Aperture and Object Mode Appearances in Images

J. J. McCann*
McCann Imaging, Belmont, MA 02478

ABSTRACT

Vision scientists have segmented appearances into aperture and object modes, based on observations that scene stimuli appear different in a black -no light- surround. This is a 19th century assumption that the stimulus determines the mode, and sensory feedback determines the appearance. Since the 1960's there have been innumerable experiments on spatial vision following the work of Hubel and Wiesel, Campbell, Gibson, Land and Zeki. The modern view of vision is that appearance is generated by spatial interactions, or contrast. This paper describes experiments that provide a significant increment of new data on the effects of contrast and constancy over a wider range of luminances than previously studied. Matches are not consistent with discounting the illuminant. The observers' matches fit a simple two-step physical description: The appearance of maxima is dependent on luminance, and less-luminous areas are dependent on spatial contrast. The need to rely on unspecified feedback processes, such as aperture mode and object mode, is no longer necessary. Simple rules of maxima and spatial interactions account for all matches in flat 2D transparent targets, complex 3D reflection prints and HDR displays.

Keywords: modes of appearance, luminance, contrast, stellar magnitude, Hipparchus, aperture mode, object mode, illumination mode, spatial comparisons

1. INTRODUCTION

Our understanding of appearance is based on both experiments and the intellectual constructs or frameworks we build around the experiments. At the start of the 19th century Thomas Young suggested that the retina had three different types of spectral receptors. In the middle of that century James Clerk Maxwell devised a matching experiment that measured the spectral sensitivity of these color receptors. After that, the problem of color became much more complicated because of observations that colored objects appear constant in different spectral illuminations. The simple, elegant theory relating color appearance to retinal receptor response was either wrong, or incomplete. Experiments showed that identical receptor quanta catches do not always generate the same color. The debate still continues about the nature of the missing elements in color constancy.

In 1953 the OSA Committee on Colorimetry[1] summarized an intellectual framework that included ideas from Goethe, Hering, Helmholtz, Katz, Gelb, Evans and others.[2] This framework describes 5 *modes of appearance* and 15 attributes and dimensions of color. The experimental fact of color constancy led to an assumption that humans inferred from the scene the spectral composition of the illumination. By this theory, appearance is significantly altered by scene inferences. Inferences determine the mode of appearance, which in turn affects appearance of each pixel in the scene. Katz described 11 *modes of appearance*.[3] Evans suggested that Katz's 11 *modes* be combined in to three: *Aperture* or *Film* mode (without objective reference), *Object* mode, and *Illumination* mode. The OSA subdivides *Object* into *Surface* and *Volume*, and *Illumination* into *Glow* and *Fills Space*. All this complexity is a consequence of trying to fit experimental data into the framework that inferred *modes* control appearance.

There is another framework that can account for color constancy without *modes of appearance*, namely spatial comparisons. Starting with Keffer Hartline's experiments on Limulus eyes[4], followed by neurophysiology of Kuffler, Barlow, Hubel & Wiesel and Zeki, our mid 20th century understanding of visual mechanisms has changed. Vision is no longer a biological array of pixels. It became a progression of spatial comparators. At the same time the work of Campbell, Gibson and Land provided psychophysical evidence for spatial mechanisms that did not require inference. It was no longer necessary to find the illumination of a scene to explain color constancy.[5,6] Quantitative measurements of color constancy were accurately predicted by spatial comparisons without determining the illuminant.[7] Modes of appearance were no longer needed to account for constancy.

This raises the question of whether *color constancy* appearances correlate with illumination predictions. In other words, is there an experiment that predicts different results from a spatial comparison mechanism, than from an inferred illumination mechanism? Departures from perfect constancy are a signature of the mechanism. Inferred illumination hypotheses predict imperfect correction for illumination shifts – illumination dependent predictions. Spatial comparison predictions predict imperfect corrections due to cone pigment crosstalk – object dependent predictions. Recent experiments with 27 illuminants show a dependence on objects, thus supporting a spatial comparison mechanism. This experiment failed to find evidence for an illumination mechanism. Not only are *appearance modes* unnecessary, they predict the wrong color matches.[8,9]

If color constancy fails to provide experimental support for modes of appearances, is there still a need for these intellectual frameworks in achromatic experiments? Alternatively, is there a simple spatial mechanism that can be used to unify the thousands of experiments performed in trying to understand achromatic vision? This paper describes appearance matches of components of complex images in different levels of illumination. These results will help us evaluate the need for modes of appearance.

One of the first reported psychophysical experiments was the classification of stellar magnitude by Hipparchus of Nicea in the 2nd century B.C. Although his original manuscripts have been lost, Ptolomy documented them. After many centuries, stellar magnitude is in common use today. It has been modified to be a photometric measurement starting with Pogson in 1856. The stellar magnitude changes by 100 : 1 when the measured luminance changes by 100,000 :1. In other words, stellar magnitudes have a slope of 0.4 in a plot of $\log_{10}$ luminance vs. $\log_{10}$ stellar magnitude.[10,11] With achromatic stimuli there is excellent correlation between stellar magnitude and the aperture mode of appearance. Both study high luminance spots of light in low-luminance surrounds. Bodmann's magnitude estimates for 2 degree spots[12] correlate well with stellar magnitude.

This paper's first study investigates the role of luminance and contrast in complex images. It uses eight different transmission patches in a white, a gray and a black surround. These patches are viewed at 5 different luminances and matched to a constant standard. The goal of the study is to understand the limits of constancy with overall changes in luminance. The experimental data will be compared to various hypotheses such as discounting the illuminant, simultaneous contrast, and the ancient low-slope change of appearance with luminance found in stellar magnitude. A further goal is to expand the range of luminances matched in related studies.[13,14,15,16] The second study investigates the role of luminance and contrast in complex 3D reflection prints. It looks at matches of identical reflectances in bright light and in shade. The third study investigates the appearance of 4 identical gray scales in different luminances in single complex images. It looks at the role of local maxima.

2. FLAT-2D TRANSPARENT DISPLAYS

The experiment asked seven observers to match uniform luminance patches to a standard display. Both test and standard displays were transparent photographic films viewed on two high-luminance Aristo lightboxes. The lightboxes had light emitting surfaces of 20 by 24 inches, but only the most uniform central 10 by 12 inches were used to illuminate the transparent contrast test targets. The viewing distance was 21 inches. The two light boxes were mounted at right angles so that the observers turned their heads back and forth to make matches. The left eye was used for observing the contrast targets and the right eye for observing the standard. Each observer had excellent color discrimination as shown by a score of less than 20 in the Munsell Hundred Hue Test.

2.1 Experiments

This study uses eight different transmission patches (2.7° by 5.5°) test patches in a white, a gray and a black surround. These patches were viewed at 5 different luminances and matched to a constant standard. The standard was a series of 9 patches, each with a different luminance transmission. The nine patches were surrounded by white (1000 ft-L). The luminances of the matching patches were 1000 = [9.0], 900 = [8.0], 610 = [7.0], 432 = [6.0], 177 = [5.0], 91.5 = [4.0], 36.5 = [3.0], 13.0 = [2.0], 4.82 = [1.0]. The patches were selected to have equal differences in appearance between white [9.0] and black [1.0]. In the experiments described below, the observers were asked to report on the mixture of colors on a palette that would match what they saw. Observers were asked to interpolate between the 9 reference values seen in the standard display.

The three contrast targets consisted of 8 transparent patches in a white, a gray and a black surround. Corresponding patches had the same transmissions. In addition, a series of 4 different uniform transparencies (O.D. [0.4] = 42.7%, [0.8] = 17.65, [2.0] = 1.13%, [3.0] = 0.056%) were sequentially placed behind the test target to control the illumination level of the lightbox. The dynamic range of the test targets covered 2.3

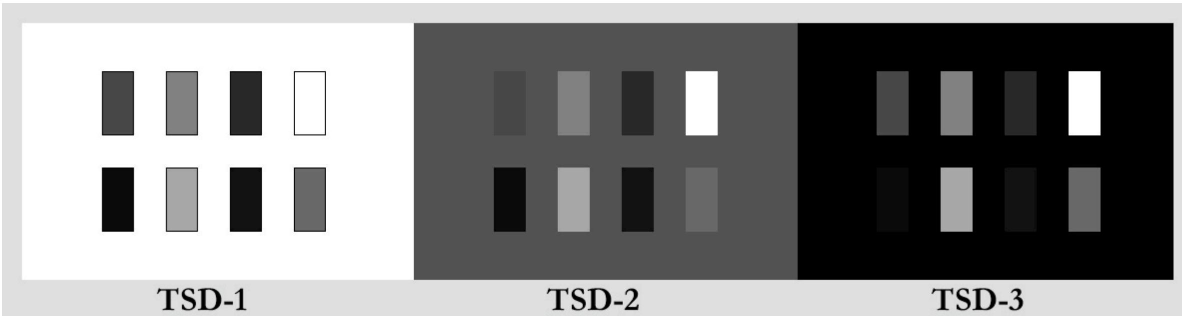

Figure 1 shows the three contrast targets. The transmissions of corresponding test patches are the same in the white, gray and black surrounds.

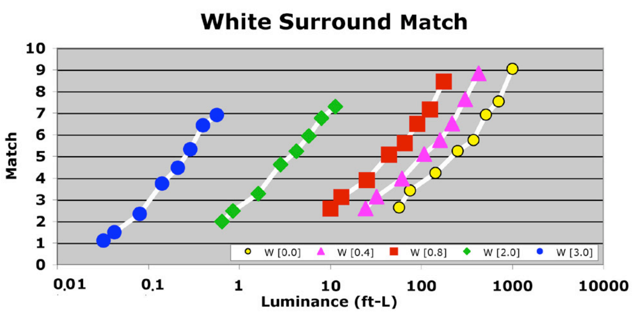

Figure 2 plots the match for 8 test areas in TSD1 target with a white surround.

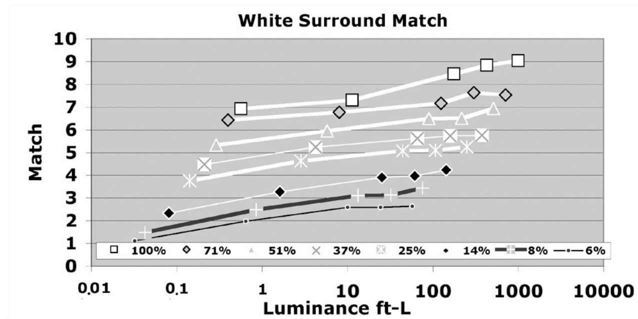

Figure 5 replots the match for 8 test areas in TSD1 target in a white surround. Lines plot the matches for one patch.

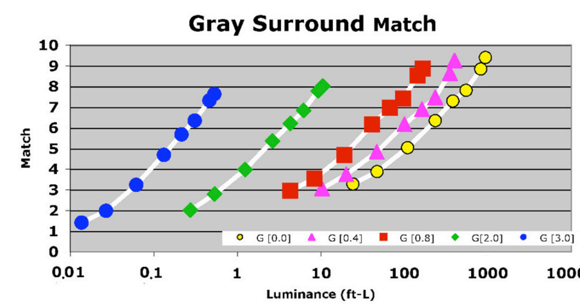

Figure 3 plots the match for 8 test areas in TSD2 target with a gray surround.

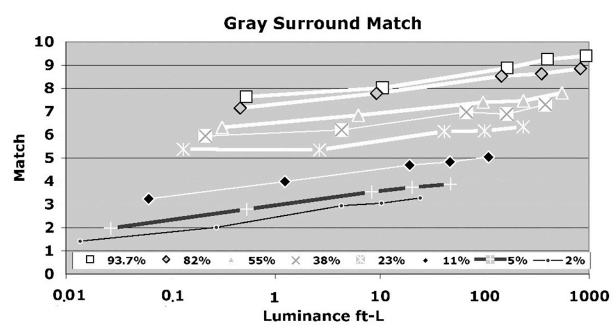

Figure 6 replots the match for 8 test areas in TSD-2 target in a gray surround. Lines plot the matches for each patch.

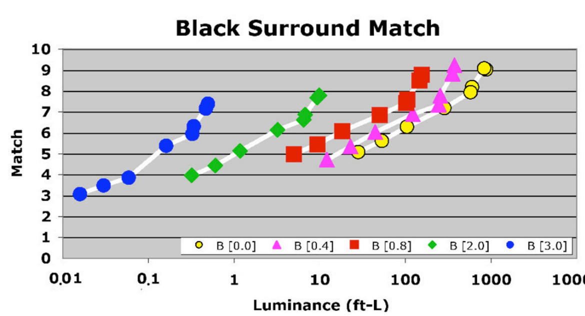

Figure 4 plots the match for 8 test areas in TSD3 target with a black surround.

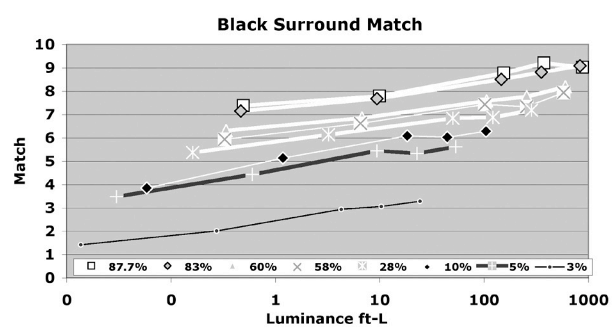

Figure 7 replots the match for 8 test areas in TSD-3 target in a black surround. Lines plot the matches for each patch.

log_{10} units and the dynamic range of the illumination covered 3.3 log_{10} units. Thus, the resulting dynamic range of the experiment covered 5.6 log_{10} units. One advantage of this apparatus is the luminance uniformity across the display and within each test patch. The luminances reported in this paper were measured with a Gamma Scientific telephotometer. The ranges of the transparent contrast targets are larger because they are not limited by paper surface reflectances. The constancy of image content is far superior than is possible in simulations on monitors and LCD displays. Another advantage of using photographic transparencies is that we can be certain that the contrast displays are exactly constant at each illumination level. This property is essential to isolate contrast from overall luminance.

The three contrast targets are shown in Figure 1. TSD-1 has a white surround (O.D. = 0.0) around the eight 2.7° by 5.5° patches. Their transmission optical densities were: 0.61, 0.32, 0.86, 0.00, 0.45, 1.16, 0.19, and 1.28. TSD-2 has a gray (O.D. = 0.70) surround around the same patches. TSD-3 has a black (O.D. = 2.34) surround around the same patches.

2.2 Results

Figure 2 plots the average match for all observers for TSD-1 white surround vs. log luminance. The lines plot the 8 contrast test patches in the five levels of illumination. The five data sets are parallel and exhibit high-slope behavior. That is, the matching value decreases rapidly with change in luminance. Figure 3 plots the average match for all observers for TSD-2 gray surround vs. log luminance. These data are parallel and exhibit high-slope behavior, but with a somewhat lower slope than with white. Figure 4 plots the average match for all observers for TSD-3 black surround vs. log luminance. Again, these five curves are parallel and exhibit high-slope behavior, but with a lower slope than with white and gray. All three data sets show a departure from perfect constancy, in that the observers chose a decreasing value for the white area as illumination decreased.

Figure 5 replots the average observer match for TSD-1 white surround vs. log luminance. The lines plot the matches for single test patches. These eight lines are parallel and exhibit very low-slope behavior. Perfect constancy predicts all lines would be horizontal (slope = 0). Figures 6 and 7 replots the average observer match for TSD-2 and TSD-3. In each case the eight lines are parallel and exhibit the same very low slope behavior.

The comparison of Figures 2, 3 and 4 show that the surround luminance has as substantial effect on observer matches. We fit the data from each line in figure 2 with linear least-square regression to calculate the linear slopes of the five linear fits for the data. The values were: 4.70, 4.75, 4.46, 4.34, 4.82. The average slope for a white surround is 4.615 ± 0.206. The linear fits for gray surround in Figure 3 were: 3.82, 3.77, 3.77, 3.83, 4.03 (Average = 3.846 ± 0.107). The linear fits for black surround in Figure 4 were: 2.59, 2.66, 2.32, 2.45, 2.83 (Average = 2.569 ± 0.195). These average slopes are plotted in figure 8 (left).

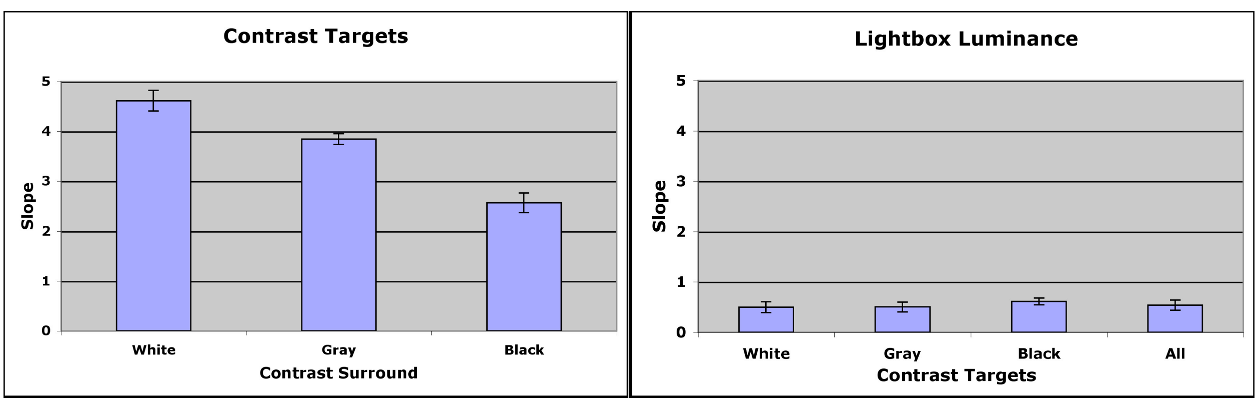

Figure 8 (left) plots the average slopes and standard deviations for white, gray and black surrounds. The effect of the surround produces different rates of change of match with luminance. (right) This plots the average slope for each patch in 5 illuminants. Here we see nearly constant behavior that is the same for white gray and black surrounds.

Figures 5, 6, and 7 study the low-slope change in match with luminance. These *Hipparchus lines*, similar to stellar magnitude, plot the rate of change of match with overall changes in illumination. The comparison of Figures 5, 6 and 7 show that the white, gray and black surrounds have no differential effect on the slope of observer matches with changing illumination. We used a least square regression linear fit to the data from each line in figure 5 to calculate the linear slopes of the eight patches. The average slope for a white surround is 0.500 ± 0.108. The average linear fit for the eight patches in gray surround in Figure 6 was 0.503 ± 0.108. The average linear fit for the black surround in Figure 7 was

0.612 ± 0.066. These average slopes are plotted in figure 8 (right). The average linear fit for all lines in Figures 5, 6, and 7 was 0.539 ± 0.103. The average slopes are the same for all three backgrounds. The average slopes are the same for all areas. Surrounds do not affect slope. The average slope of 0.54 is in good agreement with the magnitude estimation data by Bodmann (slope = 0.3) using a 2° test spot on a black surround.[12] It also is quite similar to the Pogson's standard for stellar magnitude that has a slope of 0.4[1]

2.3 A Simple Two-Step Physical Description

These results are very simple, and require only a simple physical description. As with color, constancy is not perfect.[8] As with color, departures from constancy have simple physical correlates[9]. We can model this data with a two-step process. The first step is to find the area with the maximum luminance in the fields of view. Appearance is almost constant, but with a large-enough change in the value of the maximum luminance, changes in appearance are obvious. That area's luminance predicts its match on the low-slope Hipparchus line. The second step calculates matches for nearby less-luminous areas. The composition of the surround determines the slope: White = 4.6; gray = 3.8; Black = 2.6. The ratio of the darker area's luminance to the maximum luminance determines the distance of the match along the high-slope line. Figure 9 illustrates the two-step process. It shows four sets of scene-dependent high-contrast lines for four different values of uniform overall illumination.

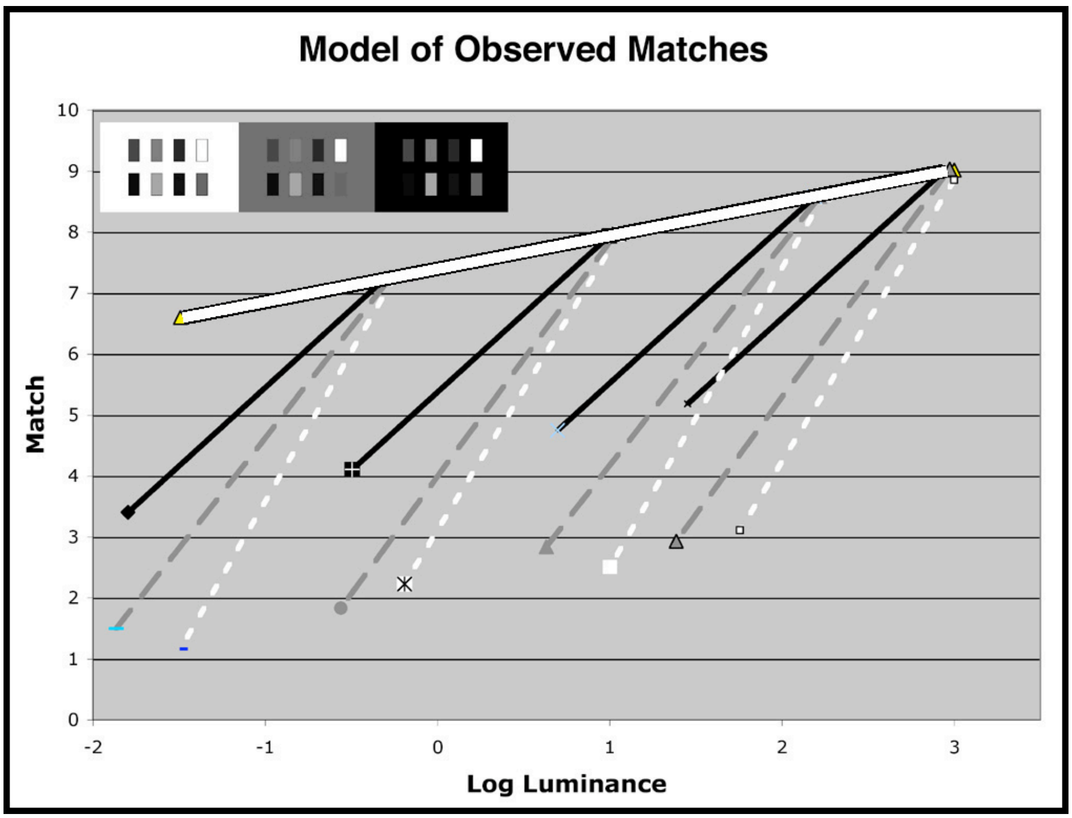

Figure 9 plots the two-step physical description for overall changes in luminance. The upper (white solid) line plots the low-slope Hipparchus line (slope 0.54 - see Figure 8 right). The dotted white lines have slope 4.6 (white surround); the dashed gray lines have slope 3.8 (gray surround); and the solid black lines have slope 2.6 (black surround- see Figure 8 left). The display's maximum luminance determines the starting point of these high-slope *contrast* lines. The background controls the value of the high slope. Use luminance to predict the match of the scene maxima, and spatial contrast [ratios of (luminance/max)] to predict darker areas.

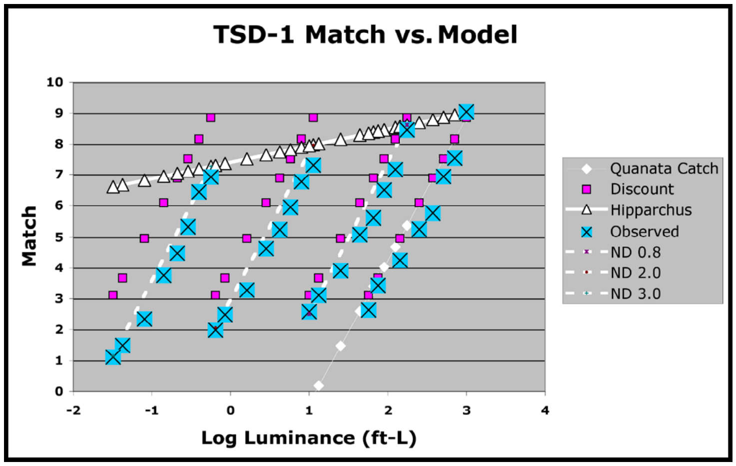

Figure 10 plots the white-surround physical description vs. observer data. The slope 4.6 predictions are the dotted white lines. The Xs plot the observer data for white surround in four illumination levels. The fit is quite good. The triangles plot the low-slope Hipparchus line. The squares plot the expected matches for perfect constancy. The solid white line plots the predictions for a luminance match (Quanta Catch) to the standard display.

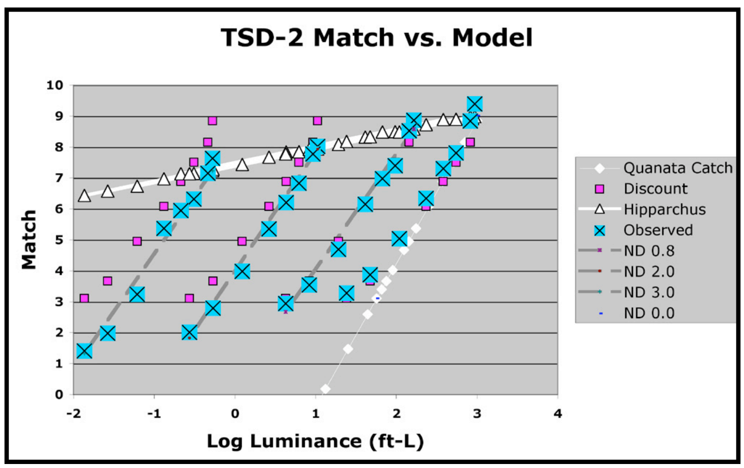

Figure 11 plots the two-step predictions for gray-surround observer data. The slope 3.8 predictions are the dashed gray lines. The Xs plot the observer data in four illumination levels.

.

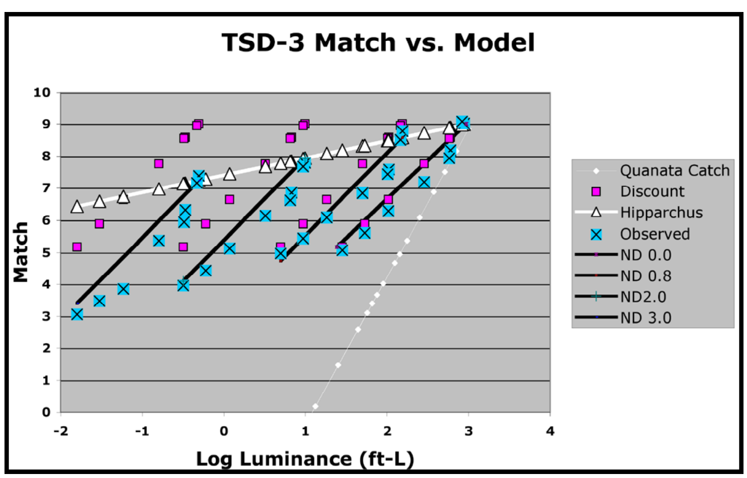

Figure 12 plots the two-step predictions for black-surround observer data. The slope 2.6 predictions are the solid black lines. The Xs plot the observer data.

Figures 10, 11, and 12 plot match vs. log luminance. The data do not show correlation with either perfect object constancy, or dependence on quanta catch (luminance). The plots show quite good fit to the simple two-step physical description of luminance and contrast (ratios). Matches to maxima are dependent on absolute luminance and less-luminous areas are dependent on spatial contrast interactions. These results measure the value of *Hipparchus-line* slope for complex images. We can use the simple two-step physical description of maxima and spatial contrast to evaluate complex scenes using direct and shadow illumination.

3. COMPLEX 3D SCENES

The 3D experiments study the influence of uniform direct illumination and shade in a real 3D scene. The experiments use printed-paper targets that are folded. The images on each side of the fold are the same. One side was in direct illumination and the other in shade. A separate card has standard reference reflectances printed on the direct illumination side (Figure 13 left). Observers matched these patches in both direct and shade illumination. This data can be used to assess whether real 3D illuminations of scenes influence the appearance of matches. If humans *discount the illumination*, then these matches will differ from those reported in *flat-2D transparent* experiments. If the observers behave the same as with 2D targets, then we have no need for *discounting the illumination* in complex scenes.

In trying to tease apart the mechanism of appearance it is essential to control the question presented to observers. McCann[17] used a photograph of a float to illustrate that observers give different answers to different questions about the same stimulus. When asked to recognize the paint on the sides of the raft, observers say it is white, even though one side is in sunlight and the other is in shade (perception). When observers are asked to hypothetically mix paints to render the appearance in a painting of the scene, they select a whiter, more yellow match for the sunny side, and a darker, more blue match for the shady side (sensation). Arend and Goldstein[18] documented this observation in experiments using display Mondrians. Bloj and Hurlbert also make this distinction in the analysis of Mach Card experiments.[19] In the experiments described below the observers were asked to report on the mixture of colors on a painters palette that would match what they saw. They were instructed not to try to guess the reflectance of the patch they were matching.

3.1 Experiments

A 4.4 by 2.8 inch folded card was placed on a table on a black cloth. The light falling on the paper came from 2 two-foot fluorescent lamps (distance = 18 inches). Care was taken to make the illumination of each side of the card uniform. The side directly illuminated had a 99.3 ft-L luminance from the white part of the card. The other side had 4.86 ft-L from white. The shade was 4.9% of the bright side. The standard card was slightly wider than the test targets. The 13 standard patches covering the range of 9.0 to 3.0 were calibrated to have the same % reflectance as the % transmission in the standard in the *flat-2D transparent* study. The reflectance standard had lower luminance and lower dynamic range than the transmission standard. The luminance values (ft-L) of the standard were: 99.7 = [9.0], 92.5 = [8.5], 81.6 = [8.0], 69.1 = [7.5], 54.7 = [7.0], 44.6 = [6.5], 34.8 = [6.0], 24.6 = [5.5], 14.8 = [5.0], 10.0= [4.5], 8.36 = [4.0], 4.93 = [3.5], 4.47 = [3.0].

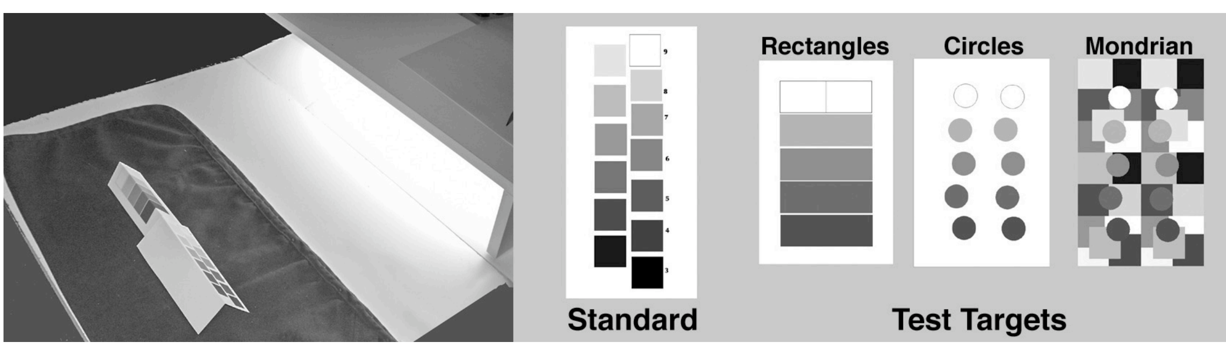

Figure13 (left) shows the 3-D display. Two fluorescent lamps were mounted in a white box placed on a white table. The standard set of gray patches and folded test card were placed on a black cloth. The distance between the cards and the lamps controlled the direct illumination on the cards. To the left of the photograph (out of the image) was a large white reflector. The distances between the lights, the cards and the reflectors were adjusted to control the level of the shade illumination. All cards were measured with a telephotometer to insure uniform direct and shade illuminations.

Figure 13 (right) shows the Standard, the three test targets. The test targets were folded along the vertical centerline. Matches for the five test areas were measured using the Standard as a reference.

Measurements of the luminances from the card showed that the illumination was uniform over the entire card. The black cloth under the paper plays an important role in uniform illumination. Without a black cloth, it is very difficult to control unwanted light reflected from the table surface, leading to higher luminances along the bottom of the card. A large white surface (2 by 2 feet) was parallel to the lamps on the far side of the folded paper target. It acted as a reflector to control the uniformity and illuminance falling on the paper on the darker side of the fold. A black card (3 by 3 feet) was placed perpendicular to the lamps to reduce reflected light onto the card from that direction. The observer viewed the folded card and the matching palette from a distance of 21 inches using both eyes. Binocular vision prevented perceived reversal of depth for the cards.

The experiments used three different folded cards shown in Figure 13 (right). Observers were asked to match test areas in the Rectangles, Circular Spots and Mondrian targets. In addition, they were asked to make additional matches within areas of uniform reflectance of the Rectangles target.

3.2 Results

Figure 14 plots the average of the matching data for all targets. The data show that there is very little difference between matches with the center of the Rectangles, the Circular Spots, (both in white surrounds), and a Mondrian. Further, the data fits very well the physical relationship described for the *flat-2D transparent* experiments. The whites in the direct illumination have matches averaging 9.0. The average match in shade was 8.4 and falls on the Hipparchus (slope 0.54 line).

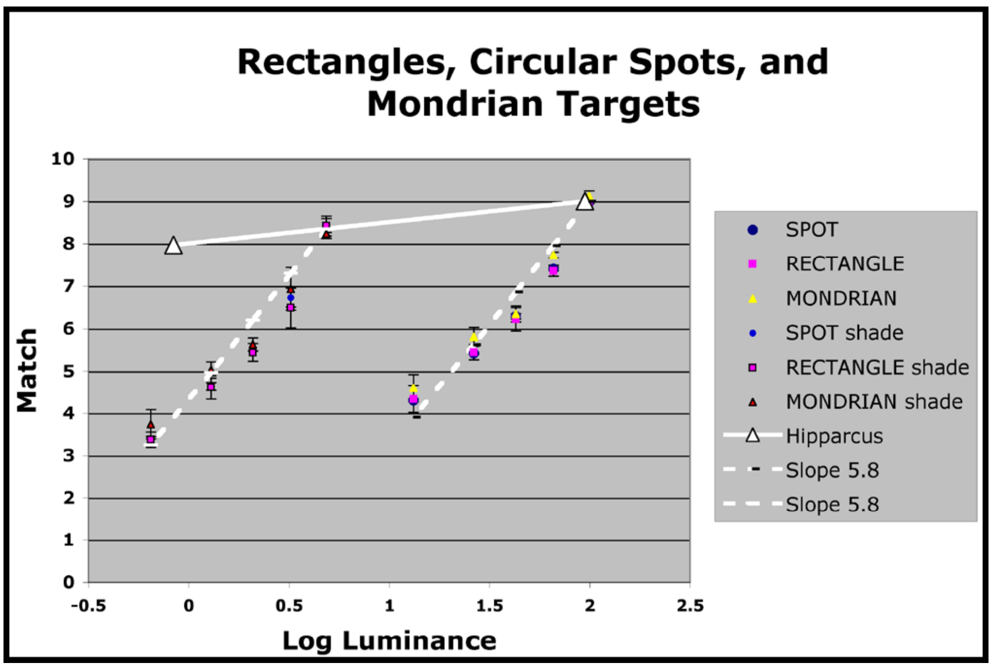

Figure 14 plots the average of eight trials (2 observers) ± the standard deviation for three different backgrounds around the matching patches. The linear regression fit for circular spots with a white surround has a slope of 5.2 for direct and 6.2 for shade. The fit for the Mondrian surround has a slope of 5.0 for direct and 6.1 for shade. That is not very different from the slope of 5.1 for direct and 6.8 for shade in the Rectangles experiment. The average slope is 5.8. The lines are the predictions made in simple physical description described above. The solid white line plots the Hipparchus line that predicts the matches for whites or local maxima. The dashed white line plots slope 5.8.

Observer matches are the same as in uniform illumination. The observer seems to follow the simple physical rule that the local maxima respond to luminance. Areas less-luminous than the local maxima in white surrounds are controlled by the same high-slope contrast mechanism.

It is interesting to note that the Mondrian background, despite its lower average luminance, has the same slope as the other two white backgrounds (Circular Spot and Rectangular patches). This fact is important because it shows that standard matching targets should use white surrounds. Uniform gray surrounds do not have the same visual effect as complex images.

The targets in Figure 13 are binocular variants of the Mach Card demonstration. These demonstrations have considerable variability with spatial content.[20] The appearance matching experiments in this paper differ in three properties from Mach perceptual experiment. First, the displays have three different complex spatial patterns printed on them. Second, the displays were seen in binocular vision that inhibited the depth reversal necessary for change in the perceived reflectances in the Mach card experiments. After all matches had been completed, observers were asked if they could make the card reverse using binocular vision. They said they could not. Third, we asked observers the artist's palette question of finding a value in the standard that looked like the patch. Again, after all matches had been made, observers were asked to use monocular vision to see if they could make the card reverse in depth. They could. They were then asked if the reversal changed the matches of the gray patches on the card. They said that the reversal did not. Although there are physical similarities to Mach card, there are also important differences. These results are not in conflict with perceptual studies of Mach's original perceptual experiment, they are different answers to different questions using different stimuli.

3.3 Do uniform stimuli appear uniform?

Additional matches were made along the rectangular patches as illustrated in Figure 15 (left). Observers were asked to match all along the gray stripe that started near the table at the bottom of the card, traveled to the top and continued down the shade side. At the top the observer was asked to fixate on the edge created by the shadow at the very top. Here the observers were asked to match the edge they observed at the transition.

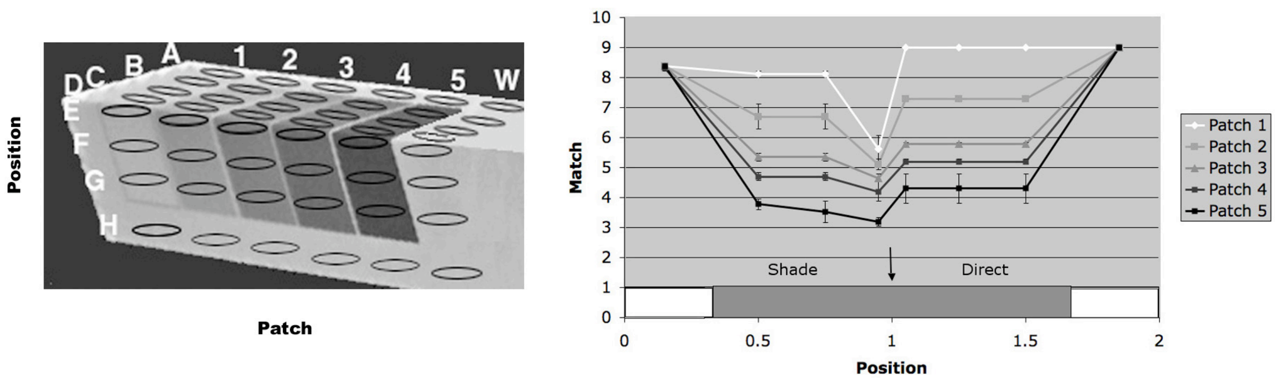

Figure 15 (left) shows the diagram given observers to identify the test patch segments for matching and spatial positions. Figure 15 (right) plots the matches along the rectangular patch for 5 target patches. The horizontal axis is the distance along the paper from white surround in shade to fold at the center and on to the white surround in the direct illumination.

Figure 15 (right) plots the average matches for image segments along the rectangular patches. The plot starts at the bottom of the card in the shade (Position 0). The first matches are in the white surround below the rectangles (position 0.15); the next match was one-third the way up the patch (position 0.50); the next match was two-thirds the way up (position 0.75); the next match was at the very top on the shade side (position 0.95); the next match was at the very top on the direct-light side (position 1.05); the next match was one-third the way down the patch (position 1.25); the next match was two-thirds the way down (position 1.67); last match are in the white surround below the rectangles (position 1.85).

The results in Figure 15 (right) show that uniform luminances do not always appear uniform. The right side of the graph shows that the gray rectangles appear nearly uniform in direct light. At the edge created across the rectangle by the change from direct to shade illumination there is a significant decrease in match followed by higher values further along the strip. The match at the center of the shade portion of the strip falls on the Hipparchus line. The spatial comparisons at the illumination edge report a much darker patch. All the rest of the spatial comparisons report a lighter patch consistent with the spatial comparisons to the local maxima. This non-uniform spatial appearance is an important piece of data for any computational model using multi-resolution computations. This data can be used to identify the contributions of different size spatial components.

4. LOCAL MAXIMA

In a later paper in this conference (6292-41) we show magnitude estimation data for 40 pie-shaped test sectors in white and in black surrounds. We used the target in High Dynamic Range (HDR) experiments. The 40 sectors have a luminance range of 18,619:1. The plot of appearance estimate vs. luminance is reproduced in Figure 16. The displays are made of 4 identical transparencies with 10 gray steps. Each transparency is combined with a 0.0, 1.0, 2.0, or 3.0 neutral density filter. With a no-light surround the targets each have a 10x luminance factor between them. Observers estimated that the highest luminance in each circle fell on a low-slope line. Adjacent, and nearby sectors, change more rapidly with luminance. Observers can discriminate all 40 test sectors. (With a maximum-light surround the appearance estimates are more complex, involving both contrast and veiling glare. The details are discussed in the second paper.) The relevant facts here are that the local maxima within a single field of view demonstrates the Hipparchus low-slope line. Adjacent, and nearby sectors, change more rapidly with luminance.

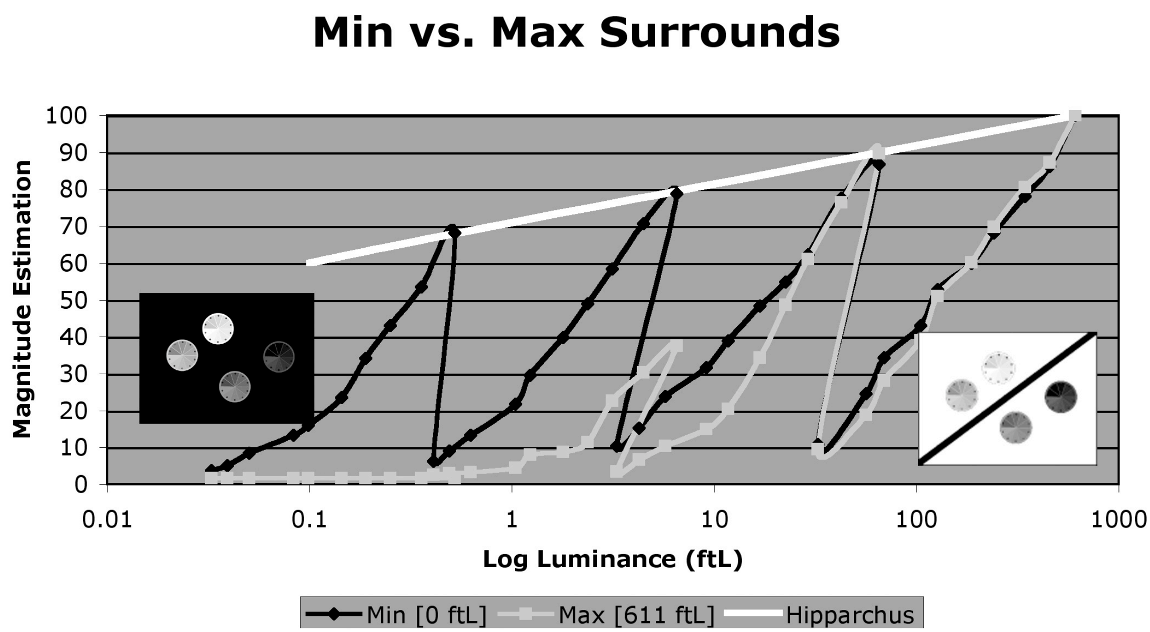

Figure 16 plots magnitude estimation of appearance vs. calibrated luminance for the 40 sectors in *4scales Black* and *4scales White* test targets. Although the target luminances are exactly equal, the appearances are not. With a black surround observers can discriminate all 10 sectors in all four displays. With a white surround observers cannot discriminate below 2 ftL.

The results of Figure 16 show that the same pair of descriptive rules found in previous experiments applies to HDR images. Low-slope changes for maxima; higher-slope ratio-dependent changes for less-luminous sectors. The distinctive property here is that the Hipparchus line behavior is seen for local maxima in the same field of view.

5. DISCUSSION

One principle goal of these experiments was to measure the extent of constancy with changes in luminance. We studied *flat-2D transparent* targets and *complex 3D* shapes in direct light and shade. To make these measurements we must use an experimental design that accurately quantifies constancy. We chose to instruct the observer to make the artist's palette judgment to match the appearance of the test patch. We told the observer not to guess the reflectance of the patches. Guessing the patch's reflectance does not accurately quantify the appearance. Two patches that look different could be assigned the same apparent reflectance[2]. Such surface estimates are appropriate for measuring how well human do at reflectometry,[3, 17, 21,] but do not help quantify the accuracy of appearance constancy matches.

So far in this paper there has been no mention of lightness and brightness. The reason is that there are different definitions used by different authors[3,16,,22,23] Beck[2] (page 14) cites many different definitions of brightness. They involve a variety of instructions to observers. For the moment we will just discuss the effects of physical measurements of luminance (ft-L) on observer matches. It is beyond the scope of this paper to relate these measurements to Appearance Models based on measurements of single pixels and their illumination[24] and to computational models using arrays of radiances[25]. This paper reports on the relationship of luminances and appearance.

These experiments were designed to measure the magnitude of the phenomenon called *discounting the illuminant*. We measured the changes in match with overall, uniform changes in illumination (*flat-2D transparent* targets). In 3D, we measured identical reflectance patches in direct and shadow illumination. We found no difference in observer matches in uniform illumination and matches in non-uniform illumination in real 3D scenes. We found similar behavior for local maxima in magnitude estimates of scale targets in an HDR image. We found no evidence for perfect constancy. We found no evidence for high-level recognition of illuminants and mechanisms that discount those illuminants. Instead, we found that that the maxima in the field of view, and the local maxima, follow the low-slope decrease in match with luminance. This is the simplest form of response to light. Response is proportional to log luminance. Areas less luminous than the maxima show a rapid change in match due to contrast [slope 5.4 (*flat-2D transparent* targets) and slope 5.8 (*complex 3D* targets)]. These two simple low-level mechanisms are all that are necessary to explain luminance constancy in *flat-2D* and *complex 3D* targets as long as observers were asked the *painter's palette* question.

Human vision does not exhibit perfect constancy in luminance and in color. The departures in both are small enough so that they are easily overlooked in everyday observations. Careful matching experiments can quantify the departures from perfect constancy. These measurements are the signatures of the visual mechanisms that approach perfect constancy. Human vision normalizes images using the maxima in each color channel. Experiments matching color in a Mondrian showed a slow change in appearance in L, M, and S channels from shifts in overall illumination.[7] Other experiments have shown that departures from perfect color constancy correlate with crosstalk between color channels.[8] Such crosstalk is the result of spatial comparisons within a single set of receptors.[9] Human vision normalizes images using maxima. This behavior is seen in color constancy, rod-Lcone color[26], and here in achromatic experiments.

How do these new experiments, relating appearance to luminance, affect our intellectual frameworks of human vision? As discussed above, stellar magnitude (*Hipparchus line*) is the same as aperture, or film, mode of appearance. The experiments with 2D transparencies and 3D folded prints show that the maxima in these complex images are no different from aperture mode. The shaded areas in the folded card and the HDR *4scaleB* experiments show that local maxima also act in aperture mode. Nearby, lower luminance segments in all these images show spatial-dependent contrast. There is no difference between contrast and *object mode* of appearance.

This analysis leads to the same pair of alternatives discussed for color in the introduction. There is a 150-year-old framework for vision that assumes the stimulus determines the *mode*, and unspecified mechanisms control feedback that determines appearance. An alternative framework combines the *Hipparchus line* from stellar magnitude with spatial contrast. Contrast is the 50-year-old legacy of spatial interactions. This framework suggests that the experiments used to build the mode of appearance framework can be more easily predicted by the combination of Hipparchus line and contrast.

6. CONCLUSIONS

Objects in complex images appear almost constant. This is true with changes of the overall level of illumination. The small departures from perfect constancy provide important evidence on the underlying mechanisms. First, this paper measures the departures from constancy with changes in overall luminance. Second, it measures the effects of contrast using white, gray, and black surrounds. Third, it compares the results from flat-2D transparent displays with those using 3D shapes. Fourth, it measures appearances in HDR targets. In all cases we found that the appearance of local maxima are dependent on luminance, and other, less-luminous areas, are dependent on spatial contrast. In all the complex images studied we found no need for *modes of appearance* to explain the observer results.

ACKNOWLEDGEMENTS

The author wants to thank Sam Tatnall for his efforts collecting the *flat-2D transparent* data and Mary McCann for her helpful discussions.

REFERENCES

*mccanns@tiac.net
[1] OSA Committee on Colorimetry, "The Science of Color, Thomas Y. Crowell, New York, 1953.
[2] J. Beck, "Surface Color Perception", Cornell University Press, Ithaca, 1972.
[3] D. Katz, "The World of Color", Trans. R. B. MacLeod and C.W. Fox, Kegan Paul, Trench, Truber, London, 1935.
[4] H.K. Hartline, H.G. Wagner, F. Ratcliff, "Inhibition in the Eye of Limulus", J. Gen. Physiol, **39:5** 651-673, 1956
[5] E. H. Land "The Retinex", *Am. Scientist*, **52,** 247-264, 1964.
[6] E. H. Land and J. J. McCann "Lightness and Retinex Theory", *J. Opt. Soc. Am*., **61,** 1-11, 1971.
[7] J. J. McCann S. McKee and T. Taylor "Quantitative studies in Retinex theory: A comparison between theoretical predictions and observer responses to 'Color Mondrian' experiments" *Vision Res*.**16,** 445-458, 1976.
[8] J. J. McCann, Mechanism of Color Constancy, Proc. IS&T/SID Color Imaging Conference, IS&T/SID, Scottsdale, Arizona, 12, 29- 36, 2004.
[9] J. J. McCann, "Do humans discount the illuminant?", in Proc. SPIE 5666**,** Human Vision and Electronic Imaging X; B. E. Rogowitz, T. N. Pappas, S. J. Daly; Eds., San Jose, p. 9-16, 2005.
[10] R. E. Zissell, "Evolution of the "Real" Visual Magnitude System", JAAVSO **26**, 151, 1998.
[11] J. J McCann, "Rendering High-Dynamic Range Images: Algorithms that Mimic Human Vision", in *Proc. AMOS Technical Conference*, Maui, p 19-28, 2005.
[12] H. W. Bodmann, P. Haubner and A. M. Marsden, "A Unified Relationship between Brightness and Luminance", CIE Proc. 19th Session (Kyoto) 99-102, 1979, CIE 50-1979.
[13] S.S. Steven and Stevens
[14] D. H. Jameson and L. M. Hurvich, "Complexities of perceived brightness", *Science*, **133**,174-179, 1961.
[15] C. J. Bartelson and E. J. Breneman, "Brightness perception in complex fields", *J. Opt. Soc. (A),* **57**, 953-957, 1967.
[16] A. Gilchrist, Ed. *Lightness, Brightness and Transparency*, Lawrence Erlbaum Associates, Hillsdale, 1994.
[17] J. J. McCann and K. L. Houston, "Color Sensation, Color Perception and Mathematical Models of Color Vision," in: *Colour Vision*, J. D. Mollon, and L.T. Sharpe, ed., Academic Press, London, 535-544, 1983.
[18] L. Arend and R. Goldstein, "Simultaneous Constancy, Lightness and Brightness", J. Opt. Soc. (A), **4**, 2281-2285, (1987).
[19] M. G. Bloj and A. C. Hurlburt, "An empirical study of the traditional Mach card effect", Perception, **31**, 233-246, 2002.
[20] A, C, Hurlburt, "Editorial: Illusions and reality-checking on the small screen", Perception, 27, 1998,
[21] R. Robilotto and Q. Zaidi, " Limits of lightness identification for real objects under natural viewing conditions", J. Vision, **4**, 779-797, 2004.
[22] E. H. Land, "Smitty Stevens' Test of Retinex Theory", in: *Sensation and Measurement, Papers in Honor of S. S. Stevens*, H.Moscwitz et. al. Ed., Applied Science Publishers Ltd., London,363-368, 1974.
[23] G. Wyszecki and W. S. Stiles, *Color Science: Concepts and Methods Quantitative Data and Formulae*, *2nd Ed*, John Wiley &Sons, New York, 164-169, 1982.
[24] N. Moroney, M. D. Fairchild, R.W.G. Hunt, C. Li, M. R. Luo and , T. Newman, "The CIECAM02 Color Appearance Model", IS&T/SID Tenth Color Imaging Conference: Color Science and Engineering Systems, Technologies, Applications, Scottsdale, Arizona, p. 23-27, 2002.
[25] J. J. McCann, "Capturing a black cat in shade: past and present of Retinex color appearance models", J. Electronic Img. **13**, 36-47, 2004.
[26] J.J. McCann, J. L. Benton, S. P. McKee. "Red/white projections and rod/long-wave cone color: an annotated bibliography", J. Electronic Img, 13, 8-14, 2004.