Measuring Constancy of Contrast Targets in Different Luminances
Part II – Complex 3-D scenes

Abstract
This paper measures the departures from perfect constancy with changes in luminance and contrast surrounds. Instead of the 2-D transparent displays used in Part I, these experiments use folded paper targets with printed reflectance patches. This paper targets are illuminated in direct light and shadow. The match results showed the same small decrease in matching value with large decreases in illumination level (low-slope behavior) found in Part I. Within the direct light and in the shade parts of the targets the matches showed the same high-slope contrast behavior. Here, the arrangement of reflectances, illumination and depth from binocular vision did not affect the appearance matches made by observers.

Introduction
In Part I observers matched the appearance of eight white, gray and black patches using different illuminances. The results showed that all matches fit two simple physical rules. First, the match for the highest luminance in the field of view decreased at a slope of 0.54 with luminance. Second, matches for darker areas decreased at a higher, background dependent, slopes with luminance (4.6 for white, 3.8 for gray and 2.6 for black). These experiments used uniform illumination with uniform transmittance patches. All matches were made to a standard target with maximum luminance of 1000 ft-L.

Part II studies the influence of uniform direct illumination and shade in a real 3-D 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 1). Observers matched these patches in both direct and shade illumination. This data can be used to assess whether real 3-D illuminations of scenes influence the appearance of matches. If humans discount the illumination, then these matches will differ from those reported in Part I. If instead, the matches follow the same two physical rules, then we will fail to find evidence for “Discounting the Illumination” in complex scenes due to recognition of the light sources.

Figure 1 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.
In trying to tease apart the mechanism of appearance it is essential to control the question presented to observers. McCann 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 documented this observation in experiments using display Mondrians. Hurlbert also makes this distinction in the analysis of Mach Card experiments. 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.

**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 Part I. Reflectance standard had lower luminance and lower dynamic range than the transmission standard. The luminance values 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].

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 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 illumination 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 2. Observers were asked to match test areas in the Mondrian background, the white background and the rectangles. In addition, they were asked to make additional matches within areas of uniform reflectance of the Rectangles target.

![Figure 2](image_url)

Figure 2 shows the standard, the Mondrian background, the white background, and the rectangles targets. Matches for the five test areas were estimated using the standard as a reference.
Results

Figure 3 plots the observer matches vs. luminance for the Rectangles test patch card. Figure 3a plots the matches for with the standard deviations for one observer; Figure 3b plots the results for a second observer.

Figure 3a plots the average of four trials ± the standard deviation for Mondrian, white and rectangles target for observer MAM. The legend identifies plots match vs. log luminance for the gray scale in direct light (slope =5.0) and in shade (slope =6.9). In addition, change in match for each area is plotted. The average slope is $0.59 \pm 0.23$. The individual slopes are $A=0.45$, $B = 0.34$, $C = 0.58$, $D= 0.64$, $E =0.95$.

Figure 3b plots the average of four trials ± the standard deviation for Mondrian, white and rectangles target for observer JMC. The legend identifies plots match vs. log luminance for the gray scale in direct light (slope = 5.2) and in shade (slope = 6.7). In addition, the change in match for each area is plotted. The average slope is $0.56 \pm 0.13$. The individual slopes are $A=0.43$, $B = 0.62$, $C = 0.43$, $D= 0.64$, $E =0.70$. 
Figures 3 show that both observers made very similar matches. Figure 4 plots the average of the data in Figure 3 and compares it with the average data from Part I with uniform illumination. In addition, Figure 4 plots average matches for two other folded cards with different backgrounds. The data from the circular spots on a white background and the same spots on a Mondrian background are plotted in Figure 4.

![White, Mondrian and Rectangular Targets](image)

Figure 4 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 Mondrian surrounds 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 (Figure 3). The average slope is 5.8. The lines are the predictions made in simple physical description described in Part I. The dot-dash line plots the Hipparchus line that predicts the matches for whites or local maxima. The solid white line plots the high-slope behavior found for white surrounds. The slope here is the average 5.8 found in this data, slightly higher than the 5.4 found in Part I.

Figure 4 shows there is very little difference between matches with a white, a Mondrian and the center of the rectangles targets. Further, the data fits very well the physical relationship described in Part I. 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). The darker patches fall on the 5.8 slope line, indicating that there is no difference between matches made in uniform illumination and real 3-D scenes. We find no evidence for discounting the illumination. 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 darker 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 (Spot and Rectangular patches). This fact is important because it shows why standard matching targets should use white surrounds. Surrounds with gray surrounds will not behave the same as complex images.

The target in Figure 2 are binocular variants of the Mach Card demonstration. These demonstrations have considerable variability with spatial content. The appearance matching experiments in this paper differ in three important 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. After all matches had been completed, observers were asked if they could make the card reverse using binocular vision. Both said they could not. Third, the question asked of observers was the artist’s palette problem 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 both said they could. They were then
asked if the reversal changed the appearance of the gray patches on the card. Both 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.

**Do uniform stimuli appear uniform?**

Additional matches were made along the rectangular patches as illustrated in Figure 5. 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 5 shows the diagram given observers to identify the test patch segment for matching.

Figure 6 plots the average matches each observer 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 patch (position 0.50); the next match was two-thirds the way up parch (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 patch (position 1.67); last match are in the white surround below the rectangles (position 1.85).

Figure 6 plots the matches along the rectangular patch for 5 target patches. The horizontal axis is the distance along the paper from white surround to fold at the center and on to the white surround on the other side.
The results in Figure 6 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 Hipparcus 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.

Discussion

The principle goal of these experiments is to measure the extent of constancy with changes in luminance. Part I studies constancy of flat uniform images, while Part II uses complex 3-D shapes in direct light and shade. To make these measurements we must use an experimental design that accurately quantities 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 would not accurately quantify the appearance. Two patches that look different could be assigned the same apparent reflectance. Such matches are appropriate for measuring how well human do at reflectometry, but do not help quantify the accuracy of appearance constancy match.

These experiments were designed to measure the magnitude of the phenomenon called “discounting the illuminant.” We performed extensive experiments to measure that changes in match with overall, uniform changes in illumination (Part I). We measured identical reflectance patches in direct and shadow illumination. We found no difference in observer matches in uniform illumination and real 3-D scenes. 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 darker that the maxima show a rapid change in match due to contrast [slope 5.4 (Part I) & slope 5.8 (Part II)]. Spatial comparisons of the test luminance and that of its surround control high-slope contrast responses. These simple low-level mechanisms are all that are necessary to explain luminance constancy in flat uniform and complex 3-D targets.

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 maxima in each color channel. This is shown by the fact that departures from perfect color constancy correlate with crosstalk between color channels. Such crosstalk is the result of spatial comparisons within a single set of receptors. Human vision normalizes images using maxima. This behavior is seen in color constancy, rod-Lcone color, and here in achromatic experiments.

Conclusions

This paper presents matches in a complex 3-D scene with direct illumination and shade. Observers matched three contrast targets to a standard. The effect of illumination was to decrease match along the low-slope (0.54) Hipparcus line. Observers matched the maximum in the field of view to this line. Image areas, less than the maxima, decreased with luminance at a much higher slope; 5.8 for the white surround, for the Mondrian surround and for the Rectangular targets. These matches were not consistent with the predictions of constancy implied by discounting the illuminant. The observers’ matches fit the simple two-step physical description of maxima, dependent on luminance, and other darker areas, dependent on spatial contrast.


