Factors Influencing the Appearance of CRT Colors

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Introduction

The color appearance of a stimulus depends on the context in which it is viewed. Well-known examples of context effects include simultaneous color contrast and color constancy. In simultaneous contrast, the color immediately surrounding a test influences its appearance. In color constancy, the visual system adapts to the ambient illumination to keep surface color approximately constant. Color constancy is a context effect because the way that the visual system interprets the light reaching the eye depends on the context defined by the ambient illumination.

To predict accurately the color appearance of stimuli rendered on a CRT monitor, we need a theory of color context effects that applies to such stimuli. Simultaneous contrast suggests that the color perceived at a particular monitor location may vary with the immediate context provided by the image at other locations on the monitor (the *monitor context*). Color constancy suggests that the color appearance of stimuli displayed on a monitor may vary with the ambient illumination of the room in which the monitor is viewed (the *illumination context*), at least if images from a monitor are processed by the visual system in the same way as reflective surfaces.

In this paper, we report initial experiments designed to measure psychophysically how the monitor context and the illumination context influence the appearance of stimuli presented on CRT color monitors. Our emphasis, however, is on the effect of the illumination context.

Experiment 1

As part of a broader empirical project, Fairchild and Lennie[1] placed a CRT monitor in a light booth and had observers make achromatic settings for a small test patch at the monitor's center. The test patch was surrounded by a monitor context consisting of a uniform field extending out to the monitor's edge. They found that the illumination context (provided by the light booth) had essentially no effect on the achromatic settings. Their result is intriguing. If general, it has the practical implication that a theory of color appearance for CRT displays need not incorporate the illumination context. Our first experimental question, therefore, was whether the illumination context has an effect on the appearance of CRT colors under more general conditions.

Method

Observers viewed stimuli presented on a computer controlled monitor. The test stimulus was always a rectangular region presented in the center of the CRT display. The observer's task was to adjust the chromaticity of the test patch so that it appeared achromatic. We had observers perform this adjustment for several different test patch luminances. This method provides a quantitative measure of color context effects.[1-4] If a change of context has an effect on the color appearance of stimuli, this effect is likely to be revealed by a corresponding change in the chromaticities of observers' achromatic settings. Although a complete characterization of context effects must also consider the perception of chromatic colors, studying which stimuli appear achromatic provides a convenient way to determine what changes of context produce large effects.

We controlled and varied two aspects of the context in which the test patch was seen. First, the test patch was displayed against a uniform field that extended from the edge of the test out to the border of the monitor screen. The luminance and chromaticity of this uniform background specify the monitor context. Second, the monitor itself was placed in an experimental room where the ambient illumination was under computer control. The luminance and chromaticity of the experimental illumination specifies the illumination context.

We used standard methods to characterize the spectral properties of the light emitted by the monitor.[5] Because our experiments were not conducted in the dark, we directly measured the light reflected to the observer from the faceplate of the CRT under each experimental illuminant. We incorporated this measurement into our stimulus generation procedures.

The experimental illumination was provided by 12 theater stage lamps arranged in four triads. The luminance of each lamp was under computer control. Within a triad the three lamps had red, green, and blue dichroic filters respectively, and the light from each triad was passed through a gelatin diffuser. Thus each triad provided a diffuse ambient illumination whose luminance and relative spectrum could be varied by changing the intensities of the three lamps. Together the four triads flooded the room diffusely, so that the overall setup gave us the ability to control the spectrum of an approximately diffuse ambient illumination. We specify our illuminants by their luminance and chromaticity. For our setup (although not in general) this specification is complete since our illuminants have only three degrees of freedom. To generate a desired illuminant, we relied on extensive characterization measurements which described how the luminance and the relative spectral power distribution of the emitted light varied with control voltage.

An experimental condition was defined by a choice of both monitor context and illuminant context. Achromatic settings for each experimental condition were measured in separate experimental sessions. The observer entered the room and adapted to the monitor and illuminant contexts for approximately 20 seconds. The observer then made a series of achromatic settings. Within a session, settings were made at different luminances in random order. Each setting was replicated in two blocks within a session, depending on the condition. At the end of each session, the spectra of the experimental illuminant, the uniform background, and the individual achromatic settings were measured directly with a Photo Research PR-650 spectral radiometer. All data we report rely on these direct measurements and are thus not subject to bias or drift in the characterization data used to generate the stimuli.

We used two monitor contexts and two illuminant contexts in a crossed design. Uniform background A had nominal luminance 20 cd/m^2 and nominal 1931 CIE xy chromaticity (0.46,0.41). Uniform background B also had nominal luminance 20 cd/m^2 but its nominal chromaticity was (0.28,0.29). The chromaticities of these two backgrounds match those of CIE daylight illuminants with correlated color temperatures of 2500°K and 10000°K respectively. Experimental illuminant A had the same nominal luminance and chromaticity as experimental background A. Experimental illuminant B had the same luminance and chromaticity as experimental background B. We measured achromatic settings for all four combinations of background and illuminant.

The test patch was square and subtended 1.35° of visual angle. The uniform background extended from the edge of the test patch to the edge of the monitor and subtended 6° vertically by 8° horizontally of visual angle.

Under certain conditions, achromatic adjustments can be influenced by the chromaticity at which the adjustment starts. To minimize any bias of this sort, the starting point for the chromaticity of the first adjustment in a block was picked randomly around a chromaticity halfway between that of backgrounds A and B. For subsequent adjustments, the starting point was picked randomly around the average of the previous adjustments in the block.

Two observers took part in the experiments. Observer KI is the second author, while observer AMO was a paid undergraduate.

Achromatic loci were determined for each session by fitting a straight line through the origin and the tristimulus coordinates of achromatic settings made at three different test patch luminances. These test patch luminances had CIELAB L* values of 50, 70, and 90 relative to the 20 cd/m^2 luminance of the monitor background and experimental illuminant. We also collected data for test patch luminances with L* values of 110, 130, and 150, but these are not analyzed here. See Chichilnisky[4] for a discussion of differences between achromatic settings for decremental and incremental test patch luminances. The chromaticity of the fit achromatic line was averaged across two sessions to provide the achromatic loci for observer KI. The results for observer AMO are from a single session.

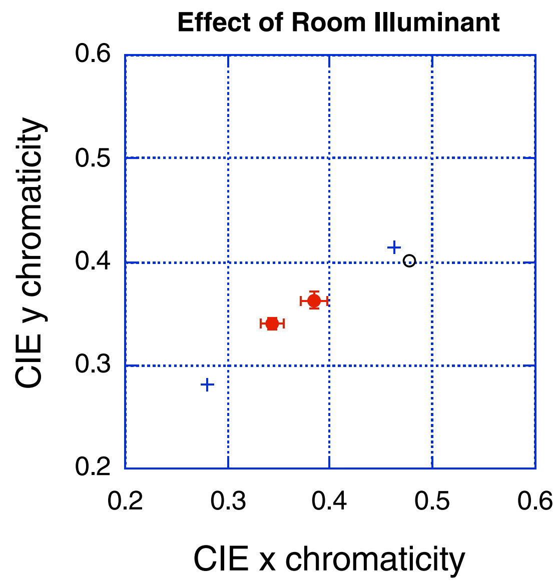

Figure 1. Achromatic loci (closed circles) for observer KI under two context conditions. Monitor context A was used in both conditions. Its measured chromaticity was averaged across conditions and sessions and is shown by the open circle. (There was negligible variation in this and other measured stimulus chromaticities across both condition and session.) Each achromatic locus corresponds to a single illumination context defined by illuminant A or B. The illuminant chromaticities are shown by the crosses. Error bars for the achromatic loci show one standard error of measurement.

Results

Figures 1 and 2 show the results for observer KI, while Figures 3 and 4 show the results for observer AMO. Each figure shows achromatic loci measured for two experimental illuminants and one monitor background (A in Figures 1 and 3, B in Figures 2 and 4).

If the illumination context had no effect on color appearance, then the two achromatic loci plotted in each of Figures 1-4 should superimpose. It is clear that they do not. Rather, changing the illumination context shifts the chromaticity of the achromatic loci modestly towards the chromaticity of the illuminant. Such a shift is qualitatively consistent with the action of mechanisms of color constancy, although quantitatively the effect is much smaller than would be predicted by good constancy. Thus our results show that a general theory of color appearance for CRT displays must incorporate the illumination context.

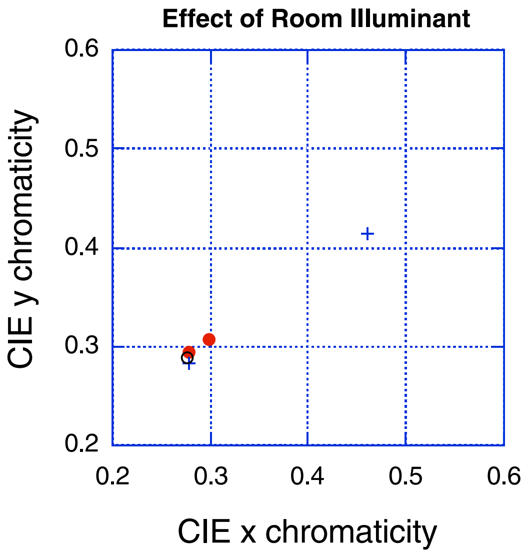

Figure 2. Achromatic loci for observer KI under two context conditions. Monitor context B was used in both conditions. The legend is as in Figure 1. For graphical clarity error bars are not shown for the achromatic loci. The standard error of measurement for these loci is roughly the same as for those in Figure 1.

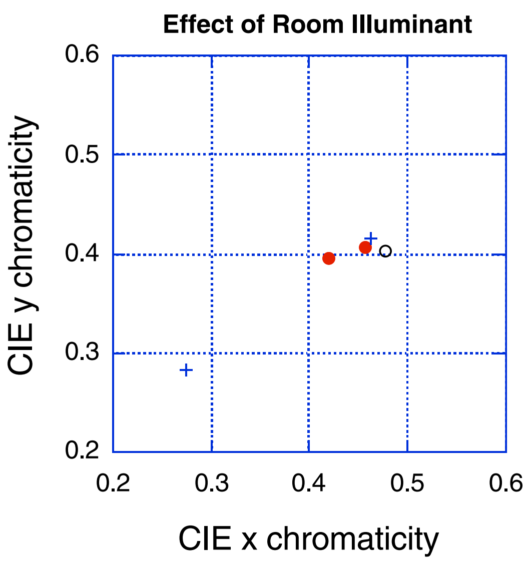

Figure 3. Achromatic loci for observer AMO under two context conditions. Monitor context A was used in both conditions. The legend is as in Figure 1. Because the data are shown for a single session, there are no error bars for the achromatic loci.

There were a number of differences between our experimental design and that of Fairchild and Lennie.[1] The visual angle subtended by our monitor background was not the same as theirs, our illuminant context was provided by an entire room in which the observer sat rather than by a light booth into which the observer looked, and the chromaticities of our experimental illuminants and backgrounds differed from theirs. In pilot experiments that employed smaller illuminant changes, we were unable to detect an effect of the illuminant on the achromatic settings for small test patches. For these reasons, we do not see our data as being in conflict with theirs. Rather, we view our experiment as testing and falsifying an interesting generalization that might have been drawn from their result.

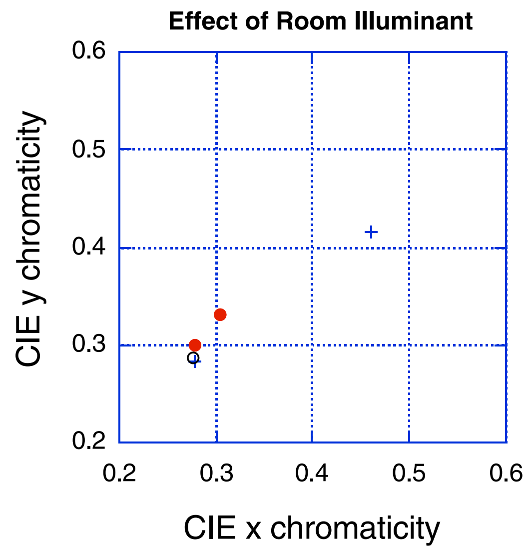

Figure 4. Achromatic loci for observer AMO under two context conditions. Monitor context B was used in both conditions. The legend is as in Figure 1. Because the data are shown for a single session, there are no error bars for the achromatic loci.

Comparison of the corresponding loci in Figures 1 and 2 and in Figures 3 and 4 shows the effect of the monitor context. In both cases, this effect is quite large. The chromaticities of the achromatic loci shift towards the chromaticities of the uniform background. The shift is more pronounced for observer AMO, but substantial even for observer KI. For both observers, the effect of monitor context is considerably larger than the effect of the illuminant context. Although the results of Experiment 1 indicate that the illumination context may not be ignored in a theory of CRT color appearance, they also suggest that more of the variance is explained by the effect of the monitor context.

Experiment 2

We were somewhat surprised by the modest magnitude of the effect of the illumination context on CRT color appearance revealed by Experiment 1. This was because the subjective appearance of a fixed uniform field presented on a monitor varies substantially with the ambient illumination. This effect is not due to changes in the ambient reflected to the observer from the monitor faceplate, as we compensated for these during our stimulus generation procedures. In Experiment 2, we tried to arrange conditions to maximize the likelihood that the illumination context would have a large effect on the appearance of CRT colors.

Method

The method for this experiment was essentially the same as for Experiment 1. The primary difference is that the size of the test patch was enlarged to fill the entire monitor screen. Thus in this experiment, there was no monitor context. In addition, the monitor was moved relative to the observer so that the test patch subtended 5.6° by 6.8° of visual angle. (This latter move was to facilitate the comparison of Experiment 3, see below.) In this experiment, we only collected data for decremental test patch luminances with CIELAB L* values of 50, 70, and 90.

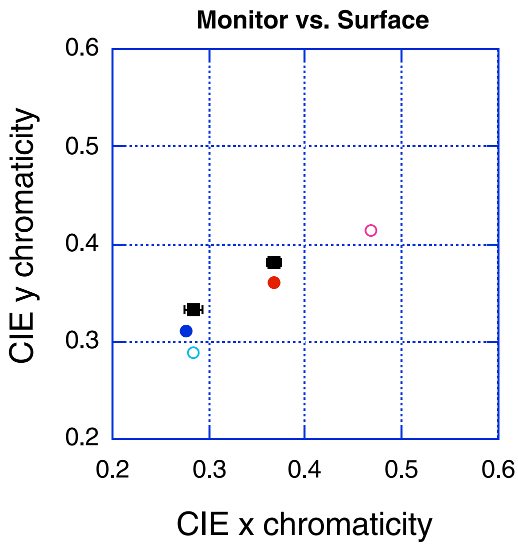

Figure 5. Achromatic loci for observer KI from Experiments 2 and 3. Closed circles show the achromatic loci from Experiment 2, where the test patch filled the monitor screen. Closed squares show achromatic loci determined from Experiment 3, where the test patch appeared as a reflective surface. In case the distinction between closed circles and squares is difficult to make in the final copy, the circles are the lower member of each pair of loci . Each achromatic locus corresponds to a single illumination context defined by illuminant A or B. The illuminant chromaticities are shown by the open circles. These chromaticities are the average of measured chromaticities across sessions in both Experiments 2 and 3. (Differences in measured illuminant chromaticities across session and experiment were negligible.) Error bars for the achromatic loci show one standard error of measurement.

The same two observers as in Experiment 1 participated in this experiment. Achromatic loci for both observers were determined in two sessions for each condition.

Results

Figures 5 and 6 show the results for observers KI and AMO respectively. The achromatic loci determined in Experiment 2 are shown as the filled circles. In case the distinction between closed circles and squares is difficult to make in the final copy, the circles are the lower member of each pair of loci in both figures.

The results show that there is a substantial effect of the illuminant context on the achromatic loci for both observers. The large shift in location of the close circles may be compared to the much smaller shifts of Experiment 1. The implication of this result is that the effect of the illuminant context on CRT colors interacts with the size and location of the test patch on the CRT. A successful theory of context effects for CRT colors must take this interaction into account.

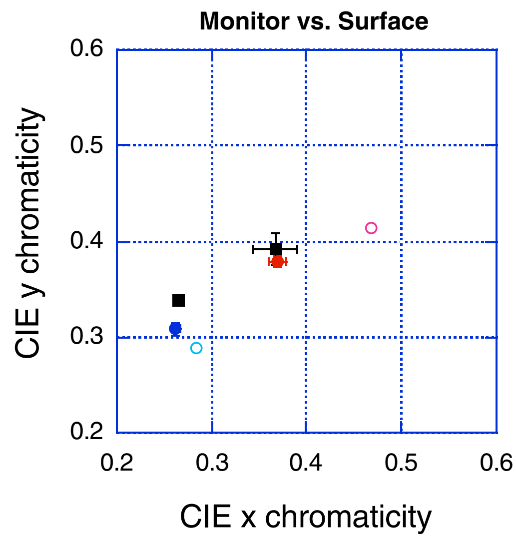

Figure 6. Achromatic loci for observer AMO from Experiments 2 and 3. The legend is as in Figure 5.

Experiment 3

The purpose of Experiment 3 was to compare the effect of the room illuminant on the appearance of CRT colors with its effect on colors that appeared as reflective surfaces.

Method

The method was the same as in Figure 2, except that the monitor was replaced by a test patch that consisted of a dark gray matte paper (Munsell N 3/) spot illuminated by a projection colorimeter. The colorimeter is a custom device that will be described more fully elsewhere. It provides independent control of the intensity of red, green, and blue primaries that are projected in register with the test patch. Thus the light reaching the observer from the test patch consists of two components. One component is the reflected room illumination. The other is the reflected light from the colorimeter. To the observer, the overall appearance of the test patch is that of a reflective surface. Varying the settings of the colorimeter causes the appearance of the test patch to vary. To the observer, this looks as if the reflectance of the test patch is changing.

We put the test patch in the same location of the room as the monitor had been for Experiment 2. The test patch subtended 5.3° by 6.9° of visual angle.

The same two observers as in Experiment 1 participated in this experiment. Achromatic loci for both observers were determined in two sessions for each condition.

Results

The results of Experiment 3 are shown in Figures 5 and 6 along with the results of Experiment 2. The achromatic loci determined in Experiment 3 are shown as the filled squares. The achromatic loci determined for test patches that appear as reflective surfaces are very similar to the achromatic loci determined for test patches that fill the entire monitor screen. This suggests that the mechanisms that adjust visual processing according to the ambient illumination do not differentiate between reflective and self-luminous stimuli, at least for the viewing conditions used here. A feature of our experiment is that the context in which the two types of stimuli were viewed was carefully equated. The small differences between the two sets of achromatic loci shown in Figures 5 and 6 are most likely due to small differences in the viewing context. The monitor test patches were surrounded by the monitor casing. The reflective test patches were surrounded by a plywood panel painted a neutral gray.

Summary and Discussion

We have presented three experiments. Experiment 1 shows that varying either the monitor context or the illumination context can affect the appearance of CRT colors. Experiment 2 shows that the effect the illumination context on a test patch depends on the configuration of the monitor image. Experiment 3 shows that for one set of viewing conditions, the effect of the illumination context is the same for a monitor test patch and for a test patch that appears as a reflective surface.

The results of Experiments 2 and 3 together suggest that CRT stimuli are processed by the same visual mechanisms as reflective surfaces. This raises the hope that a single model of color appearance could apply to both types of stimuli. Experiment 1 shows that such a model must incorporate both local context effects (e.g. the monitor context) and global context effects (e.g. the illumination context). We are not completely optimistic, however, that a common model can be found. Recall that in Experiment 1, local context effects (i.e. the monitor context) had a large effect on the color appearance of the test patch. In experiments that use a test patch that appears as a reflective surface, however, Brainard has found only small effects of the immediate surround.[6,7]

Further experimentation is required to determine whether this difference is due to simple factors such as test patch and surround size, or whether it reflects a fundamental difference in the way in which CRT and reflective stimuli are perceived.

Acknowledgment

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