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Effects of chromatic surrounds on the perceived color balance of reflection prints

David R. Odgers

EFFECTS OF CHROMATIC SURROUNDS
ON
THE PERCEIVED COLOR BALANCE
OF
REFLECTION PRINTS

by

David R. Odgers

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CERTIFICATE OF APPROVAL

M.S. DEGREE THESIS

The M.S. Degree Thesis of David R. Odgers
has been examined and approved
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for the thesis requirement for the
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Submitted to the
Center for Imaging Science
in partial fulfillment of the requirements
for the Master of Science degree
at the Rochester Institute of Technology

ABSTRACT

A colored surround, via chromatic adaptation, can affect the perception of a colored area. Past work done with solid color areas was extended to include complex scenes, such as in photographs. The direction and extent of shifts in color balance was determined.

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Dedication

To my parents, my wife, Maureen, and my daughter, for their loving support, and to Neal Ziller, my high school mentor, without whom my interest in imaging science would not exist.

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Introduction

Many have pursued an understanding of factors that affect color perception. One such factor is the viewing condition under which an observation occurs. For example, the appearance of a color patch is altered by the color and luminance of the area surrounding it. Even if this perception is subconscious, it still influences the viewer's judgments. Thus, one expects that the perception of a complex scene, a photograph, will also be changed by a colored surround. This paper investigates such an effect, thereby increasing the understanding of color perception.

The analysis of color perception can be examined by two different approaches. One is the physical, answering the questions of radiance, spectral distribution, and media interactions - absorption, reflection, refraction. The psychological method shows similarities, but expresses itself in different terms - hue, saturation, lightness. Tying the two together are years of research leading to psychophysical concepts.

Colorimetry utilizes principles stated by Grassmann (1853), derived from experiments in tri-color mixtures:

1. The eye can distinguish only three kinds of difference or variation (expressible, for example, as variations in hue, brightness, and saturation.

2. If, of a three-stimulus mixture, one stimulus is steadily changed (while the others remain constant),

the color of the mixture steadily changes.

3. Lights of the same color (that is, same hue, same brightness, and same saturation) produce identical effects in mixtures regardless of their spectral composition.

   All modern colorimetry is based on this principle. It means that we can deal with stimuli on the basis of their colors alone, without regard for their spectral composition.[1]

The spectral reflectance curve of a colored object can be reduced to the three variations mentioned above by use of psychophysical functions.

A color can be conveniently described as a vector in a three dimensional space demarked by three color primaries (unit vectors). Scalar multipliers, called tristimulus values, of these vectors fix the color vector in this space. Tristimulus values (X,Y,Z) can be determined by use of the following equations:

$$X = k \sum R(l)S(l)x_{10}(l)\ \Delta l\ ,$$

$$Y = k \sum R(l)S(l)y_{10}(l)\ \Delta l\ ,$$

$$Z = k \sum R(l)S(l)z_{10}(l)\ \Delta l\ ,$$

where r(l) is the spectral reflectance of the object, S(l) Δ l is the spectral distribution of the source irradiating the object and x,y,z are weights known as color-matching functions. The normalizing factor k is often chosen as $k = 100/\sum s(l)y(l)\ \Delta l$. If each tristimulus value is divided by the sum of all three, chromaticity coordinates result:

$$x = X/X+Y+Z,\ y = Y/X+Y+Z,\ z = Z/X+Y+Z.$$

Psychophysical functions can be defined in several ways, but have been standardized by the International Commission on Illumination (in French, CIE) by way of the 1931 two-degree color-matching functions, the 1931 x,y-chromaticity diagram, and the 1964 ten-degree color-matching functions. In addition, several attempts have been made to produce a uniform chromaticity scale (UCS) diagram giving equidistant plots of chromaticities of perceptually equal difference, one of which is the 1976 L*A*B* space.

The effects of viewing conditions are important in color perception. The overall illumination level is a factor, because under extreme conditions, retinal responses differ dramatically from the norm. Proper judging of colors requires that the eye has adapted to the prevailing illumination and color. As defined previously, tristimulus values are influenced by the spectral distribution of the illuminating source.

The eye's sensitivity changes to compensate for both the amount of light incident on the retina and the color. The latter is the response of interest in this paper. It is called chromatic adaptation, which is described as "transient changes in sensitivity, ascribable to photopic chromatic stimulation, that result in changes in chromatic sensation and perception"[2] and as "modifications of visual response, particularly the response to chromatic test stimuli, brought about by chromatic conditioning (adapting) stimuli that are surrounding or pre-exposed."[3] This adaptation is manifested in several ways. Colored objects when viewed under light sources of different spectral distributions (daylight vs. tungsten, for example) have (to a great extent) the same color appearence, an effect called object-color constancy.

Color contrasts also influence perception. A color in juxtaposition to another will alter its appearance, a change known as simultaneous contrast(see example in ref 4). In successive contrast, the complementary color and lightness of a color just seen is added to that currently viewed. (These perceptionally related effects may, however, be due to different mechanisms of the visual system, such as photochemical reactions in the retina vs. neural interactions on the paths to the brain.[5,6]

Chromatic adaptation occurs rapidly[1], the major part in a few seconds and any remaining in minutes if the conditions stay the same. However, the eyes rarely reach a steady-state condition because they usually shift from one object to another. For the most part, the changes happen quickly enough to be unnoticed.

An early model explaining chromatic adaptation, known as the von Kries coefficient law,[7] still provides the simplest good first approximation to the effect. If the tristimulus values of a color viewed under first one illumination, R',G',B', and then another, R,G,B, the von Kries law gives their relationships as

$$R' = K_R R,\ G' = K_G G,\ B' = K_B B,$$

where the K's are proportionality constants for that change of illuminant.

Much of the work in standardizing colorimetry was done with the color being judged placed against an achromatic surround. However, the standard observers (1931 & 1964 color-matching functions) are not intented to predict what an observer with normal color vision will see. As mentioned above,chromatic adaptation must be considered. Some of its effects on the discrimination of color have been investigated in several studies.

Wright[8] asked observers to adjust one-half of a square bipartite field (2^o) so that it differed in color from the other half by a small constant amount. The two halves started at the same point in color and intensity, then one was changed some step greater than the just noticeable difference, his reasoning being that it was easier for the observer and cut the observation time. Equal intensity was maintained by adjusting the second half. This was done at various chromaticities and the results were plotted as dashes on the 1931 CIE diagram (Fig. 1) The data was also transformed to the rectangular uniform-chromaticity scale of

Figure 1

(from ref.1)

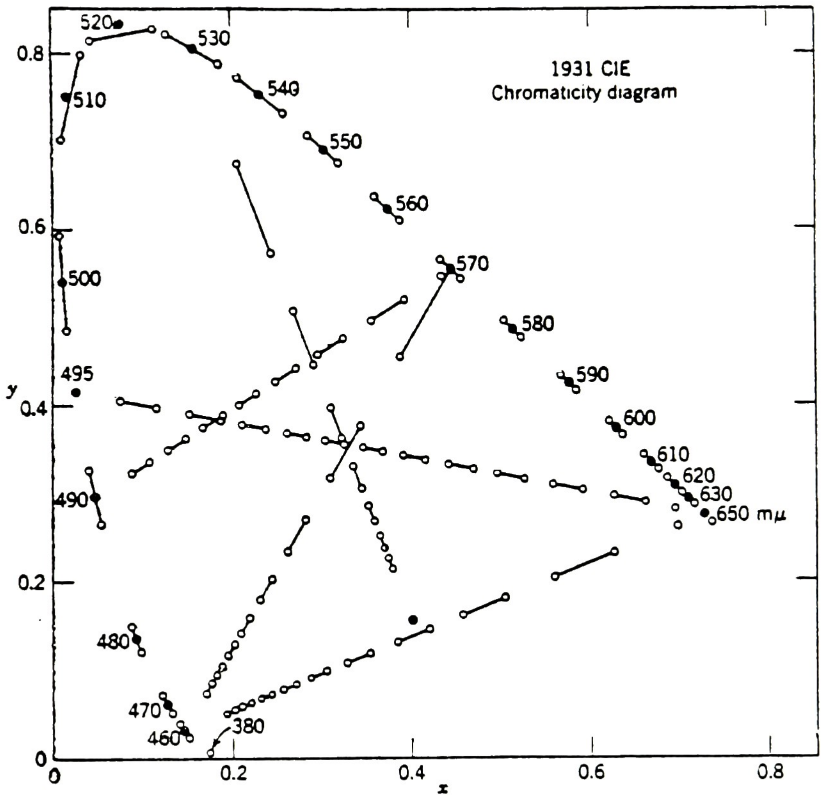


FIG. 1. 1931 CIE (x,y)-chromaticity diagram. Dashed lines indicate chromaticity intervals, all of which correspond to the same degree of perceptibility (after Wright, 1941).

Breckenridge and Schaub.[9] The surrounding field was dark.

MacAdam[10] conducted a similar experiment, with a two-degree circular field divided in half vertically and a 42 degree surround adjustable to any desired adaptation. The observer had only one control knob, partially because the system automatically compensated to provide constant luminance. Changes were made in several directions from each fixed chromaticity point. Thus, his plots (Fig. 2) show ellipses rather than dashes. The data indicates that, for the same observer, the just noticeable color differences are three times the standard deviations of color matching. MacAdam's ellipses resulted from these standard deviations.

In another experiment[11], his colorimeter had a binocular system that enabled the observer to sit back a few feet. The surrounds were made with fluorescent cloths. His results were plotted in 1931 CIE x,y coordinates as generally curved lines radiating from a center point. In his conclusion he states,

> "For instance, when color transparencies still or motion pictures are projected, appreciable distortion of hue will be produced by the surround if its chromaticity is appreciably different from that of a portion of the screen on which the picture or white object is focused and if its luminance is greater than about 10% of the luminance of the screen."

In several studies, Brown[12-17] examined the effects of luminance, field size, and chromatic surrounds on color discrimination. The ellipses grow as the luminance

Figure 2

(from ref. 3)

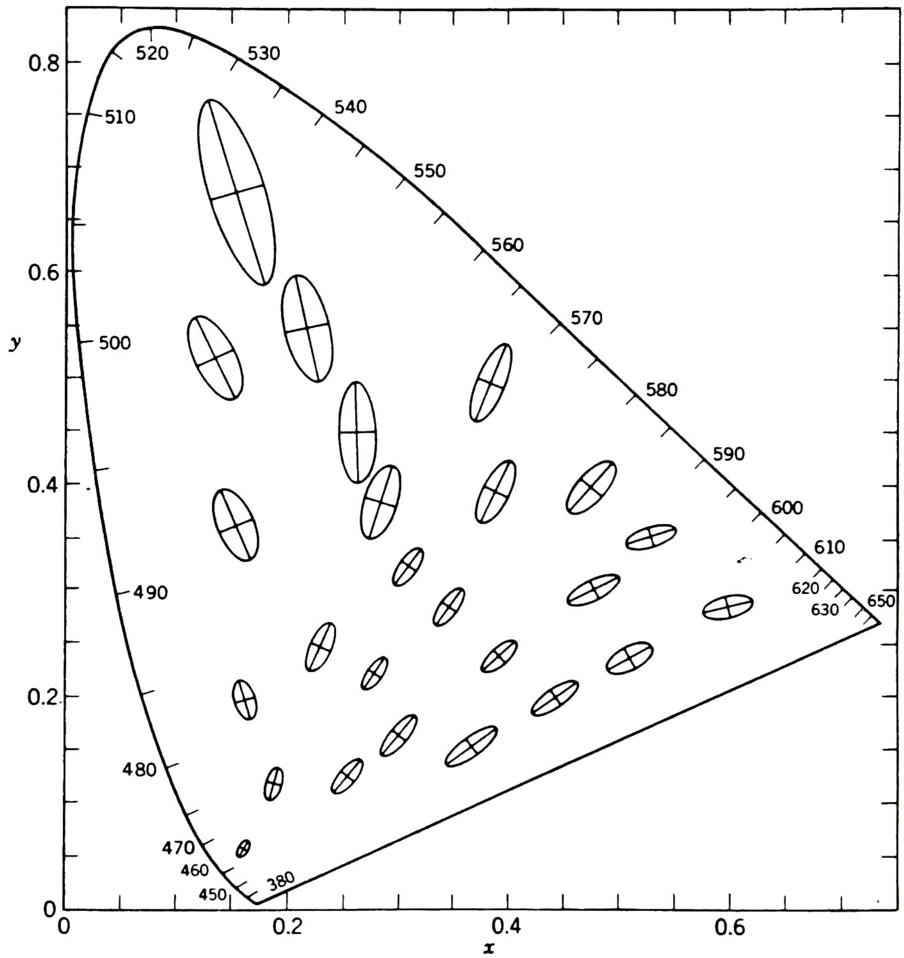


Fig. 2 MacAdam (1942) ellipses (observer PGN) plotted in CIE 1931 (x, y)-chromaticity diagram. The axes of the plotted ellipses are 10 times their actual lengths.

decreases, generally in a nonlinear fashion. There may also be a change in the orientation of the ellipsoidal axes. In comparing two field sizes, it was shown that discrimination was better and less affected by the surround with the 12° field than with the 2° field.

Brown[15] used the same colorimeter as in the second MacAdam experiment[11] given above, with surrounds of red, green, blue, white, and black, and binocular matching fields of red, green, blue, and white. Discrimination in the red fields was best with the red surround, followed in decreasing order by black, then green and white about equal, and ending with blue. With the 2° field, blue also rotated the ellipse axis toward blue.

For the 2° green field the order was black, green and white, red, then blue, with the last two rotating the axis toward their respective chromaticities. However, for the 12° green field, only the red surround had any significant effect. Little effect by the surrounds was noted for the blue fields.

White discrimination was quite affected by the surrounds, the axes being rotated toward that color in each case, and even more pronouncedly for the 2° field. While the ratio of field to surround luminances had very little effect on chromaticity discrimination, it was more difficult for the observer when the surround was brighter than the field.

He states that use of the colorimeter is different than what people would actually use in observing because generally are looking at things greater than 2 degrees and surrounds are seldom dark. The objects are probably chromatic , and lighter or darker than surrounding colors. The principal observer had 8 sessions of 30 color matches for each combination of field size , color and surround, for a total of 13,203 color matches. In the footnotes he points out that a normal Gaussian distribution in three variables is different from a distribution in one variable.

Visual sensitivity was always improved when a large field was used. When field size is large , color discrimation is only slightly affected by highly saturated surrounds. Matching fields at larger sizes would not result in any important improvement in color discrimation. Large matching field effect of surrounds was significant only in the case of red matching fields. He compares the cross-sections of two of his ellipsoids (dark surround - 2 and 12 degree fields with those in different experiments: PGN[10], and Brown as principal observer in Brown and MacAdam[12]. From these he concludes that for small matching fields, the chromaticity of surround is an important factor in color discrimination, that the eye's ability is reduced in the presence of a surround differing in chromaticity from the colors compared. When the matching fields and the surround have the same chromaticity , the sensitivity is slightly greater than with a white surround; however, this effect is not great enough to account for the differences between previously reported results and the set of ellipses published by Stiles[18]. Stiles' work was near the spectrum locus as opposite to the near-white values. Color discrimination is much less dependent on the color of the surround when the field is large. The effect is the same qualitatively, but smaller and often insignificant. When comparing the two field sizes there was sometimes a change in the orientation of the ellipsoids.

Brown[17] later gathered 12 observers, instead of the usual one to three, to get data representing an average observer. They viewed small color differencs at 22 color centers distributed thoroughout the chromaticity diagram. The matching field size was 10 degrees in a binocular, wide-field device[11], with a broad surrounding field. "Binocular nature of this colorimeter together with its large field size in the presence of a surrounding field makes its use very similar to the conditions under which colors are usually matched and compared." The observer had no eyepiece to look in, so he was free to gaze about the observing booth in any manner he desired. It was easier for the observers if luminance of surround was lower than that of the test field. This experiment had surrounds made with fluorescent paints sprayed on cardboard with a circular hole cut in it. Their luminance level was adjusted by putting filters over the UV source. A diversifed group of observers was selected, all under 30 years of age, 8 men , 4 women. They were allowed to take as little or as much time as desired. In his calculations Brown utilized a weighting factor for the various observers depending of their level of experience and expertise.

He stated for future reference that in designing an experiment one can make many observations with one or two skilled observers or get the same number of total matches with larger numbers of less skilled observers, and that less would be known about the individual observers but the result is a better average of the population. The second leads to the possiblity of learning on the part of the unskilled observers. That is why he used the weighting factors - to help eliminate the time trends. The skilled observers were less likely to change in their level of learning than the unskilled.

In a comparison with MacAdam[10], he notes similarities: that the experimental technique was identical, except that the earlier was with a monocular apparatus and a dark surround, while this experiment was binocular with a light surround. The "principal difference in these results is a reduction in the ratio between the sizes of the largest and smallest ellipsoids as a function of chromaticity. ...This could be expected, since the mean of a group of observers is unlikely to vary as much from chromaticity to chromaticity as would a single observer. In addition, the binocular matching conditions and the white surrounding field may tend to reduce the color discrimination differences to some extent.

Wyszecki and Fielder[19,20] sought to compare previously produced ellipses and added three sets of their own. They used a binocular colorimeter designed earlier by Wyszecki. It contained two adjacent hexagonal fields, each of 3^o diameter, with a 40^o white surround. The luminance of each test color was set equal to 12 c/m2, and the surround at 6. The primaries in one field were fixed to one of 28 test colors, and in the other hexagon the primaries were adjusted by the observer to match. Each of the three observers had normal color vision and extensive experience. The colorimeter most closely approximates ordinary viewing in that central vision and both eyes were used, with no strict fixation (a headrest was used). The 28 resulting ellipsoids were computed in x,y,l space, with the plane of constant lluminance determined for comparison with other sets. An ellipsoid contains 95% of any random set of matches, using $(ds)^2 = 7.81$, (corresponses to a chi-squared value with 3 degrees of freedom) rather than $(ds)^2 = 1$ for the constant standard deviation ellipsoids used in earlier studies. For each observer the orientation, shape, and size varied with the location of the center of the ellipse.

The data from the same observer on different occasions do not show the repeatablity suggested by the statistics. Some factors may have been missed that influence the visual mechanism. While the eight sets illustrated show an over-all similarity, at a given color center there are vast differences between different observers.

In a comparison with MacAdam[10], Brown and MacAdam[12], and Brown[17] he notes that an average, such as done by Brown for his 12 observers, does not give an observer intermediate to a group.

In most of these intercompared studies the observer operated the three control knobs of a three-primary colorimeter. On the other hand, observer PGN made color matches by turning a single control knob so as to vary the color of one-half of the visual field along a straight line in the chromaticity diagram. The question arises whether the use of three fixed primary colors producing color matches inadvertantly introduces a bias in the distribution of the color matches for a given test color. They noticed the tendency of the color-matching ellipse to orient itself toward the chromaticity point of the nearest primary. The similarity of the orientation of the ellipses presented by

Wyszecki and Fielder, and those obtained by Brown, and MacAdam and Brown may be due to the fact that the different experiments involved primaries of similar chromaticities. On the other hand, experiments made by observers PGN and WSS do not involve mixtures of three primaries fixed throughout the experiments. Obviously further tests are required to resolve the discrepancy between the two groups of data.

While the different observing conditions of each experiment from the different researchers was expected to influence the ellispes, only the effect of a larger field size to produce better discrimination could be specifically noted with some certainty. Also, further experiments are needed to show the effect of the luminances and chromaticities of the surrounds.

It is shown in the presented body of previous work that a surround, via chromatic adaptation, can affect the perception of a colored area. Since much of this work was done with colorimeters and solid color areas, the effects on complex scenes, such as exist in a photograph, remained to be investigated. The purpose of this project was to determine the direction and extent of possible shifts in perceived color balance induced by a colored surround for complex scenes.

Experimental Method

In order to test the hypothesis that colored surrounds affect the perception of complex scenes as well as solid colored patches, it was necessary to produce photographs, make appropriate measurements, and do calculations to quantify the results. The first was accomplished by making scene exposures, processing the film, and printing some of the negatives. The second was done by having observers judge the prints, and by measuring spectral reflectivities. In the Results section the calculations are shown.

The remainder of this section gives the details of how the experiment was conducted - the equipment and materials used, the way they were used, and the observer judging. Many of the resources and procedures are commonly used and available.

To initiate the experiment suggested above, exposures of various scenes under different illuminations(bright sunlight, shade, and indoors with electronic flash) were made on three separate occasions. Three sheets of 4x5" Kodak Vericolor film, and two 36 exposure rolls of 35mm Kodacolor II(Emulsion #5035 398)were used. In both cases the film speed was ASA 100, the camera lens was of normal focal length, and no filters were used. A total of 53 useful frames resulted.

In most of the photographs taken, a subject was holding a gray card, a white card, a gray scale, and a scale of color patches which were taped together for ease of handling. These references were assembled from two Eastman Kodak products, the first being the Neutral Test Card kit (Publication No. R-27; CAT 152 7795) which contains 8 x 10" cards having 18% reflectance on one side and 90% reflectance on the other, and the second being Color Separation Guides and Gray Scale (No. Q-14, CAT 152 7662, 14" size). The subject was standing in neutral or natural surroundings. The three basic colors were represented in flesh tones, grass, and sky. Some indoor shots were also taken. One exposure was made of a white & black building against a blue sky, with no cards or flesh tones.

After all the shooting was completed and the film processed, four of the negatives were selected for printing, two with the subject outside, one inside, and the one of the building with no reference cards or flesh tones. (For an example of color printing, see ref. 21). Each of these four negatives were printed in a "ring-around" of six colors - magenta, red, yellow, green, cyan and blue -at four filtration levels (CC02,05,10,20)from that giving a nominally correct color-balanced print to the experimenter. This nominal print was balanced by direct comparison of the original gray card with the card in the print (in the same type of viewing booth as described later in this section).

The nominal print was labeled "N" and the other prints were labeled by numbers according to increasing filtration differences from the nominal, such as G1,G2,G3,G4. A Durst L900 enlarger with a CLS450 colorhead (contained dichroic filters and diffuse illumination), a glassless negative carrier, and a Rodenstock Rodagon 80mm,f/5.6 lens was used in a darkroom equiped with #10 safelight filters. The prints were made on Kodak Ektacolor 74RC color print paper(Emulsion #236100-41354M). The non-specular surface (Kodak designation "N") was chosen to avoid distracting reflections. Four prints were made on each 8 x 10" sheet of paper, with help of a Saunders Repeating Easel. Each print when trimmed of white borders measured 3 5/8" x 4 5/8". The paper was processed shortly after exposure in one of the School of Photographic Arts and Sciences' automatic color print processors (manufactured by Kreonite, Inc., and utilizing the EP-2 process formulated by Kodak).

To define the color of gray card areas in CIE color space, the spectral reflectivities were determined with a Beckman DK-2A spectrophotometer configured for reflectance readings. This was accomplished before observer viewing so that any minor surface damage would not affect the results. The scans were done from 350-750nm, at a scanning time of 180 nm/min. Only two sets of the prints, one with the subject outdoors and the one indoors, had large enough gray card areas to fill the entrance pupil (3/8" diameter) of the instrument. The areas were twice the minimum size necessary in order to insure that only gray patches were measured, not adjacent colored areas.

For proper results to be obtained from the observations, the viewing conditions were standardized with the use of a MacBeth Color Print Viewing Booth containing lamps of 5000^{o} color temperature (four General Electric fluorescent tubes, labeled "Chroma 50", F40-C50). The distance from the front opening to the back wall was 27". Its interior was painted a neutral gray from a standard formulation provided by MacBeth.

The colored areas surrounding the prints were made with Chartpak Color Paper (Catalog #'s CL001,CL005, CL055, and CL081 thru CL083). Each sheet of this paper measured 14x17" after the borders were removed. The prints subtended an 7^{o} viewing angle and the surrounds a 25^{o} angle. These angles are approximate because the observers were not required to maintain a particular distance from the print-surround combination. Extremes were discouraged. The reflectances of these sheets were read after the observations were completed. Small enough pieces to fit on the spectrophotometer had to be cut from the large sheets, thus the wait to read their reflectances. These readings were done on the Applied Color Systems, Inc.(ACS) Spectro-Sensor II.

Before the subjects began the observations, their vision was allowed to adapt to the illumination in the viewing booth (room lights off) while instructions were given regarding the testing. (No color-blindness test was given). They were asked to state if the print had a color cast, and if so, what color. The example was given of how sometimes prints returned by a commercial lab have a peculiar color. They could volunteer their perception of the extent of the cast. No mention was made of the reference cards shown in the scene. They did not see the labeling on the back of the prints. After each print was placed for viewing (located to compensate for observer height), they were allowed as much time as needed to reach their conclusion, but they were exhorted to "keep moving" so that the total time for an individual's session was not excessively long. Most of the 20 subjects completed the observations in 30-60min. Recording of the responses was done by the researcher so as not to disturb the adaptation of the viewer.

Generally only one set of photographs was used, giving a maximum 175 print-surround combinations (a complete factorial design, i.e., every print with every surround). (One of the first observers viewed the set of prints of the subject taken indoors. After that, it was decided that for the sake of simplicity and consistency, only one set should be used.)

The prints were shown in random order. Any possible biasing of the order by the experimenter was overruled by the pace of mounting the prints for viewing and recording the observations (the order was also recorded). Examples of extreme print casts are shown in Appendix A.

Results

When the experimental work was completed, the data collected was in two general categories - spectral reflectivities and observer responses. Several steps were taken to calculate and display the results. Computer programs were written to assist in these steps. Data from both categories were entered with the help of programs designed to insure typing the correct number of observer responses or reflectivities. In the following paragraphs the steps taken are described, first for the spectral data and then for the observer data. The goal was to plot ellipses in chromaticity space, as done in the literature.

The Beckman spectrometer scans produced tracings on chart paper from which the reflectivities of the gray card on each print were read & tabulated from 380-750nm in 10nm increments. The slight occasional horizontal shifts in the chart registration were accounted for, but the slight deviation in the 100% reflectance line was ignored. The scans for the surrounds were done later on the ACS. Its microcomputer printed the reflectivities in 20nm increments and the chromaticities. However, since these were for CIE Illuminants A & D_{65}, they were re-calculated for D_{50} , as explained next.

Values of several variables were needed to calculate the chromaticity coordinates - the acquired spectral reflectivities from the prints and the surrounds, the spectral power distribution of the illuminating source (from CIE tables), and the color-matching functions (ten degree data). The last was found in reference tables[3]. The tristimulus values were found by multiplication and summation of the above variables, as shown in the Introduction. Then the chromaticity coordinates (Table 1, Fig. 3 & 4) were determined using the 1976 CIE L*A*B* formula, as follows:

$$L^* = 116(Y/Y_n)^{1/3} - 16$$
$$A^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$
$$B^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}],$$

provided all fractions are >0.01. This formula was chosen from those available as providing the best display of the data by more evenly spacing the coordinates.

Since the goal of this experiment was to see if surrounds affect perception, the response count was used to determine the extent of any shifts. Points were selected corresponding to prints at the 50% threshold of the group of observers reporting a color cast, i.e., ten or more of twenty observers said a print (against a particular surround) had a color cast. A point in each color direction was selected and an ellipse was drawn that roughly connected the points. This was done for each surround. The points and ellipses were plotted first by hand and then using computer graphics.

Table 1

PRINT & SURROUND COORDINATES

LABEL	L*	A*	B*
N	58.5082	3.955	2.095
M1	57.1480	5.568	1.771
M2	58.5550	6.771	0.881
M3	54.7410	9.333	0.792
M4	51.6300	14.174	-0.775
R1	55.6150	4.615	1.964
R2	55.0220	6.475	4.053
R3	54.8730	8.663	8.291
R4	47.9850	14.563	19.033
Y1	57.8520	4.452	4.522
Y2	57.7470	4.333	4.735
Y3	55.1230	4.734	10.251
Y4	53.7260	5.485	22.723
G1	57.5420	3.741	1.761
G2	58.5200	1.874	2.335
G3	60.6040	-1.115	3.928
G4	63.4410	-5.505	6.093
C1	56.9850	3.580	2.359
C2	59.2610	2.248	0.393
C3	61.8620	-1.209	-1.733
C4	67.3780	-5.576	-3.982
B1	55.4550	4.818	1.028
B2	56.3050	4.457	-1.041
B3	57.2970	4.601	-4.259
B4	58.4510	4.765	-9.338
MS	60.2020	53.838	6.161
RS	53.1040	57.103	18.361
YS	88.0770	4.650	85.112
GS	75.1760	-30.986	57.437
CS	54.3790	-37.656	-27.200
BS	47.0580	-15.902	-37.834

Figure 3

PRINT & SURROUND COORDINATES

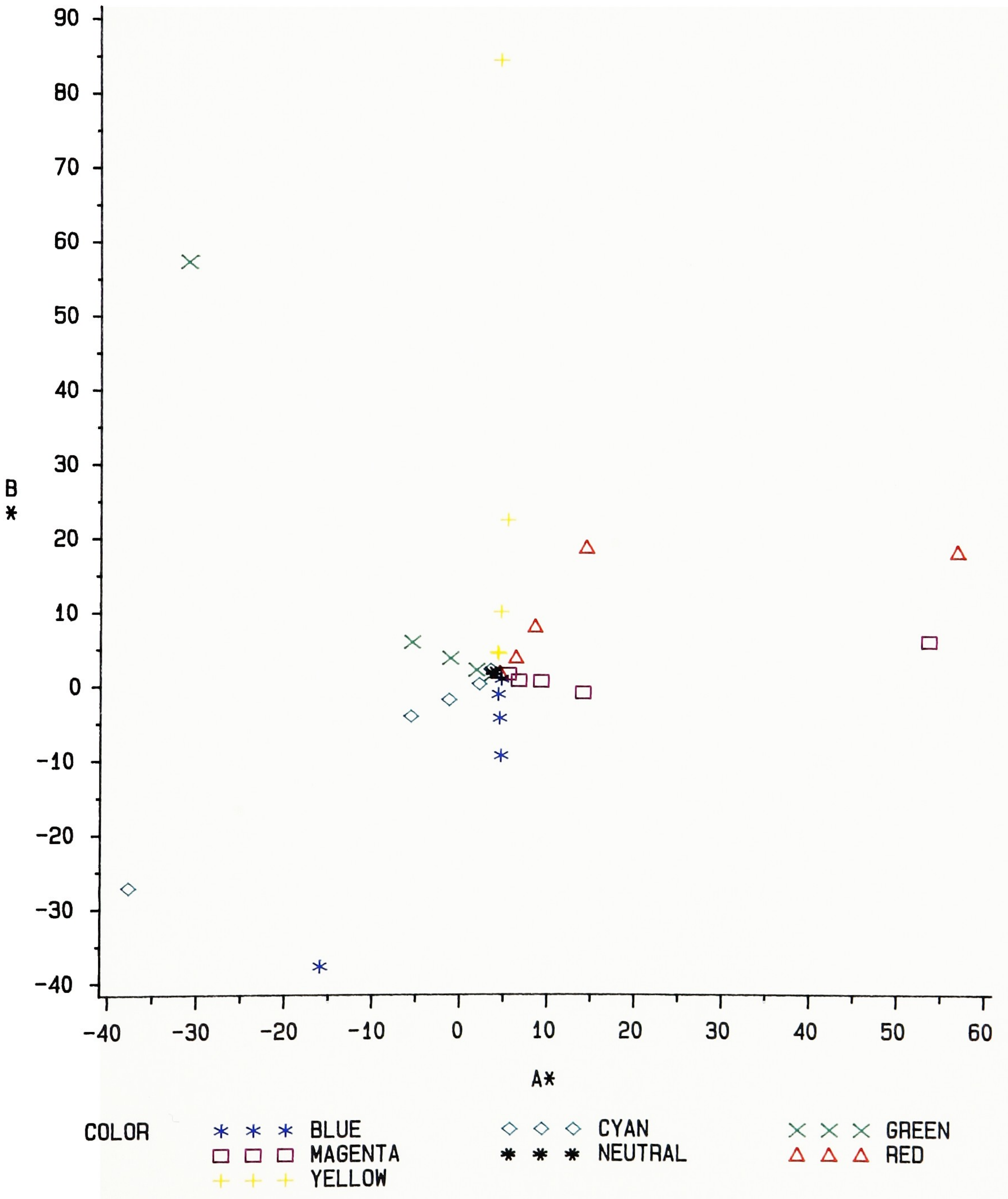
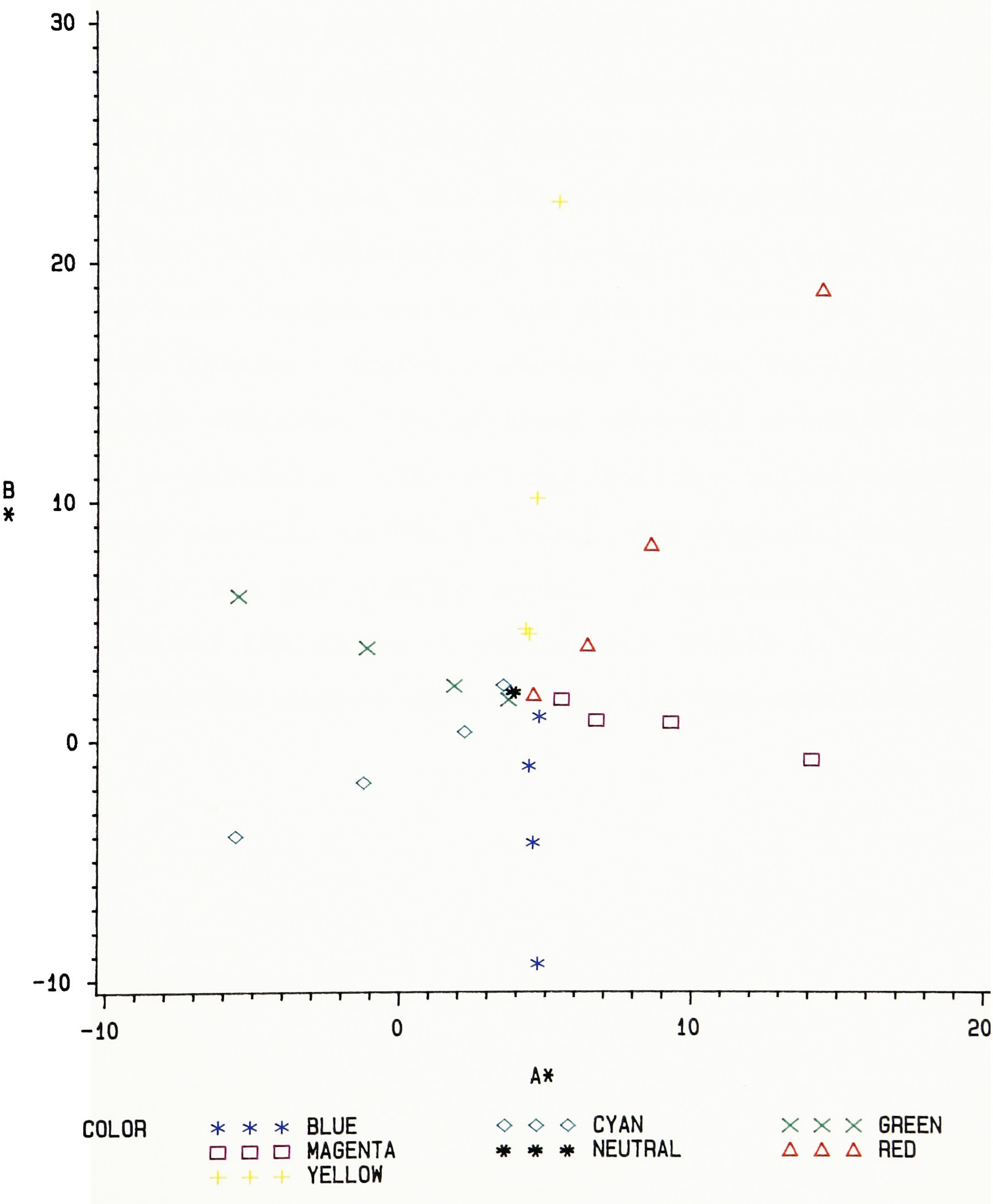


Figure 4

PRINT COORDINATES



The hand-drawn plots showed that, for each of the ellipses, the point "Y1" would be outside the ellipse, or the point "R1" would be inside the ellipse. Thus one or the other of these two points, as appropriate, was excluded for each ellipse. The computer-drawn ellipses (Fig. 5-11) were done utilizing the results of a principal component analysis, which gave the mean, standard deviations, eigenvalues, and eigenvectors. The last two specified the ellipse axes length ratio and the orientation to the coordinate system. However, because so few points(5) were used in the analysis, the ellipses were all oriented at 45 degrees to the axis. (The ellipse for the yellow surround was forced parallel to the B^* axis.) The mean of the points was used as the the ellipse center. A comparison of these means showed the shift in perception (Table 2, Fig. 12). The standard deviations were used as the semi-axes lengths.

Figure 5

NEUTRAL SURROUND

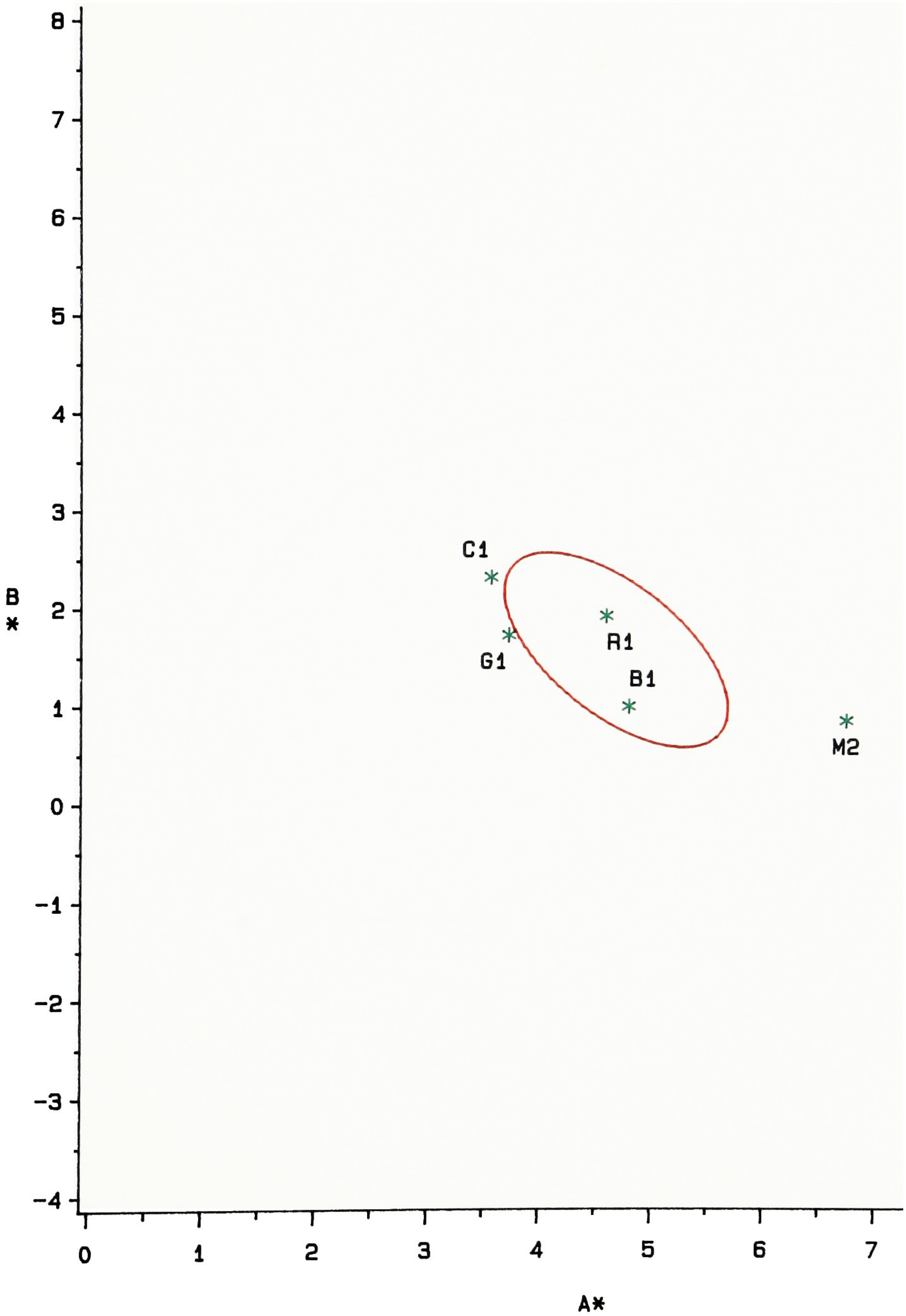


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Figure 7

RED SURROUND

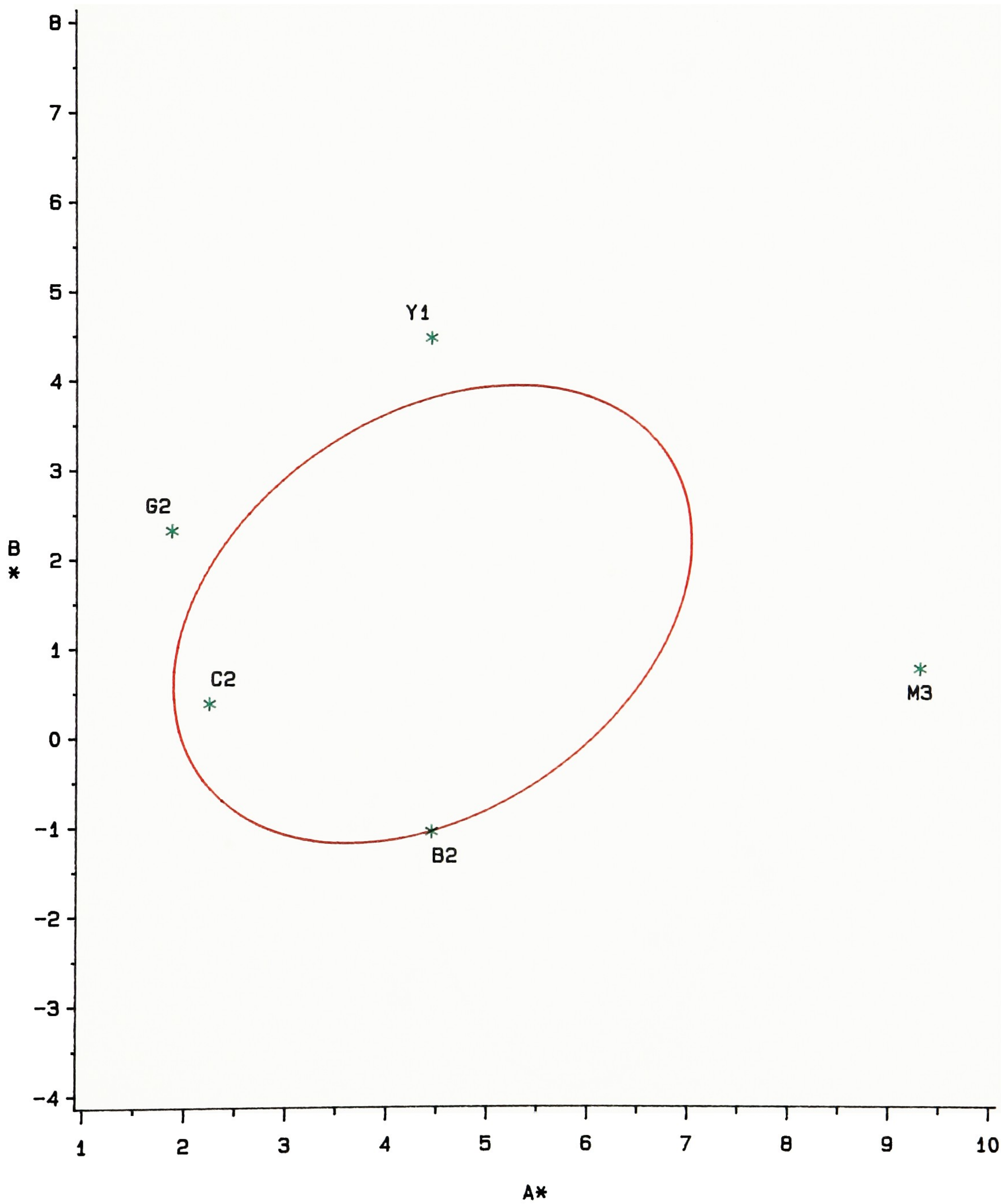


Figure 8

YELLOW SURROUND

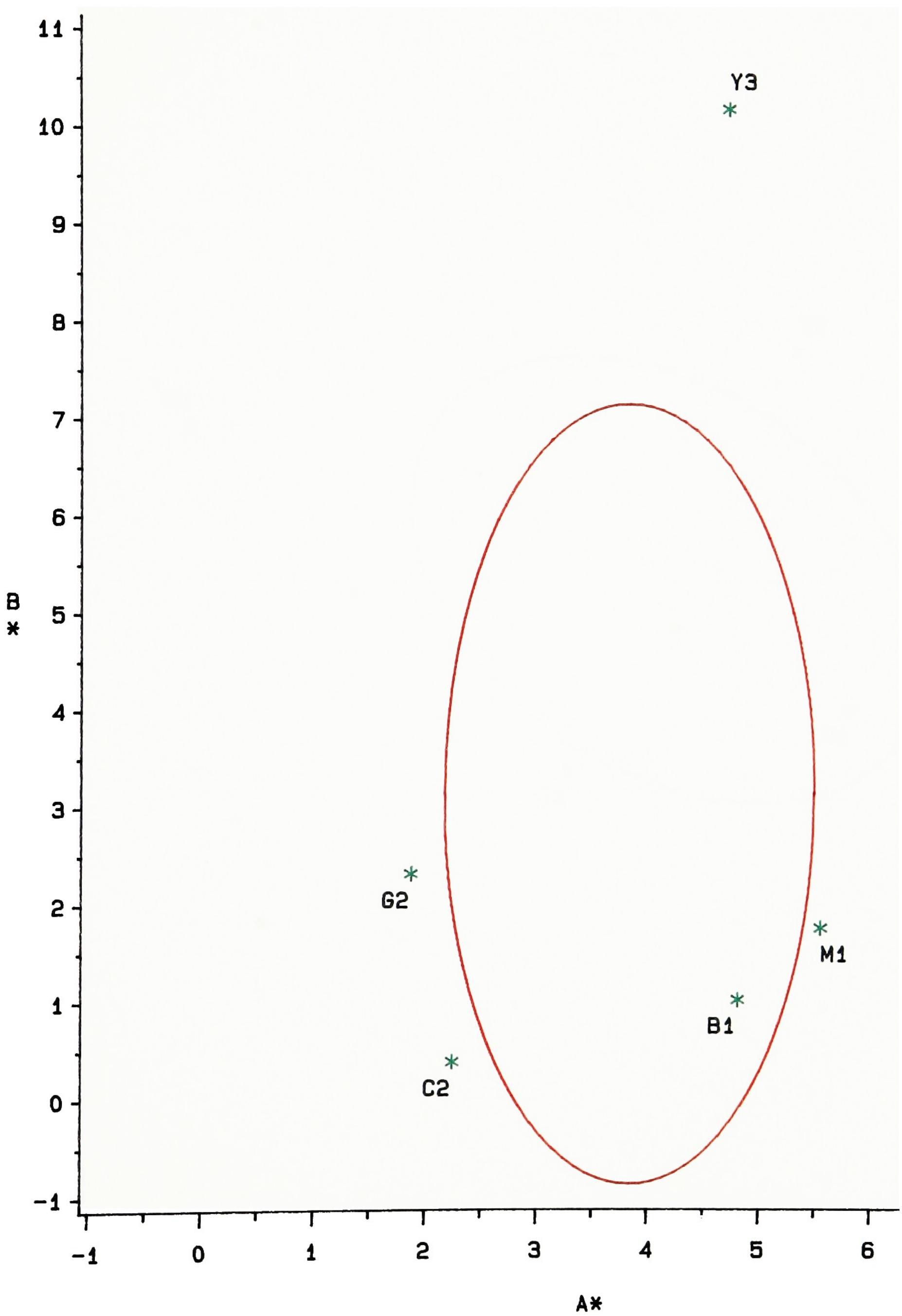


Figure 9

GREEN SURROUND

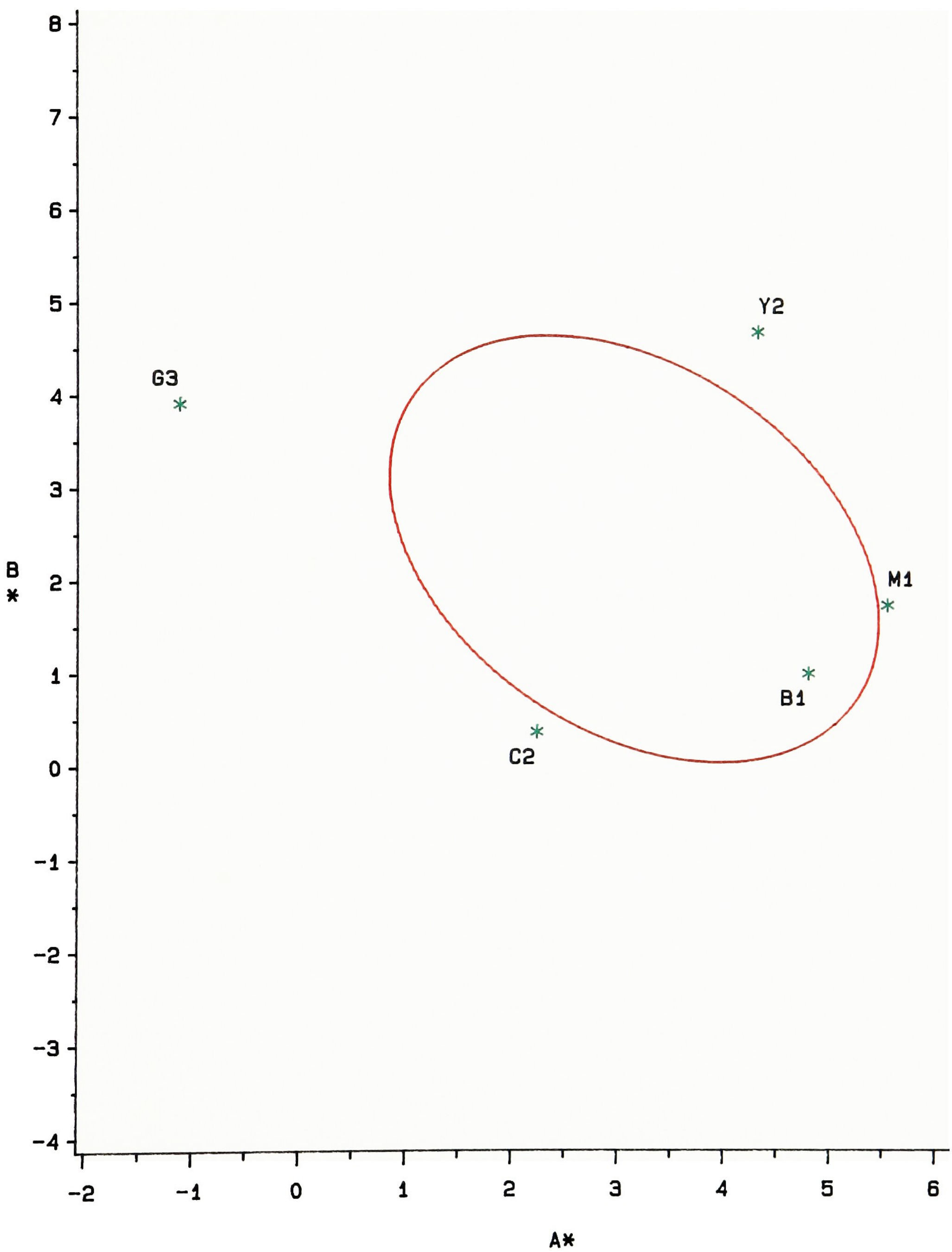


Figure 10

CYAN SURROUND

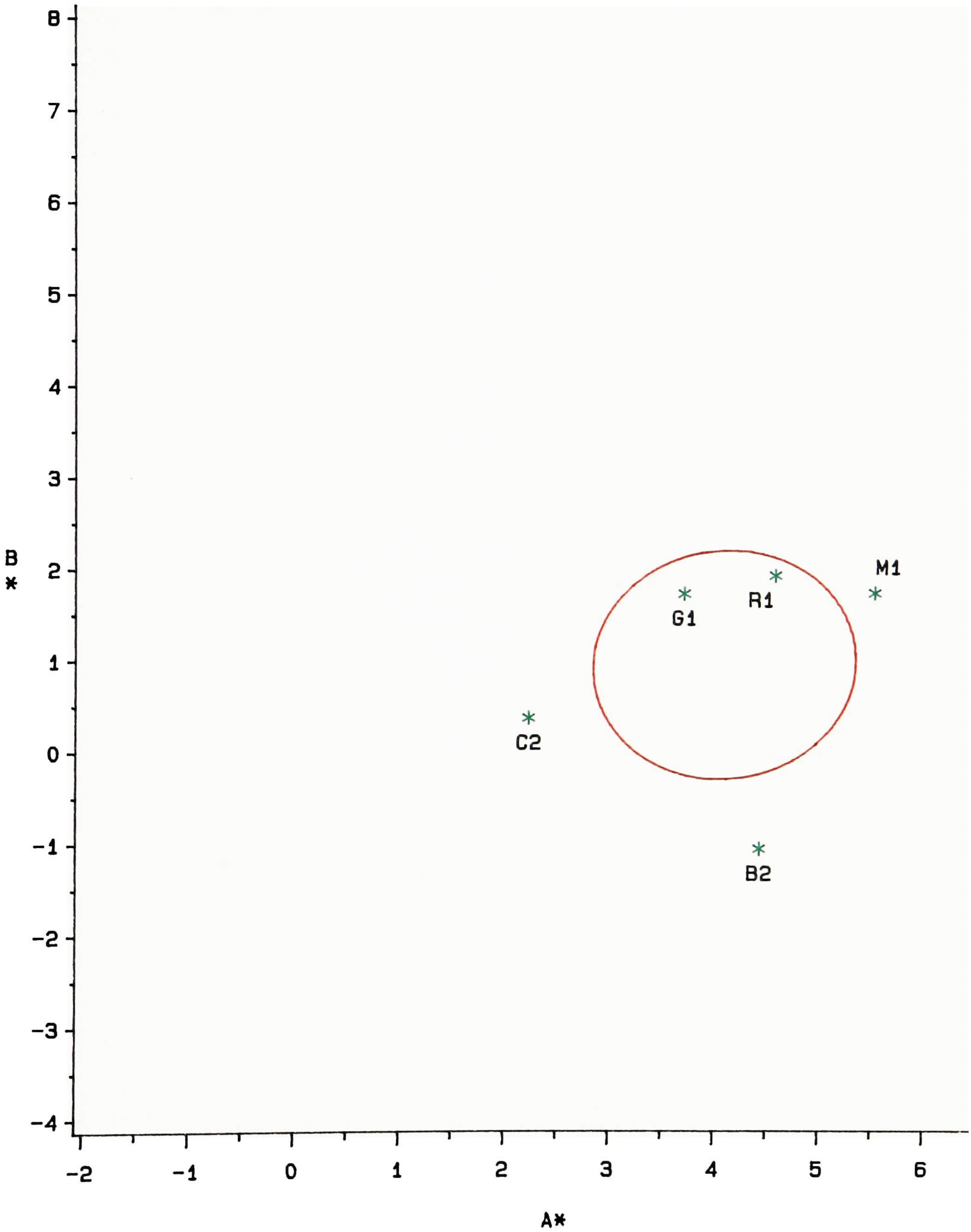


Figure 11
BLUE SURROUND

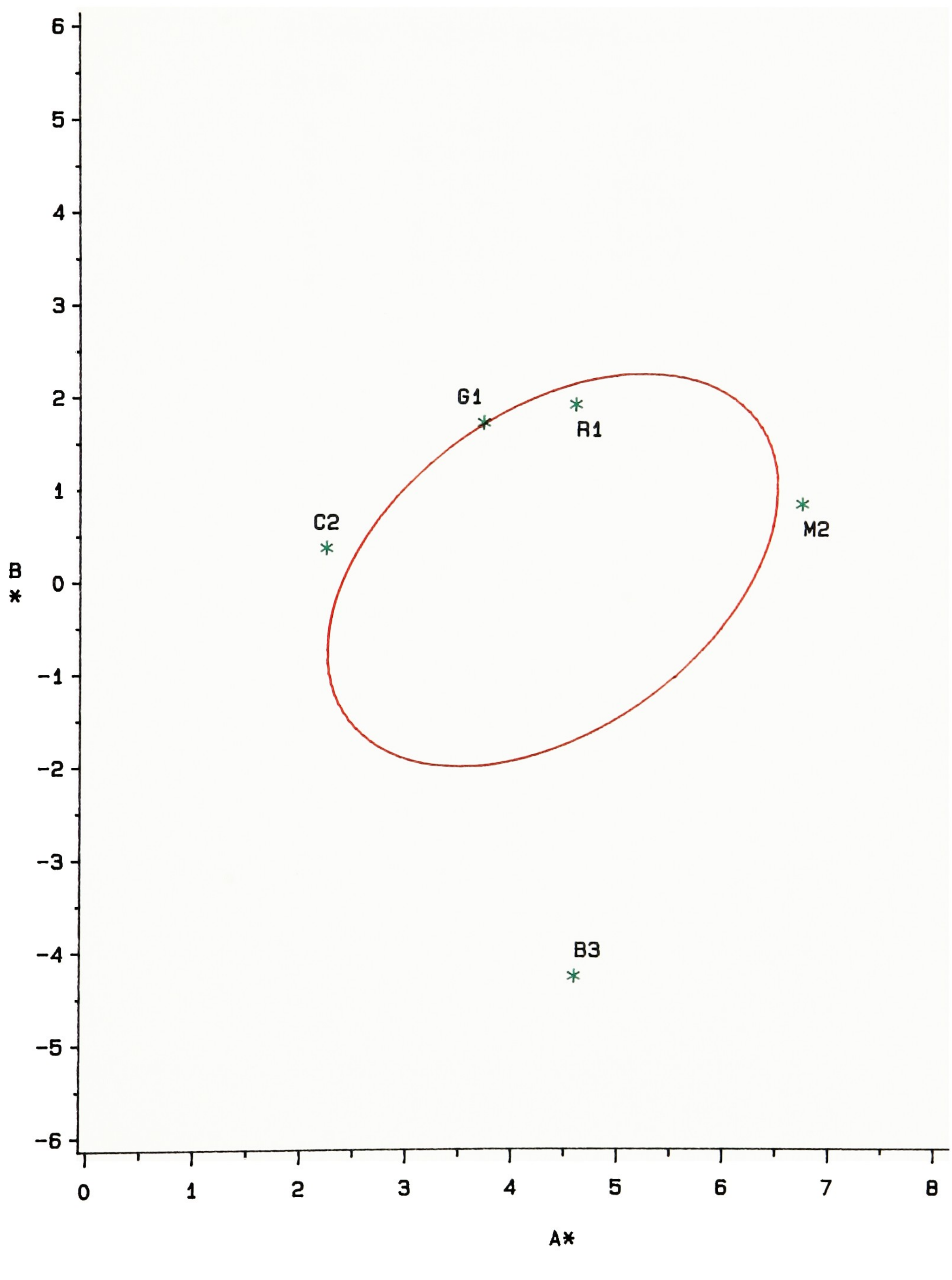


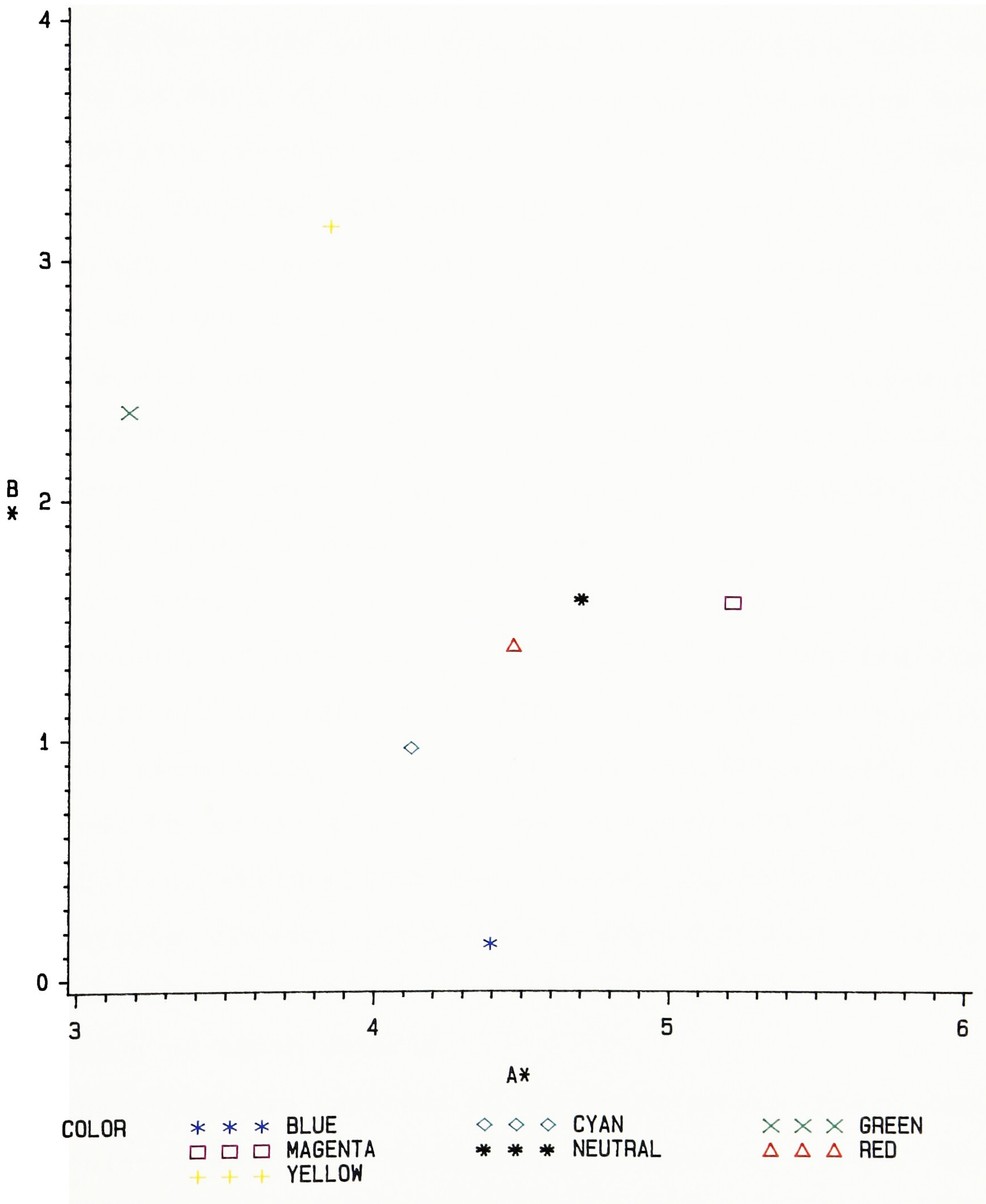
Table 2

ELLIPSE CENTER COORDINATES

COLOR	A*	B*
N	4.70506	1.59855
M	5.21750	1.58075
R	4.47282	1.40021
Y	3.84814	3.15590
G	3.17014	2.37134
C	4.12568	0.96974
B	4.39526	0.14798

Figure 12

ELLIPSE CENTER COORDINATES



Discussion

The purpose of this experiment, as stated previously, was to test the previous knowledge of colored surround effects on perceived color such that this knowledge could be extended to the field of color photography. The desire was to determine whether results similar to those in the literature could be obtained from complicated scenes in a photograph. Results obtained for the photographs were similar to those published concerning color patches.

The material presented here starts with an overview of previous work, then compares it with conditions in this experiment, follows with an elaboration of the results, and ends with points to consider.

The eye, responding to the influence of its environment, adjusts for incoming light by changing the pupil size and the retinal sensitivity. The three ranges of spectral sensitivity, according to the von Kries law[7], are altered in proportion to any differences in color distribution, whether from the illuminating source or from the objects viewed. Thus it is expected that a large colored area in the field of view will affect the color perception of other objects.

The literature reviewed in the Introduction showed that when color fields were viewed with colored surrounds, the ability to match colors was altered. In Brown's work[15], discrimination in the red fields was best with the red surround, and for green fields was second to the best with the green surround. White fields were affected by all surrounds and blue fields by none of the surrounds. In all cases for white, and in some cases for others, the ellipse axis was rotated toward the chromaticity of the surround, meaning that the discrimination of the eye was reduced in that direction. In general, such a reduction in ability to perform color matching occured when the surround color was different from the field. This concurs with the description in Ref. 2 of color matching against surrounds.

Brown also showed that the size of the field is another factor. The 12^{o} field was less affected by the surrounds than the 2^{o} field. In this project, the prints viewed subtended 7^{o}, but certainly the individual color areas in the photographs were far smaller. (The print size was not varied.) The surrounds did not, however, fill the entire field of view as this was not thought necessary. This type of surround condition is similar to that in many previous experiments - beyond the finite surround the view was either dark or otherwise non-chromatic. It would have been too cumbersome to cover (and frequently change) the entire inside of the booth with colored paper.

Since the luminances of the different surrounds were not equal, there might have been a luminance effect overlaying the chromatic, which was not the desired examination. MacAdam[11] stated that a surround luminance of at least 10% of that of the field would have an effect. Brown[17] remarked that it is easier for the observers if the surround is not brighter than the field (although their discrimination was not affected). The L^* values for the prints and the surrounds (see Table 1) were in the same range, except for the yellow surround.

Brown also offers for consideration the differences between using a few observers and using many. One of these differences is that unskilled observers may learn as they are tested. Perhaps a note should have been made to distinguish which of the observers in the current work were skilled and which were unskilled. What effect learning may have had could be difficult to determine. The 50% threshold was limited to four discrete points for each of the six color directions. Since the prints and surrounds were shown in random orders, the postions on the "learning curves" would also be randomized.

No observer repeated viewing sessions. It may have been useful with some to have done so. However, Wyszecki and Fielder[19,20] noted greater variations with repeat observations than expected, pointing out limitations in the gain from repeated viewing.

Comparisons with the literature may be limited for those experiments whose approach was to match two halves of a solid field. Detecting a color cast may share only parts of the same mechanisms. It should be remembered that the intent of this experiment was to extend the understanding of adaptation to how it affects the perception of complex scenes. The experiment was not designed to test color-matching or discrimination, but rather shifts in perception.

In the current results, a direct comparison of the plots (Figs. 5-11) shows shifts, and differences in the shapes, of the ellipses drawn. The ellipse for the neutral surround is the smallest (best discrimination). For the magenta surround the ellipse is elongated specifically in the magenta direction. The ellipse for the red surround stands out as being dissimilar to the others. Discrimination is decreased for all colors <u>but</u> red. (The ellipse is drawn ignoring the red point.) In fact, the perception of a cast exceeded the 50% threshold for the three "worst" red prints with <u>all</u> surrounds. The yellow and green surrounds reduced discrimination moderately for prints of their respective color, but also somewhat for each other and cyan. The cyan surround reduced discrimination slightly in the cyan & blue directions. The blue surround also reduced discrimination for blue and somewhat for cyan and magenta. In summary, the second most extreme print of that particular cast was the 50% threshold for magenta, yellow, green and blue surrounds.

It is interesting to note that this does not hold for red and, to some degree, cyan, which are complementaries. None of these results conflict with those given previously.

Most of the ellipse centers are shifted Ø.6 - 1.5 units in the A^*B^* diagram (Fig. 12), which is equivalent to Color Compensating (CC) filters of Ø2-Ø5 (1ØØ x density). A single, moderately skilled observer can see a CCØ5 change in many colors, and for Caucasian skin even CCØ2 is detectable. Therefore, for the means of twenty observers, at 5Ø% threshold, to shift to these extents is significant. (The reduction in error is proportional to the square root of twenty). This result supports the hypothesis that there is a shift in the perception of complex scenes due to background. This extension of chromatic adaptation into the field of photography is the major output of this study.

Red shifts the ellipse center opposite to the expected direction, due probably to the reduction in discerning color casts for all other colors. It is also the smallest shift.

The direction of the shifts in four of the six cases is toward the surround in use. As mentioned, red goes in the opposite direction. The shift induced by the yellow surround is skewed in the green direction, but is one of the greatest in magnitude. Some of the surrounds (Fig. 3) are in line with the four prints of corresponding color - cyan, yellow, and roughly magenta and blue. However, red is particularly off. If the line through the cyan coordinates is extend in the red direction, the red prints are on one side of the line and the red surround on the other.

One unexplained item in the plots is the coordinates of the nominal print, which in A^*B^* space might be expected to be Ø,Ø. The difference of roughly five units may have several possible causes, three of which are discussed here. First, the dyes in the photographic paper are capable of only a metameric match with the original gray card, not a spectral one. Secondly, since the $D_{5Ø}$ source is approximated by the use of fluorescent tubes, which are often deficient in red, the spectral power distributions of the actual source and the CIE standard source are different. Thus the chromaticities derived would be slightly incorrect representations of the print coordinates. Finally, the gray card might not be strictly neutral, although this is unlikely. Kodak states in the instructions enclosed with the cards that "Manufacture of the Test Card is controlled within close limits to produce neutral surfaces of standardized reflectance values" and "may be helpful in controlling the color balance of reproductions".

There are some topics that were not thought of or sufficiently considered during the planning and execution phases of this experiment. One was how to measure or confirm the validity of the data gathered. In any scientific pursuit utilizing experimental subjects there is concern for the effect those subjects may have on the results acquired. The skill of the observers varied greatly - from those able to discern only the grossest color distortion to individuals as familar with the technical terminology and appearance of "cyan" and "magenta" as they were with red, green, and blue. A few seemed to learn as the observations progressed.

Another difficulty may have been the level of alertness (both for the observer and the experimenter). One person was so tired that he was there only 15 minutes and ultimately the results had to be ignored, deleted from the summations.

The spectrophotometric data were generally accepted without regard for possible instrument variation. No scans were repeated on the same spot of a print gray card area. However, the nominally balanced print was scanned each time the four of a particular color cast were done (which would not have been in precisely the same spot). When the chromaticity coordinates from these repeated scans were calculated, they were averaged before plotting. The standard deviation for A^* is Ø.14 and for B^* is Ø.23.

The statistical design chosen was a method of categories, rather than a ranking of several prints or a paired comparison. The viewers merely stated if there was, or was not, a cast.

For example, the number of observers responding "Yellow" to Print"Y2" is as follows:

BACKGROUND						
Neutral	Magenta	Red	Yellow	Green	Cyan	Blue
5	5	5	3	3	1Ø	8

It appears in this example and in the other observer data that a matching color reduces the number of people able to see the cast and that a complementary color increases it. As a cautionary note, calculations show that the differences for this print are not statistically significant at a level commonly desired. Using a chi-squared test of significance, $X^2 = (O-E)^2/E$, where O is the observed number and E the expected number, the data for Print"Y2" gives a $X^2 = 7.1$. The value in the tables for six degrees of freedom and a Ø.Ø5 level of significance is 12.6. Being greater than the calculated value, the data shows no difference. On the other hand, if there were twice as many observers with the same ratios in responses, the calculated X^2 would be 14.3. Thus there would be a more statistically significant difference. However, this statistical hypothesis test was done only for one print. The ellipses and the shifts thereof are calculated from the points of five prints.

As the data and plots given above shows, there is an effect on the perception of color due to backgrounds. The chi-squared test given is only one way of analyzing the data. Much in colorimetry is not done at the 95% confidence level. Since error is proportional to the square root of the number of observers, to halve the error would require four times the number utilized, i.e. 80 observers. For the set-up used, such a number would have been unmanageable.

Conclusion

The goal of this project was to test the hypothesis that colored surrounds would influence perception of a color photograph. The subject was introduced by a survey of the literature. Then the experimental method and results were given, followed by a discussion of the preceding steps.

In this section, conclusions are stated and recommendations given for future investigations. While this experiment was an advance in this area, extending beyond the information known about solid areas or colored lights, there still are steps that need to be taken.

Two statements can be inferred from the results of this project: 1)The appearance of a photograph with poor color balance can be improved by viewing it against a background of the same color. 2)A neutral print can be made to have a cast complementary to its background. This knowledge may be of use in displaying photographs. A machine-produced print or an old, faded one may not have the best color balance. The proper choice of surround would often make the difference between having a good effect and a poor one. On the other hand, certain color mounting arrangements for display may not be suitable for a good print because of the shift that may be induced in some areas.

If continuations, or modifications of this experiment are attempted, some items to consider are: 1)the print and surround sizes and number (using more would probably better determine the location the ellipses), 2)the number (would need many more for any significant inprovement), condition, and skill of the observers, 3)whether or not to fix the viewing distance, 4)the possibility of learning on the part of the observers, 5)simplifying the display of prints and the recording of responses - to free the experimenter from fatigue and possible bias, and to reduce the time needed to display the next print, 6)using more than one set of prints, of different scenes or illuminations (this may help solve the dilemma of the neutral point shift and would examine effects of memory color).

Many of these suggestions probably define different experiments than the one just described. Others might give a firmer foundation to the conclusion reached here - colored surrounds affect the perception of color photographic prints.

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Appendix A
Photographic copies of Prints M4 and G4