Impact of Chromatic Surround on Display Perception

Mitchell R. Rosen, Changmeng Liu*, Mark Updegraff*, Mark D. Fairchild*, Justin L. Laird† and Ingrid Heynderickx†*
[*]Munsell Color Science Lab, Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, Rochester, NY USA
†Group Visual Experiences, Philips Research Laboratories, Eindhoven, The Netherlands

Abstract

Perceptual changes in colors on a display due to highly chromatic surrounds were examined. While classical experiments showed that achromatic surround luminance levels impact contrast response, here hue and chroma of the surround were also varied. In Part I, observers were found to systematically change their calibration of what color constitutes a neutral based upon the surround color. Red, yellow, green and blue surrounds were all shown to draw observers' neutral points on a display toward the hue of the surround. The impacts increased relative to surround chroma. Lightness of the chromatic surround did not appear to have a large impact. Part II probed the question of whether the color in the visual periphery had a non-uniform impact on the chroma scale for patches on a display. Evidence from Part II indicates that in certain regions of color space a complex rearrangement of color distances may take place as surround colors are changed. The red chromatic scale on the display appeared to be particularly sensitive to change in surround.

Background

Based on Jones' work [1] and that of other pioneers in the photographic industry, it was understood as early as the 1940's that a higher contrast factor is required for reproductions viewed in dark surround relative to reproductions viewed in light surround. Slides, viewed in the dark, were found to require a 1.5 times higher contrast than prints viewed in average surrounds. Breneman [2] and Bartelson and Breneman [3] in the 1960's further investigated the question. They showed that overall luminance and surround relative luminance both had significant impacts on perceived contrast. The influence of surround on perceived chroma has been studied to an extent by Breneman [4], Hunt, Pitt and Ward [5] and others. These studies, though, relied on relatively achromatic surround.

The question being examined with this study is how highly chromatic surrounds impact the perception of colors on a display. Liu and Fairchild described an experimental room and preliminary findings that indicated a difference between expert and non-experts responses [6]. They also documented changes in color matching functions as one moves away from the fovea [7]. The current work delves into the impact that these highly chromatic surrounds have on the perception of neutral and also offers a first look at how chromatic scales are impacted by chromatic surrounds.

Introduction to the Experiments

The relationship between hue, intensity and chroma of surround illumination on the perception of colored patches on a display was considered. There were two parts to this experiment. Part I asked the question of how chromatic surround illumination impacts the perception of neutrals. Four different surround hues, red, yellow, green and blue were used and for each, four different L^* and C^*_{ab} levels. These sixteen conditions plus dark surround were presented to users who were asked to adjust a patch on the screen to a good neutral. It was found that surround conditions had a systematic impact on observer adjustments. Higher chroma in the surround appeared to increase the effect. Change in lightness of the surround did not have high impact.

In Part II of this experiment, observers adjusted the chroma of a patch with instructions that it should be set to appear half the color distance between a neutral and a chromatic primary. The same 16 surround colors from Part I plus dark surround were used. The chromatic primaries were set at three different lightness levels making for 51 different conditions. In this part of the experiment, it was shown that surround conditions did have some impact on perceived uniformity of the colorspace. For all colored surrounds, observers on average decreased the chroma of all color centers compared to adjusted color centers with dark surround. When surround hue was similar to the hue of the adjustment task, average color uniformity was disturbed the least.

For both experiments, a room with RGB LED illuminators hidden from the observer was used. See Figure 1. The LED lights were under computer control. Figure 2 illustrates the calibrated sources tuning to various color temperatures within the LED gamut.

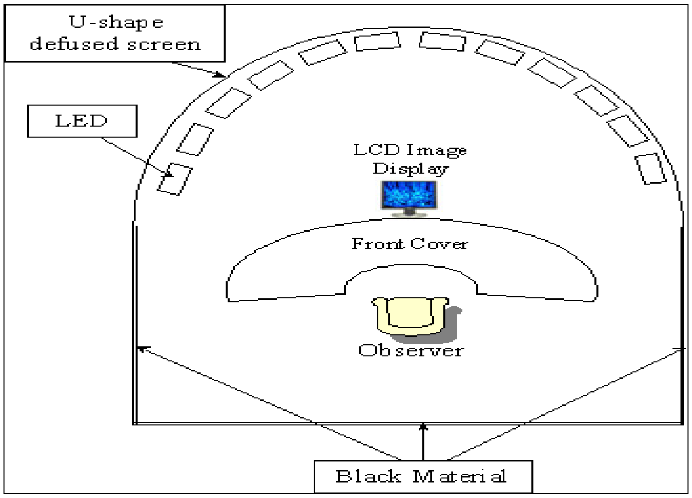

Figure 1: Experimental room with RGB LED illuminators under computer control hidden from observer.

Figure 2: Any color temperature within the LED gamut can be set as surround. Surround on the left is relatively achromatic, while on the right is highly chromatic.

Part I – Neutral Adjustment

In the first part of the experiment, a color test patch is displayed with a reference white patch. The background was a chromatic noise pattern image. The surround color was modulated in terms of hue, lightness and chroma (see Table I). For each surround color plus dark surround, the observer was asked to adjust the test color patch to make it achromatic. See Figure 3. The observer was given adjustment controls that allowed the test patch to be modified in two opponent directions: red/green and yellow/blue.

Table I: Surround Conditions

Condition	Surround Hue	Surround L^*	Surround hue$^{\circ}_{ab}$	Surround C^*_{ab}
1	Dark	-	-	-
2	Red	64	24	47
3	Yellow	64	86	50
4	Green	63	162	45
5	Blue	63	247	46
6	Red	45	24	30
7	Yellow	45	91	30
8	Green	44	162	30
9	Blue	44	245	29
10	Red	76	18	64
11	Yellow	75	91	47
12	Green	74	167	63
13	Blue	75	239	49
14	Red	69	24	30
15	Yellow	69	89	29
16	Green	68	162	30
17	Blue	68	244	29

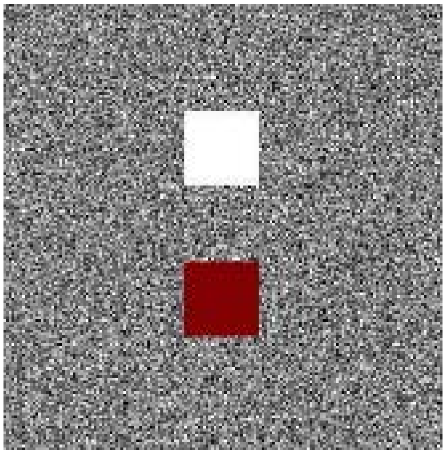

Figure 3: Observer task was to adjust the chromatic patch to be a neutral under various chromatic surrounds.

Figure 4 illustrates the Part I results. These are averages over 21 observers. The large symbols show the positions of the surround color. The smaller symbols are the a*b* positions of the averaged observer-adjusted neutrals. Observers were instructed to adjust a patch until it was perceived as neutral. To calculate the means, the outlying 5% of the responses (2.5% on each end) were trimmed from the population.

Note that around the center of the plot, where the adjusted neutral for dark surround sits, the results for blue surround are clearly biased toward the blue surround points; the results for the three other colors are similarly biased toward their own surround hues. This indicates that, on average, surround color systematicly changes the perception of neutrals. Another way of summarizing these results is that colors that appear neutral under dark surround take on an apparent hue opposite to that of a chromatic surround.

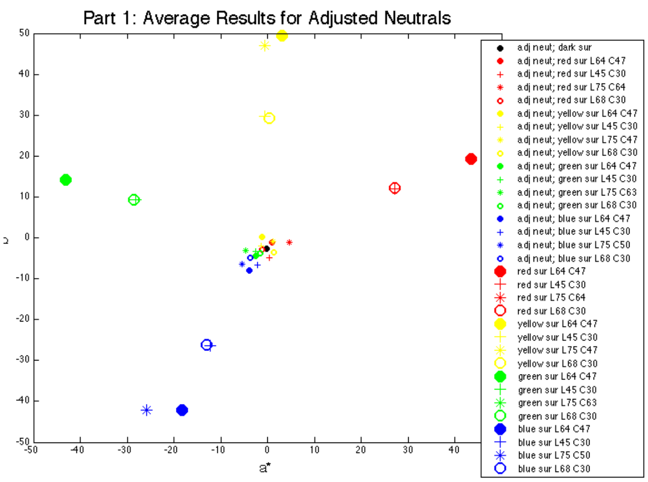

Figure 4: Data set from Part I showing a and b* position of background (large symbols) and a* and b* position of the the average observer-adjusted neutral (small symbols). For this graph, the averages are calculated on the center 95% of each grouping.*

Correcting to the average observer-adjusted color under dark surround as the standard neutral, each condition's average adjusted neutrals were normalized and are presented in Table II.

Table II: Part I Average Normalized Results

Condition (from Table I)	Adjusted Neutral	
	Average Normalized hue$^{o}_{ab}$	Average Normalized C^*_{ab}
1	0	0
2	59	2.3
3	101	2.8
4	203	3.1
5	232	6.3
6	285	1.7
7	147	1.2
8	184	2.2
9	246	4.1
10	21	5.9
11	58	2.7
12	184	4.3
13	213	5.9
14	183	0.9
15	4	1.3
16	210	1.2
17	207	3.6

Figure 5, below, takes into consideration the variance of the population data. Ellipses are constructed based on the standard deviation data. From Principle Component Analysis of each group, the major axis is specified by one population standard deviation derived in the direction of the 1st principle component and the minor axis is specified by one population standard deviation in the direction of the 2nd principle component.

Ellipses, especially those associated with the higher chroma surrounds are being pulled toward the surround color. Red and blue appear to be most heavily influenced. Multiple ellipses do not overlap at all. For example the ellipse for red surround of $L^* = 75$, $C^*_{ab} = 64$ is clearly distinct from all blue ellipses and most green ellipses. The high lightness and chroma ellipse for yellow surround is also distinct from several blue ellipses.

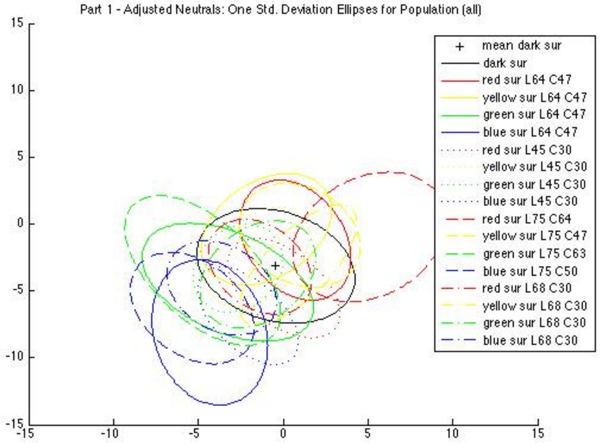

Figure 5: Uncertainty ellipses centered about the a and b* positions of average observer-adjusted neutrals for various surrounds. The black '+' is the average position of observer-adjusted neutral under dark surround. Elipse major and minor axes were specified as one standard deviation in the 1st and 2nd principle component direction, respectively, for each surround condition.*

Part II – Adjustment of mid-Chroma Patch

For Part II there were 19 participants. Four patches were displayed: a reference white patch, a neutral, a reference chromatic patch and a test patch to be adjusted. The neutral and reference patches were constrained to be the same L*. The background was a chromatic noise pattern image. For each surround color plus dark surround, the observer was instructed to adjust the color of a test patch until it was perceived as being halfway between the neutral and the chromatic color patch.

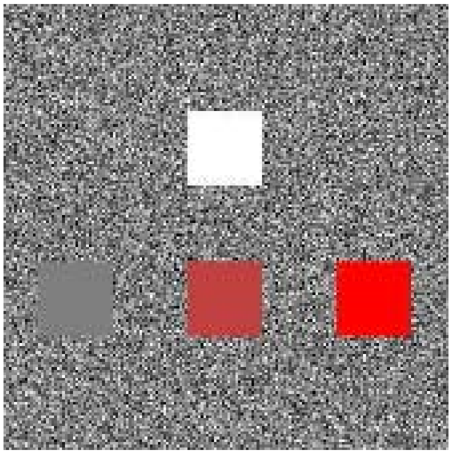

Figure 6: Part II task was to adjust the center patch to be perceived as being half the distance between the gray (left) and the reference chromatic patch (right) under various chromatic surrounds. White patch was for reference.

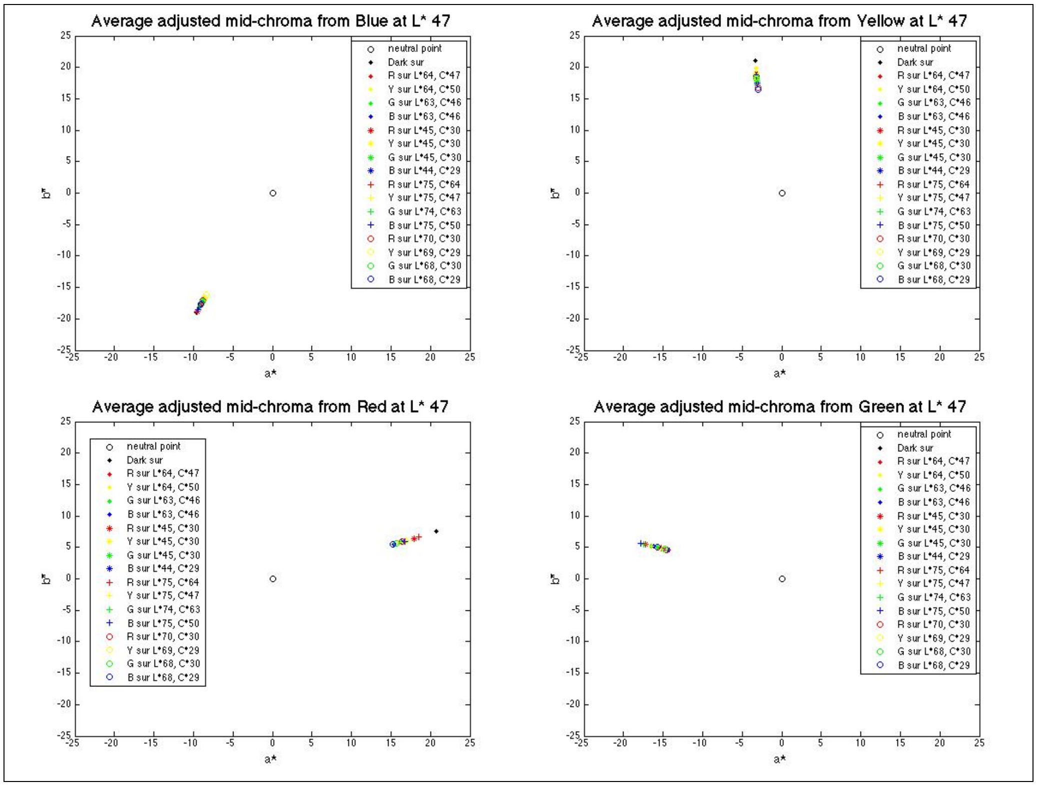

Figure 7: Average observer-adjusted mid-chroma for reference chromatic patches at L = 47. Patch hue clockwise from upper left: blue; yellow; green and red.*

For each reference chromatic patch, there were 17 surrounds presented to the observer. These surrounds were enumerated in Table I. There were four combinations of chroma and lightness for each surround hue. The chromatic color patches also took on the hues of red, yellow, green and blue at three different lightness levels.

The question to be answered by this exercise is whether the population changed its choice for mid-chroma for a particular reference chromatic patch based on the color of the surround. Figure 7 demonstrates that observers systematically changed their perception of mid-chroma as the surround changed.

In Figure 7 the L* of the neutral patch and the reference chromatic patch was 47. We observe that on average, the observer-adjusted point for the dark surround is the most chromatic. For surround of the same hue as the chromatic color patch, the observer-adjusted mid-point remains relatively highly chromatic. It is for surrounds of the "opposite" hue (yellow vs. blue, green vs. red) that the highest compression is found.

T-test evaluation was performed to determine if for a given reference color patch and surround condition the population of observations could be separated from the populations of observations for each of the other surrounds and that reference chromatic patch. Given 17 surround conditions per reference color patch, a 17x17 matrix was created for each reference color patch. A t-test was performed for each combination testing the null hypothesis that the observations come from the same population. Figure 8 shows an example matrix for a t-test testing the results for the red reference chromatic patch L* = 52.

Although the average results showed interaction with the lightness of the reference test patch where more local compression of color space appeared to be present with the darker reference chromatic patches, the variance of the population responses allowed for significant separation of the observations only for limited pairings. These separations were far more frequent for the red reference patches than for any of the yellow, green or blue.

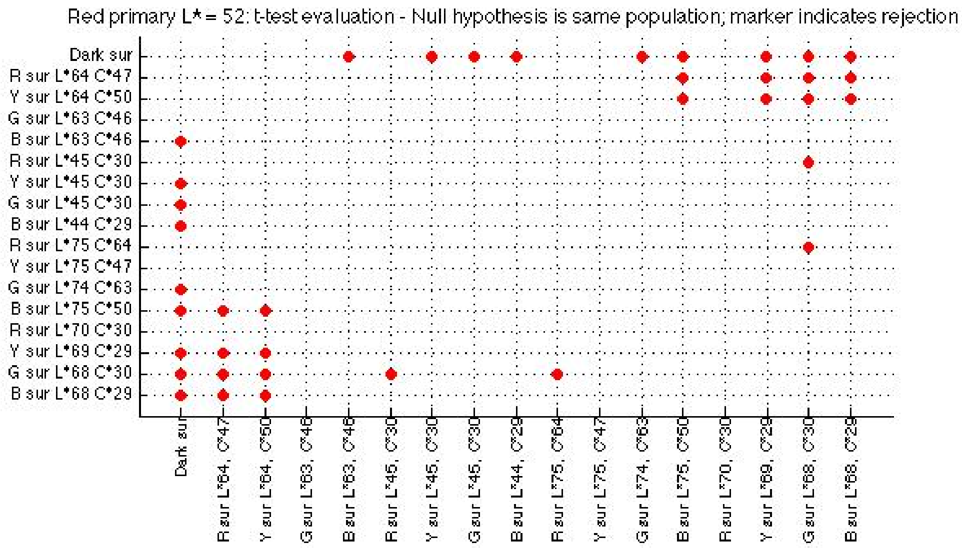

Figure 8: Example full factorial t-test analysis. Here the 17 surround conditions for red reference chromatic patch with L = 52 is shown. Red dots indicate rejection at 95% confidence level of null hypothesis that surround condition pairs have the same mean.*

Conclusions

Through Parts I and II of this experiment observers were shown to react differently to both neutrals and chromatic samples when the surround was changed.

Part I results show that when a patch is adjusted to appear neutral it will have chromaticities closer to those of the chromatic surround compared to the observer-adjusted neutral under dark surround conditions. When both surround color and the content of display is under a single system control, taking advantage of this phenomenon can be useful in producing higher quality presentations.

Part II indicated an interaction between surround color and the perception of chroma scales. Four surround hues at different lightness and chroma values plus a dark surround were tested against a set of 12 reference color patches coming from a set of 4 different hues (red, yellow, green and blue) with three different lightness levels. Average results showed interaction with the lightness of the reference test patch where more local compression of color space appeared to be present with the darker reference test patches. Population variances were high, reducing certainty in interpreting the results.

A new set of experiments are underway allowing for more quantitative analysis and broader understanding of the stimulus/response aspects of surround color vs. display perception phenomena. For example, in Part II of this experiment, only the mid-chroma point was evaluated. This single point evaluation cannot in itself verify the shape of a model. Additional data along the chroma vector will be invaluable to uncovering useful information and hopefully reducing population variance. Additionally in Part II, reference chromatic patches were varied only in lightness. More samples are needed to improve the understanding of how surround changes one's perception of displayed stimuli.

References

[1] L.A. Jones, "Psychophysics and Photography," J. Opt. Soc. Am. 34, 66-88 (1944).

[2] E.J. Breneman, "The Effect of Level of Illuminance and Relative Surround Luminance on the Appearance of Black-and-White Photographs," Phot. Sci. Eng. 6, 172-179 (1962).

[3] C.J. Bartleson and E.J. Breneman, "Brightness Perception in Complex Fields," J. Opt. Soc. Am. 57, 953-957 (1967).

[4] E.J. Breneman, "Perceived Saturation in Complex Stimuli Viewed in Light and Dark Surrounds," J. Opt. Soc. Am. 67, 657-662 (1977).

[5] R.W.G. Hunt, I.T. Pitt, and P.C. Ward, "The Tone Reproduction of Colour Photographic Materials," J. Phot. Sci. 17, 198-204 (1969).

[6] C Liu and M.D. Fairchild, "Measuring the Relationship between Perceived Image Contrast and Surround Ilumination," Proc. of 12th CIC, 282-288 (2004).

[7] C Liu and M.D. Fairchild, "The Surround Color and Color Matching Functions," Proc. of 14th CIC, 203 – 208 (2006).

Author Biography

Mitchell Rosen is a research professor in the Munsell Color Science Laboratory of the Chester F. Carlson Center for Imaging Science at RIT and director of the Infinite Pixel Liberation Laboratory. His current research projects deal with color management, ambient imaging, variable print data and the impact of surround on color perception. At RIT he teaches courses on color systems and story-telling utilizing novel imaging modalities. He teaches tutorials on color management, color reproduction and spectral imaging. From 2002 – 2007, he was Color Imaging Editor of IS&T's Journal of Imaging Science and Technology. He is past tutorial chair of the Color Imaging Conference and current sponsorship chair. He is active in organizing international conferences on spectral imaging. His website is http://www.cis.rit.edu/rosen. iPixLab is found at http://ipixlab.rit.edu. His email address is rosen@cis.rit.edu.