study. The background field is at an average luminance.

We measured color coordinates and luminance of the patterns for each scale with a CCD spectral analyzer with fiber optic probe and a photometer respectively. From the spectra recorded for each pattern, we computed the color coordinates according to the CIE 1931 standard,[3] by convolving the measured spectra with the color-matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$:

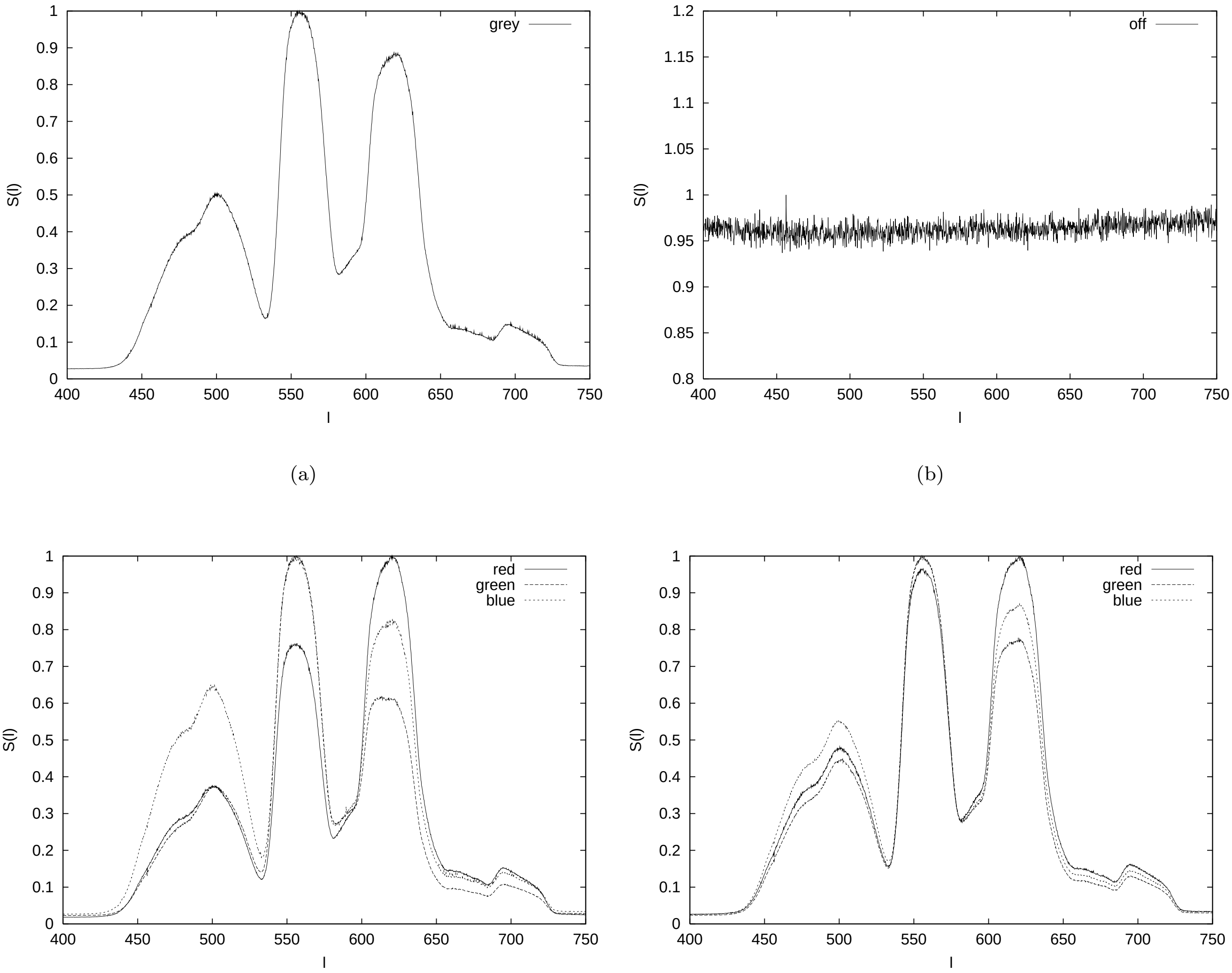
$$X = K \int_{380nm}^{780nm} S(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = K \int_{380nm}^{780nm} S(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = K \int_{380nm}^{780nm} S(\lambda)\bar{z}(\lambda)d\lambda$$

where K is a constant.

The 1931 CIE color coordinates (x, y, z) are obtained by normalizing X, Y, and Z: $x = X/(X + Y + Z)$, and $y = Y/(X + Y + Z)$. We performed independent measurements for both the luminance and the CIE color coordinates with a MINOLTA CS1000 colorimeter. The variations in color coordinates between the two methods were within 0.005, while the variations in measured luminance remained within 5%. These measurements confirmed equal luminance maps for all the targets, a crucial assumption in our experimental design. Table 2 shows the CIE coordinates corresponding to the measured spectra for the seven colored scales used in this study presented in Fig. 2.



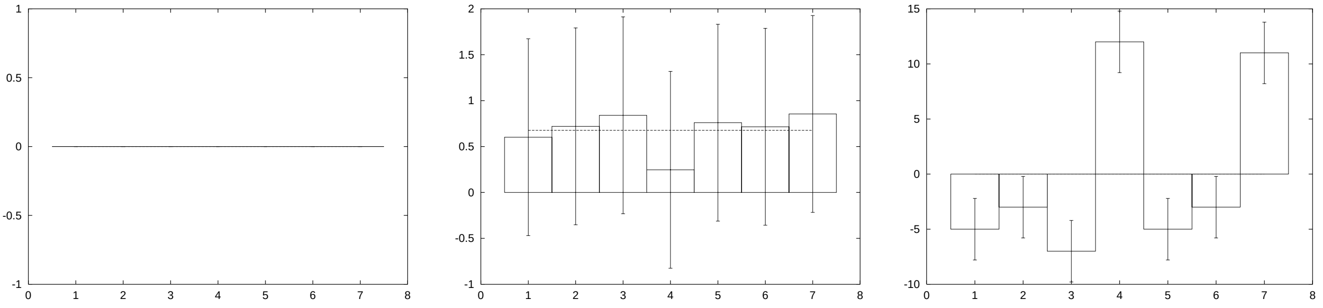
(a)

(b)

(c)

(d)

Figure 2. Measured spectra recorded from the test patterns used in this work. (a) shows the spectrum for the gray pattern. The contribution from ambient illuminance when the display is turned off is depicted in (b). (c) and (d) represent the red, green and blue scales at saturated and non-saturated levels respectively.



(a) (b) (c)

Figure 3. Preference function P^* for three observers with known response: (a) ideal observer, (b) random-response observer, (a) blue-biased observer.

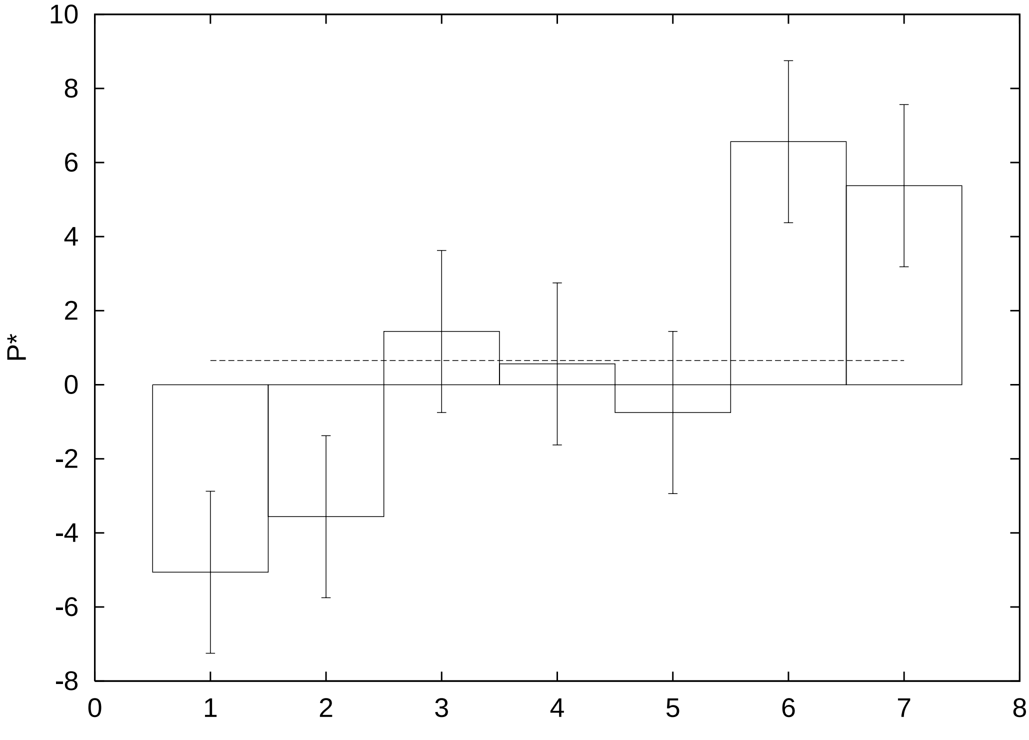


Figure 4. Response P^* for all observers with $llag = 0$ and $flag = 0$. The dashed line represents the average of P^* across the color scales.

Scale	Luminance (nit)	CIE 1931 coordinates	
		x	y
1	35.67	0.305	0.327
2	38.10	0.325	0.334
3	35.82	0.315	0.348
4	36.67	0.297	0.323
5	38.23	0.350	0.336
6	36.22	0.320	0.368
7	36.20	0.273	0.307

Table 2. Color coordinates according to the 1931 CIE standard for the scales used in this work. The scale 1 is the unmodified graylevel, scales 2, 3 and 4 represent the non-saturated red, green, and blue scales, while 5, 6, and 7 are the chromaticity coordinates for the saturated red, green and blue.

We performed an initial experiment using a spatial two-alternative forced choice scheme with random presentation of the seven colored scales arranged in pairs. All image targets presented to the viewer contained the same degree of physical contrast. We asked the observers to indicate which of the two targets appeared as having more contrast in the sinusoidal pattern. The experiment consisted of evaluating fifty image pairs. The responses of eighteen observers were compiled using HTMail and analyzed with Perl scripts against the actual order of images. Each observer selected a sequence of image pairs according to the first letter of their computer account identification name.

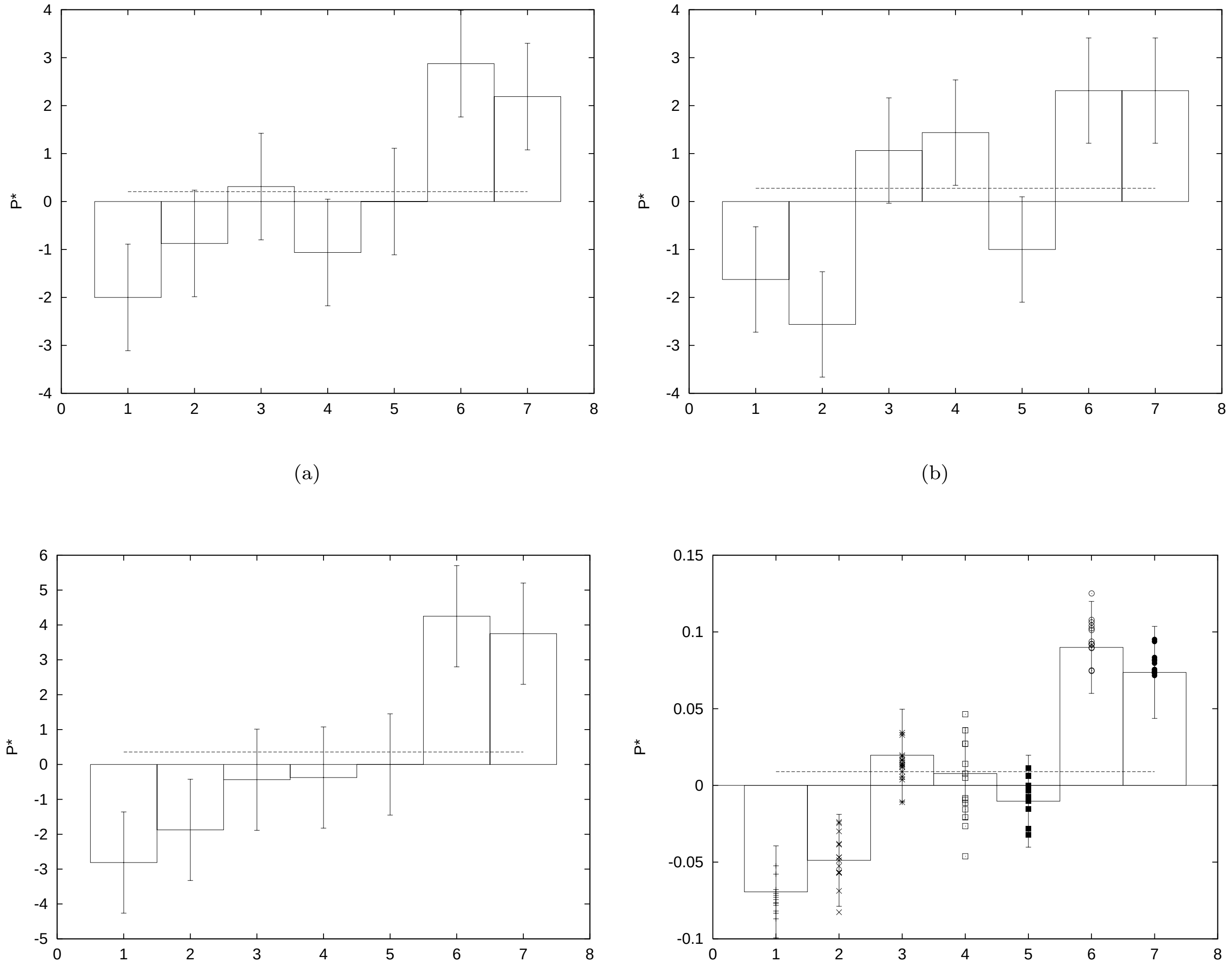
During this study, all aspects of display quality remained unchanged. We used a 1024×1256 color active-matrix liquid crystal display (AM-LCD) to present the image sets to the observers. Cathode-ray devices, specially designs based on aperture grilles, are not suitable for this study because color can affect the device resolution. We assumed that the variation in display quality parameters in the AM-LCD is minimal within the color space sampled. The luminance range of the display was measured to be about 150, with $L_{min} = 0.60$ nit and $L_{max} = 92.6$ nit.

The viewing distance was fixed using marks in the floor for positioning of the chair. We used black panel boards in the table and walls behind the AMLCD to block reflections and to control the stimulation of the observers from regions other than the display. The application menu bars were minimized or hidden when possible. We performed an initial explanation of the experiment and the questions to be answered with each observer for a period of at least 10 minutes. The training and the experiment were performed at low ambient illumination levels.

We analyzed the results by constructing a 7×7 matrix $P(M, N)$ where M and N are two of the seven color scales, with the following code: when the perceived contrast of scale A was higher than for B, $P(A, B)$ was increased by unity, and when the perceived contrast of scale B was higher than for A, $P(B, A)$ was increased by unity. When A and B appeared to have the same contrast, no addition was performed. $P(M, N)$ can be interpreted as a map of contrast perception preference, where the combinations of M and N that have the higher values signal that the scale M results in higher perceived contrast than the scale N. If we note that $P(M, N)$ is correlated to $P(N, M)$, we can construct a new matrix $P'(M, N)$ by assigning $P'(N, M) = P(N, M) - P(M, N)$. The final step in the data reduction method is the projection of the half matrix defined by $P'(M, N)$ for $N \leq M$, along the N axis to obtain the function $P^*(M)$ that is directly associated with the degree of increased perception of contrast due to the colored scales. When the perceived contrast for a scale S is higher compared to others, we expect $P^*(S) - \bar{P}^*$ to be positive and significant against the variance of P^*.

To evaluate our data processing tools, we generated results for three observers with a priori known response: an ideal observer, a random-response observer, and a blue-biased observer. In Fig. 3, we show the computed P^* for these three observers. The ideal observer in this case corresponds to an observer for which the contrast perception response is determined only by luminance contrast and therefore, it is not affected by the color of the scales.

The random-response observer plot shows that if the response of the real observers were to be random, there will be no significant variation in the value of P^* across the colored scales. The blue-biased observer is one that always perceives more contrast in patterns using blue scales. The results showed in Fig. 3 confirm that the data processing is correct, and that a difference in the perception of contrast for the color scales can be measured with this scheme.



(a)

(b)

(c)

(d)

Figure 5. Effect of the learning and fatigue lags on the response P^*. (a) corresponds to $llag = 30$ and $flag = 0$, (b) corresponds to $llag = 0$ and $flag = 30$, (c) corresponds to $llag = 10$ and $flag = 10$, and (d) shows the results for all the combinations of lags computed.

3. RESULTS AND DISCUSSION

Fig. 4 shows the average response P^* for all observers. The error bars at each point represent one standard deviation of the distribution of values of P^* among observers. The results suggest that the grayscale is perceived as having less contrast than most of the color scales. Among the color scales, the saturated blue and green appear to convey more contrast than the red, and non-saturated scales.

To understand the robustness of the experiment, we tested for possible learning or fatigue effects. We computed different responses P^* according to the described method, but disregarding the first n image pair decisions ($llag = n$), and the last m pairs ($flag = m$). The lag parameters $llag$ and $flag$ stand for "learning" lag and "fatigue" lag. For these cases, the computation of P^* is performed with only $50-llag-flag$ observations. Fig. 5 present the computed P^* for several combinations of $llag$ and $flag$. We noted that there existed a large inter-observer variability that can be attributed to varying personal sensitivities or to prior imaging experience. In Fig. 6, we show the response P^* obtained by averaging the fifty image pairs across all observers, along with the individual scores. In particular, we observe that only for two observers, the perceived contrast with grayscale presentation almost equals the perception with the green or blue saturated scales.

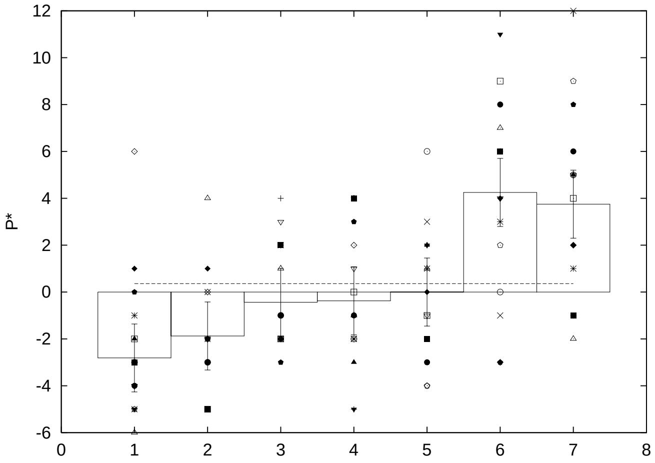


Figure 6. Response P^* for all observers with $llag = 0$ and $flag = 0$. The solid line represents the average of all P^*.

4. CONCLUSION

If it is indeed luminance discrimination that predominantly determines contrast perception, then we would expect no significant shift of the perceptual behavior due to variations in color. The results indicate that the perceived contrast of targets having the same physical contrast in a monochromatic mode varies with color.

Blue and green scales result in higher perceived contrast above the threshold. In addition, observers prefer more saturated green and blue scales (within the gamut used in the study). Grayscale is only almost equally preferred for a small fraction of the observers. The large inter-observer variability suggests that individual factors such as training, preference, color sensitivity and experience may play a role in the mechanism of contrast perception. Although this variability was detected, the results from the study are significant for the average observer.

To our knowledge, ours is the first study to address the effect of a colored grayscale on the detectability of signals and on contrast perception. Because the experiments used backgrounds of the same color as the targets, it is not clear if chromatic adaptation of fovea and periphery affects the outcome. Further experiments will address the effect of chromatic and luminance adaptation using combinations of target and backgrounds of different color. We plan to extend this study to include realistic targets and backgrounds using phantom and mammography digital images. The results of this work provide meaningful data for the optimization of medical imaging flat-panel AM-OLED structures with optimum colored grayscale and high image quality.

5. ACKNOWLEDGMENTS

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