Influence of Background Characteristics on Adapted White Points of CRTs

Peyma Oskoui
Hewlett Packard Laboratories, Palo Alto, California, USA

Elizabeth Pirrotta
Color Science Consultant, Mountain View, California, USA

Abstract

A set of psychophysical experiments was conducted to investigate backgrounds for determining the adapted white points of CRTs viewed under variously illuminated environments. A number of background characteristics were modified, such as pixel size, chroma range and lightness range. All backgrounds tested averaged to the same luminance and chromaticity. Observers viewed solid-colored samples on a field of each background displayed on a D65 balanced CRT monitor in a dark environment. Their task was to select the most achromatic appearing samples through an iterative process. Only two of the six backgrounds were found to result in near complete adaptation to the monitor: the control, a solid field of L*=60, and, an achromatic random dot pattern. None of the other tested backgrounds, which were all chromatic random dot patterns, resulted in complete adaptation, and all had very large variances. The conclusion is drawn that chromatic random backgrounds can significantly effect chromatic adaptation. This is true even if the measured background is neutral and if the background pixels average to an achromatic.

Introduction

CRT displays are very often a critical component in digital color reproduction systems because most image and document creation and editing is performed on a CRT screen. To faithfully reproduce a CRT original as a reflection hardcopy, projected slides, or, to be viewed on some other CRT, color appearance models are often utilized. Correctly applying a color appearance model, such as CIECAM97s, requires knowledge of the viewing conditions and observer adaptation states. However it is often difficult to determine the observer's state of adaptation for the viewing situations commonly employed in today's work environments. Frequently CRT images are viewed under ambient illumination, which might include uncontrolled daylight, tungsten and fluorescent sources. A method is needed for simply and reliably determining the state and degree of adaptation for any specific CRT in an uncontrolled illuminated environment, so that color appearance transforms can be readily and accurately applied.

Hunt[1], Fairchild[2] and Brainard[3] have all independently collected chromatic adaptation data using a method of adjustment. One such procedure requires an observer to adjust a centralized sample until it appears achromatic. The observer's state of adaptation is determined by averaging the chromaticites of the perceived-achromatics generated by dozens of repetitions.

Gorzynski[4] employed a multi-sample, interactive method of determining the state of chromatic adaptation. Many samples appear at the same time, and the observer selects the most achromatic. Once the sample is selected the observer is presented with a second selection of samples, this time more achromatic than the last and based on the observer's previous choice. The iteration continues until the observer has reached a standard deviation of 0.005 CIELUV units. Like the method of adjustment, the chromaticities of final perceived-achromatics are averaged to find the white point. An essential characteristic of this method is that observers are instructed not to fixate, or stare, at any particular sample. Gorzynski compared both the single stimulus and multiple stimuli methods of collecting adaptation data and concluded that they yielded the same results. The Gorzynski method is simpler to implement and is an easier task for the observer.

Role of Background

The background of a viewing field is the area immediately surrounding the sample up to about 10°.[5] It has been shown that various characteristics of the background can effect the observer's state of chromatic adaptation.[2,6] Adaptation to a solid background produces different results than adapting to a pictorial image. This research was focused on the state of adaptation achieved in a normal office environment, where users usually view an image or desktop on their monitor. While a solid background may simplify the problem, it is difficult to tell if it is representative of the adaptation conditions of interest for this research.

Additionally, a solid background does not sufficiently fit the restrictions of the situation of a CRT under ambient illumination. If the background is black, little information is conveyed to the visual system about the ambient illumination. However using a white or grey background can inappropriately bias the results of an experiment where the observer's task is to select an achromatic. The observer may decide to match the background rather than select a sample that truly appears achromatic.

To avoid the confounds of either a solid background or a pictorial image background, Fairchild[2] employed an achromatic random dot background, controlling the lightness and chromaticity. Choh et al.[7] in similar testing designed a background made of random color dots to mimic a pictorial image. Following similar lines, in this research, colored pixels were also used to generate randomly distributed backgrounds. However, it was found that some aspects of these random color dot backgrounds influenced the state of chromatic adaptation. In this study a number of backgrounds were tested to determine which ones did not affect chromatic adaptation. The goal was to select a background that would be appropriate for use in determining the adapted white points of CRTs with ambient illumination.

Experimental

Background Generation

The requirements to generate backgrounds were to closely mimic an ordinary computer users' background. The first step was to base the lightness level on the ISO 3664 viewing condition recommendation of a gray background of 60% gray. This was interpreted as L* of 60. The second step was to select a range of chroma typical to pictorial images. It was found that at this lightness, the average C* value in a range of pictures was approximately 10 while the maximum was 35, when clipping all directions to in-gamut values.

In pilot experiments it was seen that the background pixel size and color sampling most affected chromatic adaptation. To determine which random color dot pattern afforded complete adaptation, a subset of levels of these characteristics were investigated. The underlying assumption was that, regardless of the background, observers should completely adapt to the white point of the monitor.

Six different backgrounds were investigated. The average lightness level for all backgrounds was L*=60. One background was the control, which was simply solid gray. One background was a randomized image array of achromatic samples ranging from L* of 30 to L* of 90. Each gray dot was made of 4x4 pixels. Two backgrounds were randomized image arrays of colored dots of size 4x4 pixels, and of constant L* of 60 uniformly sampled in CIELAB chroma plane. They differed in that one had a large chroma range corresponding to the maximum pictorial chroma of 35. The other 4x4 background included a smaller chroma range that corresponded with the average pictorial chroma of 10. A fourth background was created in the same fashion, but had a smaller dot size of 2x2 pixels and was made of samples from the larger chroma range. To also compare these three equivalent-lightness backgrounds to a variable-lightness case, a fifth background was generated of a random image array of color dots of size 2x2 pixels, where the dots were obtained from a uniform sampling of a sphere of radius 30 in the CIELAB space. This sphere, which was the maximum sized sphere wholly contained within the monitor's color gamut, roughly corresponded to an L* range of 30 to 90, and a chroma range of 30. The background characteristics are summarized in Table 1.

While generating the equivalent-lightness backgrounds, variations in apparent lightness were seen even though the L* values were constant. This is known as the Helmholtz-Kohlrausch effect, which can effectively be predicted using L**, a lightness metric calculated from functions of hue and chroma.[8] An L** filter was used to remove samples that were not the desired perceived lightness.

Table 1. Background Characteristics

Background Name	Pixel Size	C* Range	L* Range	# of Obs.	% adapt-ation
4x4(35)	4x4	-35– -5, 5–35	0	6	.94
4x4(10)	4x4	-10– -3, 3–10	0	3	.94
2x2(35)	2x2	-35– -5, 5–35	0	6	.93
2x2 (30s)	2x2	-30– -5, 5–30	30 - 90	5	.94
4x4 (A)	4x4	0	30 - 90	5	.98
L*60, solid	1x1	0	0	6	.98

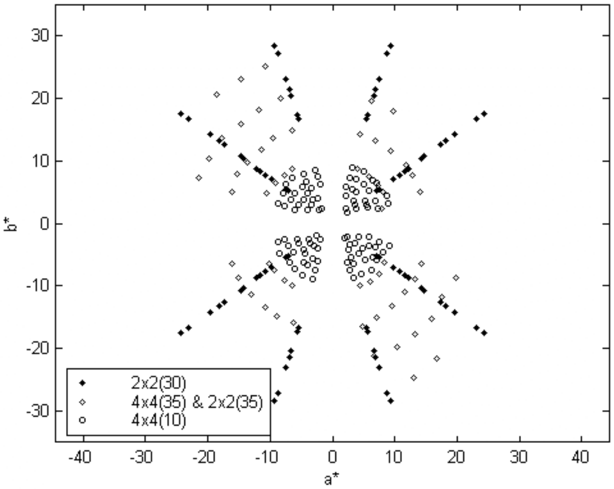

Figure 1. Distribution of background pixel colors in CIELAB space. All three samplings are shown: range of 35, range of 10 and spherical range of 30.

The sampling used for the background pixels was uniform in color space, as seen in Fig. 1, so as to average out to D65. These color samples were then assigned to a randomized location image array. Thus both lightness and chromaticity levels were controlled, while randomness was retained. While a monitor chromaticity of D65 was desired, actual chromaticity varied due to monitor drift. Weekly characterization measurements were made of the monitor, but daily drift was also noticed. For this reason the background was measured at nine locations on the monitor at the end of every set of observations.

Two sets of experiments were conducted to test the influence of the backgrounds on chromatic adaptation. In the first, three observers completed the experimental procedure 4 times, corresponding to the 4 backgrounds tested: solid gray, 4x4(35), 4x4(10) and 2x2(35). In the second experiment, 5 observers made judgements for 5 backgrounds: solid gray, 4x4(A), 4x4(35), 2x2(35) and

2x2(10s). Two of the observers from the first experiment also participated in the second experiments. The order of the backgrounds was randomized between observers for both experiments.

Hardware and Software

All experiments were performed on a Sony GDM2000TC Trinitron 17" color monitor, using a Matrox MGA graphics card interfaced with Windows 98. The Psychophysics Toolbox was used for graphics presentation. This toolbox is a MATLAB based software package developed at UCSB[9] and modified for Windows 98 by Xuemei Zhang, HP Labs. One of the features of the toolbox is to provide direct access to the display frame buffer and the color lookup table. The Sony monitor was set to its internal D65 setting with the display luminance level at 57cd/m^2, and the display white point at x=0.311, y=0.334. The monitor was characterized routinely. Monitor spatial nonuniformity and temporal instability were significant enough that no assumptions were made about the reproduction. Instead, a PhotoResearch PR-650 spectroradiometer was used to measure the selected achromatics as well as the background, immediately at the end of each set of observations.

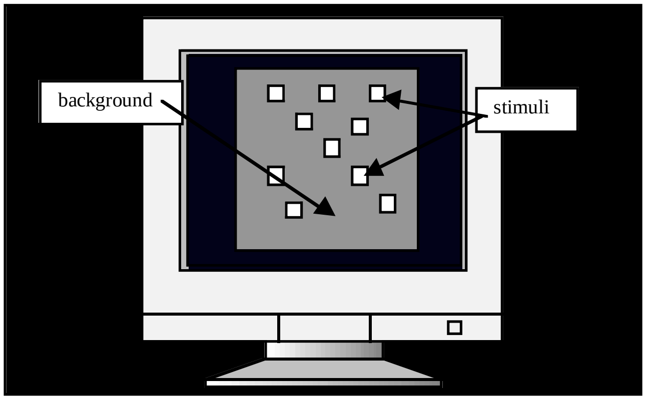

Figure 2. Example of screen image in testing environment.

All images in the experiment were made of between 8 and 17 2x2-cm rectangles, each subtending a less than 4˚ angle of view. The samples were randomly placed on a 5x5 grid, where every sample was separated from adjacent samples by a 2-cm gap in all directions. The background encompassed an area of 24x21 cm, subtending 28˚ field of view. Fig. 2 shows the view seen by an observer.

Initial Screen Sampling

The observer began the experimental task by viewing an image referred to as an initial screen. A total of 17 initial screens were used. The first two were at L* of 75 and were used for training. The other 15 initial screens were divided into five screens each at lightness levels L* of 50, 65, and 80. The goal in creating these initial screens was to evenly sample color space so as not to bias observers towards any particular chromaticity. Two methods of sampling color space were used: radial and vector. The radial method selected samples from CIELAB space in equally spaced hue angle intervals along a fixed chroma axis. The center of this radial method was D65 in this case, but other centers could be used. The vector method involved sampling from vectors that intersected the neutral point, D65. In all initial screens, the point that is actually considered neutral in CIELAB space was eliminated. Fig. 3 shows the sampling of CIELAB space used for L* 65 lightness series. Notice how all hues are equally sampled.

The L** filter was used on the initial screens to remove the presence of the Helmholtz-Kohlrausch effect. Therefore, all initial screens did not have the same number of colored samples.

Once the observer selected a sample from the initial screen, radial calculations determined the next set of samples viewed. With the selected sample as center, 16 points were equally sampled from a hue circle of predetermined chroma. The third screen seen by the observer would reduce the chroma by half or by 2/3, depending on the lightness level. When the observer could not perceive a difference between the samples, the radius was recorded as well as the RGBs of the center point.

Observer Task

All observations took place in a dedicated laboratory that was a completely dark except for the monitor. At the onset of the experiment, only the background was displayed and observers adapted to this for 60 seconds. An initial screen was then shown and the observer was asked to select the sample that appeared most achromatic. Often at this stage none of the samples appeared completely achromatic. Observers were instructed not to stare at any sample, but to keep their eyes moving over the whole grid. Once selecting the sample with the mouse, a second screen would appear with samples appearing more achromatic than before. Observers repeated the task until they reached a screen where the samples were indistinguishable from each other, and, all appeared achromatic. The observer indicated this stopping point, and a new initial screen was presented.

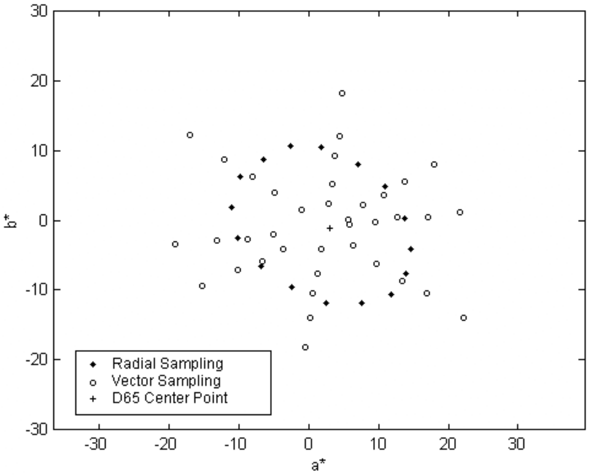

Figure 3. Initial screen sampling in CIELAB for a fixed L.*

In total 17 initial screens were presented in randomized order. The first two were practice screens and were therefore not randomized. At the end of each set of observations, chromaticites and CCT of samples selected as achromatic were measured by redisplaying them individually at the center of the screen. The background was also redisplayed and measured at nine screen locations.

Results and Discussion

The adapted white point for each observer is determined by averaging the chromaticity data of the perceived-achromatics across the 17 initial screens. The level of adaptation is expressed as a percentage of the adapted white point to the actual monitor white point. These are listed in last column of Table I. Ideally for all backgrounds chromatic adaptation to the monitor should be complete (100%). For the achromatic backgrounds, adaptation is near complete. From Fig. 4, it can be seen that chromatic adaptation is less complete for the chromatic backgrounds than for the achromatic backgrounds.

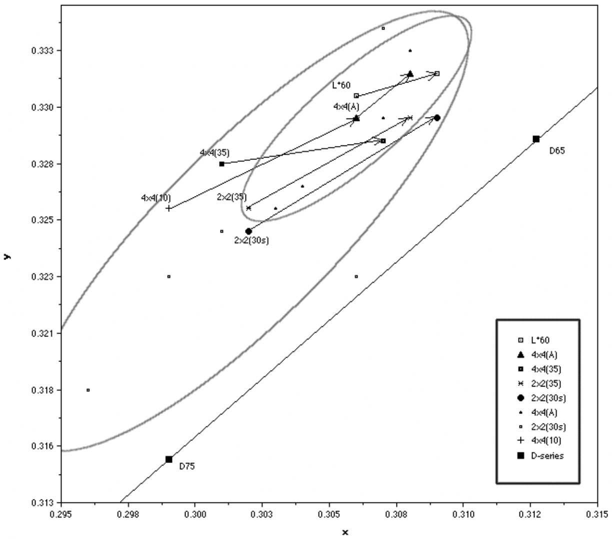

Figure 4. Level of adaptation for each background shown in chromaticity space. Arrows begin at the averaged perceived-achromatic for a particular background and end at the adapting stimulus, the monitor white point. The shorter the arrow, the more complete the adaptation. The large ellipse encompasses the range of responses for 2x2(30s) and the small ellipse indicates the range of responses for 4x4(A).

An ANOVA was performed to determine the statistically significant difference between the backgrounds. The results show that there exist significant differences between the achromatic backgrounds and the chromatic backgrounds. However, to an alpha level of 0.01, there is no significant difference between the solid background and the 4x4(A), the achromatic random dot background. Also, there are no significant differences between the 4 chromatic backgrounds. None are significantly worse or better than the others.

Observer responses varied greatly, with inter-observer variation being greater than the variation between backgrounds. Two of the five observers never completely adapted to the monitor in the control case. They always selected much bluer perceived-achromatics than the adapting stimulus. Also, the variability between and among observers is much larger for the chromatic backgrounds than for the achromatic backgrounds. For the extreme cases, the range of perceived-achromatics for 2x2(30s) is approximately 1000˚K, while the range for 4x4(A) is half that. Some chromatic backgrounds produce complete adaptation in some observers, but the trends are reversed for other observers. In short, observers differed greatly in level of adaptation to the chromatic backgrounds. Thus, none of the tested chromatic backgrounds consistently produces complete adaptation.

Because observers did not completely adapt to the monitor even with the solid gray surround, it can be concluded that the experimental methods are not quite perfected. Repeating observations, rigorously training observers and increasing the number of observers should improve both accuracy and repeatability. It is clear, however, that none of the tested chromatic backgrounds would result in as complete adaptation as the achromatic ones.

At this point it is difficult to speculate why these random chromatic backgrounds that average to gray do not affect the visual system in the same way as a solid gray background. It is not simply a question of additive mixing, since the smaller pixel size did not yield an improvement. It could be that the color sampling schemes tested are somehow not appropriate representations of typical images. Nonetheless, this research does not exhaust all possible combinations for generating chromatic backgrounds. Investigation will continue into which backgrounds to use for determining the adapted white points of CRTs with ambient illumination. Our conclusion at this point is that no theoretical assumptions can be made about the influence on chromatic adaptation of a random color background, especially the assumption that it has no influence.

Conclusion

Visual experimentation reveals that there are statistically significant differences in levels of chromatic adaptation when adapting to an achromatic random dot background versus adapting to a chromatic random dot background. Although all backgrounds tested average to the same lightness and chromaticity, the same level of adaptation is not achieved. Furthermore, the inter-observer variability for chromatic random dot backgrounds is significantly larger than variability for achromatic random dot backgounds. None of the tested chromatic backgrounds are recommended for use in determining the adapted white points of CRTs with ambient illumination.

References

1. R.W.G Hunt and L.M. Winter “Colour Adaptation in Picture Viewing Situations,” *J. of Photo. Sci.*, **23**., 112 (1973).

2. M. D. Fairchild, "Chromatic Adaptation to Imaging Displays," *TAGA Proc.*, **2**, 802, Rochester, NY, (1992).
3. D. Brainard and K. Ishigami, "Factors Influencing the Appearance of CRT Colors," *Proc. Of the IS&T/SID 1995 Color Imaging Conference*, 62, (1995).
4. M. E. Gorzynski, "Achromatic Perception in Color Image Displays," *M.S. Thesis*, Rochester Institute of Technology, Rochester, NY, 1992.
5. M. D. Fairchild, Color Appearance Models, Addison-Wesley, 1998, 164.
6. D. Brainard, "Color Constancy in the nearly natural image. 2. Achromatic loci," *J. Opt. Soc. Am.*, **15**, 2, 307, (1998).
7. H. K. Choh, D.S. Park, C.Y. Kim and Y.S. Seo, "Effects of Ambient Illumination on the Appearance of CRT Colors," *Proc. Of the IS&T/SID 1996 Color Imaging Conference*, 224.
8. M. D. Fairchild and E. Pirrotta, "Predicting the Lightness of Chromatic Object Colors Using CIELAB," *Color Res. Appl.*, **16**, 63, 385, (1991).
9. D. Brainard and D. Pelli, "Psychophysics Toolbox", http://color.psych.ucsb.edu/psychtoolbox/intro.html.