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Color Mondrian Experiments without Adaptation

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The McCann, McKee and Taylor (MMT) experiments[1] provided quantitative measurements of the change in color appearance caused by change in the L,M,S components of the illumination. These experiments provide a baseline for quantitative changes in appearance for color constancy conditions. The MMT experiments used the same display in all five cases, so that the average radiance of the entire field of view changed with the illuminant composition.

The experiments described in this paper uses the same papers and illuminants as in MMT. However, this time a new surround is added to exactly compensate for the shift in the average radiances caused by the change in illuminant. In other words, the new surround compensates for the new illuminant so that the color adaptation levels of observer are constant.

Two formats of surround were used in the experiments. First, the compensating surround was placed around the outside of the 17-area Mondrian. Second the compensating surround was placed around each individual area in the Mondrian. In both cases the color matches were found to be very similar to those measured in the original MMT experiment. The experiments show that both global and local adaptation conditions had minimal effect on the colors that the observers chose.

1. INTRODUCTION

Since the nineteenth century color constancy has been associated with the idea that a change in the color of the illumination in the outside world will trigger a change in the human response to light that will automatically compensate for that external physical change. Changes in visual response have been described in the literature and measured quantitatively. Many different mechanisms have been proposed as to how human vision makes this change in response: Helmholtz's 'psychological inference'[2], von Kries's "adaptation"[3], Hurlbert's "gray world"[4], modern Color Appearance Models' 'adaptation'[5], Land and McCann's normalization to the maximum in each of the L, M, S wavebands[6] and Ratio-Product-Reset models.[7]

The original MMT experiments can be explained by all of these mechanisms because the changes in illumination falling on the Mondrian, in a dark room, changed the average global stimulus. Yet, an adaptation, or a gray world mechanism, is a very different concept than a normalization to a maximum. The purpose of this paper is to design new Mondrian targets that hold adaptation constant. The logic is that, if the average quanta catch of the entire field of view is constant, then there can be no adaptation. Color constancy will <u>not</u> be observed, if its mechanism uses adaptation. Or, if color constancy is observed, its mechanism does not use adaptation.

2. EXPERIMENTS

The Mondrian displays[1] were illuminated uniformly with three different narrow band lights; 630 nm (long), 530 nm (middle), and 450 nm (short). The illuminant intensities for each of the five displays were chosen to compensate for one paper selected. The amount of long-, middle-, and short-wave illuminants were chosen such that the same triplet of radiances (L, M, S) comes from the gray paper in the initial illuminant; the red paper in illuminant 1; the green paper in illuminant 2; the yellow paper in illuminant 3; and the blue paper in illuminant 4.

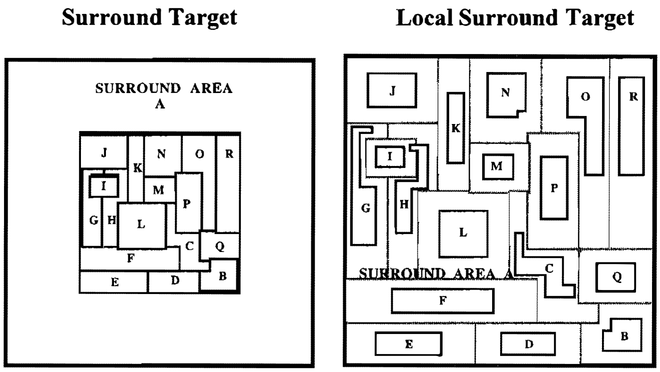

Figure 1. The left diagram is the Surround Target. Here the surround area is placed around the Mondrian. The right shows the Local Surround Target. Here the surround is placed around each individual area of the Mondrian. Solid lines show the papers; gray lines show a 2X Mondrian.

Finally, five different surround papers (See Fig. 1. - Surround Area A in Surround Target) were chosen for each of the five displays to compensate for the illuminant. The long-, middle-, and short-wave reflectances were chosen so that the same triplet of average radiances (AVL, AVM, AVS) came from the global average of each of the five targets.

Integrated radiances[1] is a measurement of radiance multiplied by the long-, middle and short-wave cone sensitivity functions of the human eye. Integrated reflectance is the ratio of the integrated radiance from a particular paper divided by those from a white paper. We measured the integrated radiance from each area in the Mondrian, in each illuminant. We measured the integrated reflectance of several hundred candidate papers in the appropriate triplet of illuminations. A computer program calculated the Total Average Radiance (TAR) for a large number of different papers, scaling the contribution of each paper based on its area. We normalized the calculation to the TAR GRAY in Table 1 setting this value to 100%. For the other targets, a value of 100.0 means that the new surround paper exactly compensates for the change in average due to the illuminant. We were able to find five papers, one for each target that were very close to exactly compensating for the change in average due to the change in illuminant. The names and values for the best five surround papers that were used in these experiments are listed in Table 1.

Table 1. Total Average Radiances for selected papers for each waveband.

TARGET	SURROUND PAPER	Total Average Radiances in percent LONG	MIDDLE	SHORT
TAR GRAY	N 6.25/	100.0	100.0	100.0
TAR RED	Color-Aid RVR Hue #2	100.0	106.4	98.2
TAR YELLOW	5 Y 8/14 Glossy	97.9	98.0	97.5
TAR GREEN	7.5 G 6/8 Glossy	95.6	97.5	98.6
TAR BLUE	Color-Aid B Tint 2	102.3	100.0	103.0

Thus we have constructed a set of five displays that have the same average over the entire field of view. Any measure of a global average or gray-world average describes the displays as identical. In addition, we have a particular paper in each display that sends to the eye identical triplets of radiances. As in the earlier Mondrian experiments, the papers have different reflectances and compensating illuminants. To what extent does the equivalence of the Total Average Radiance (TAR) for all five targets influence the observers' choice in matching color sensations?

A simple adaptation, or global gray-world model averages the quanta catch of the receptors over the entire field of view. Such a model predicts that the five papers will appear identical, because the radiance from each is identical and the Total Average Radiance is identical.

A normalization model, such as Ratio-Product-Reset model, predicts that the average radiance will have a small effect, but basically the papers will appear very similar to their appearance in the initial illuminant and initial surround. Both surround and illuminant will change the appearance of the five selected papers, but as measured in previous quantitative experiments[1], the magnitude of these effects will be small. The nonlinear reset is the underlying operation that causes the Ratio-Product-Reset model to behave independently of the average properties of the scene. It normalizes to the maximum in each waveband and is only secondarily responsive to the radiance.

3.0 RESULTS

The experiments described below measure the influence of Total Average Radiance. The first four columns of Table 2 describe the results. The first column identifies the area of the Mondrian to be matched. The second column identifies the reflectance (Munsell designation) of that area. The third column shows the Munsell designation of the average chip in the Munsell book chosen to match the Mondrian area for the original MMT target. The fourth column shows the Munsell designation of the average chip in the Munsell book chosen to match the Mondrian area (column 1) for the Surround target.

Table 2. For each target (column 1) the paper used if that area (column 2), the average paper chosen in MMT column 3), in the Surround Targets (column 4), in the Local Surround Targets (column 5), and the computed Ratio-Product-Reset predictions (column 6).

Target	Actual Reflectance	Matching Chip MMT	Matching Chip SURROUND	Matching Chip LOCAL SURROUND	Computed Match MMT
GRAY [Area P]	N 6.75/	5 YR 6/1	N 6.0/	N 6.5/	N 6/
RED [Area G]	10.0 RP 6/10	5 R 6/6	2.5 R 7/4	10 RP 7/4	5 RP 5/4
YELLOW [Area C]	5.O Y 8.5/10	5 Y 8/8	2.5 Y 8.5/8	2.5 Y 8.5/7	7.5 Y 7/8
GREEN [Area R]	2.5 G 7/6	10 G 7/4	2.5 G 7/3	5 GY 7/2	5 G 6/6
BLUE [Area H]	2.5 PB 6/8	2.5 PB 6/4	7.5 B 6/3	5 B 6/2	7.5 B 6/6

One could argue that the human visual system uses a local average mechanism rather than a global one. This assumption is more difficult to test because a local average hypothesis requires from its proponent a specific size, shape, and weighting function based on radius. One can develop alternative techniques to test the influence of local averages. Fig. 1 shows the Local Surround Target. It is made up of the same papers used in the Surround targets The papers are simply placed on the surround in a different location. Each area in the Mondrian is surrounded by the Surround A paper. Corresponding papers in all targets have the same shape and size. These new targets do not alter the physical measurements listed in Table 1; they only change the target in its local properties. Instead of surrounding the seventeen papers in the Mondrian with the paper, we changed the surround around each area of the Mondrian. This was done by simply placing each Mondrian paper in the center of the dimensions of a Mondrian twice as big.

We repeated the experiment described above and had observers match each area in each of the five Local Surround Mondrians. The five matches for the area in each target that sent the same radiance (L, M, S) to the eye are listed in Table 2 beside the matches from the Surround Targets.

4. CONCLUSIONS

These experiments test two hypotheses. First, whether human vision uses adaptation processes, or average quanta catch, in color constancy. In this series of Mondrians, unlike the original set, there is no change in the average quanta catch, so there can be no adaptation. If adaptation controls color constancy, then all five patches in Table 3, column 4 should appear identical. The triplet of radiances at each patch are all identical. The total average radiances of the each display are all identical. Nevertheless, the observers chose 5 very different colors: gray N/6, red 2.5R 7/4, yellow 2.5Y 8.5/8, green 2.5 G 7/3 and blue 7.5B 6/6. Color constancy is not controlled by adaptation, based on the quanta catch of the receptors.

The second hypothesis is whether the color constancy can be predicted by nolmalization to the L, M, S maxima. This hypothesis predicts that each patch will appear different, and essentially the same as in MMT. In Table 2. the comparison of MMT data in the third column with Surround Data in the fourth show that they are very similar. The data supports the L M, S normalization hypothesis.

Returning to Table 2, the fifth column shows the Munsell designation of the average chip in the Munsell book chosen to match the Mondrian area in the Local Surround targets. The Surround A papers are the most saturated papers we could find. We placed them so as to completely surround each area of the Mondrian. Even when changing the local surround as much as possible with papers, there was no significant change in the observer's color matches from the Surround Target. The observers again chose 5 very different colors: gray N 6.5, red 10RP 7/4, yellow 2.5Y 8.5/7, green 2.5 G 7/2 and blue 5B 6/6.

The final column in Table 2 shows the Munsell designation of the chip in the Munsell book calculated to match the Mondrian area for the original target.[1] The nonlinear reset is the underlying operation that causes the Ratio-Product-Reset model to behave independently of the average properties of the entire field of view. It normalizes to the maximum in each waveband and is only secondarily responsive to the average properties of the image. The Ratio-Product-Reset model chose 5 very different colors: gray N 6., red 5RP 5/4, yellow 7.5Y 7/8, green 5 G 6/6 and blue 7.5B 6/6. The Ratio-Product-Reset model is able to calculate satisfactory predictions of observer color matches.

Both the Surround and the Local Surround experiments show that color constancy is controlled by a normalization process. Further these experiments shows no evidence to support an adaptation process that averages quanta catch in the image.

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