Magnitude of Color Shifts from Average-Quanta Catch Adaptation

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Abstract

The 18 Area Color Mondrian Experiments by McCann McKee and Taylor (MMT)[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 five different illuminants. Therefore, 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 shift the average radiances as much as the illuminant changed the average quanta catch. In other words, the *new illuminant-equivalent-adaptation surround* in constant illumination changes the adaptation the same amount as did the new illuminant. The question is, how much will adaptation change color appearance.

Adaptation Hypothesis

When we observe a single spot of light, and we change in quanta catch, we change the color appearance substantially. When we observe a complex display, and we change the quanta catch everywhere, we change the color appearance a very small amount. Color Constancy describes the fact that colors stay very nearly the same when a display is viewed in different illuminations. The quanta catch at the receptors cannot explain Color Constancy. The addition of an average of quanta catches, as a normalization factor, generates a relative quanta catch that is consistent with color sensations

The following experiments actively test the effects of changes in average quanta catch. The adaptation idea is that a change in illumination changes the quanta catch at each pixel. The average quanta catch can be used to normalize the quanta catch at each pixel, so as to change the colors back.. It seems logical that the changes in the average quanta catch could shift the colors back. If this hypothesis is correct, then changes in average quanta catch, without a change in illumination, should cause a measurable color shift. These experiments measure the magnitude of color shifts caused by average-quanta-catch adaptation.

The original Mondrian display made of 18 different Munsell papers. These display targets were illuminated uniformly, with three different narrowband lights; 630 nm (long), 530 nm (middle), and 450 nm (short). The illuminant intensities for each waveband were adjustable. The first of five experiments was called the Gray experiment. Here the experimenter measured the long-, middle-, and short-wave radiances (L, M, S) from the gray area P. In the next, Red experiment, the experimenter measured the radiance from a red paper. In long wave light the red paper reflected more light: the experimenter reduced the intensity of the illumination across the whole field of view until the long-wave radiance was equal to L. Similarly, the experimenter adjusted the middle-, and short-wave radiances to equal M, and S. Now the red paper (Area G) sent the same radiances as a moment before came from the gray paper. The observer chose a red paper

5R5/6 to match L, M, S in the red experiment, compared with a gray paper 5YR6/1 in the gray experiment. The differences in match from identical quanta catches on the retina in Munsell space was 3 pages in Hue, the same lightness and 5 units in chroma. The experiment continued with blue, green and yellow papers. In all five different illuminants were chosen to compensate for the five paper selected. The amount of long-, middle-, and short-wave illuminants were chosen such that the same triplet of radiances (L, M, S) came 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. In each case, the observer picked papers very different from gray. The list of papers chosen and the color shift from gray is shown in Table 1.

McCann, McKee and Taylor Data							
	Matching				Color Shift		
Experiment	H	H#	L	C	H	L	C
Gray	5.0 YR	5	6	1			
Red	5.0 R2	2	6	6	**-3**	**0**	**5**
Blue	2.5PB	29	6	4	**-16**	**0**	**3**
Green	10.0GY	16	7	4	**11**	**1**	**3**
Yellow	5.0Y	10	8	8	**5**	**2**	**7**
H=Hue, L=Lightness, S=Saturation							

Table 1. The list of experiments, the papers chosen to match a single triplet of radiance on the retina (L, M, S); the page number in the Munsell Book; the lightness; chroma; the color shift from the match in the gray experiment expressed in pages of hue; lightness units; and chroma units.

The obvious conclusion is that a very wide range of color appearances are generated from a single triplet of quanta catches. The color shifts from gray cover nearly the entire gamut of colors.

The purpose of this paper is to experimentally measure the influence of adaptation on these results. As described above, one can make a case that the original MMT experiment allowed the average quanta catch to vary. It had to because the illumination changed uniformly across the field of view. In these experiments we will leave the illumination constant. We will however, change the average radiance as much as it would have if we did change the illumination. We can do this by finding a new surround paper that shifts the average. If Color Constancy uses the average quanta catches, then we would expect substantial color shifts. If Color Constancy is indifferent to average quanta catches, then nothing will happen.

Experiments

The first of two formats of surround used in these experiments is shown in Figure 1. The *illuminant-equivalent* surrounds were placed around the outside of the 17-area Mondrian used in MMT experiments.

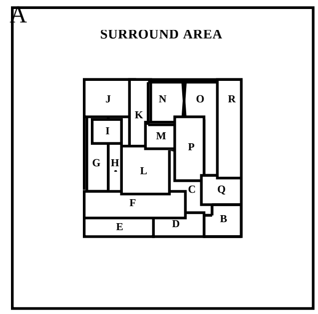

Figure 1. The surround Area A is much larger than that used in MMT. The 17 Mondrian papers were placed in the center of a target the same dimensions as MMT. The horizontal and vertical dimensions of these 17 papers were 50% the original, or 25% the area. The new surround made up 75% of the 30-degree display. The field of view outside the surround was masked to have no light.

The problem now becomes one of selecting papers that are equivalent to changing the illuminant. We used a three-step procedure to measure the change in average quanta catch. It is illustrated in Figure 2. Step 1 is a calibration process. We used the same illumination box as described by McCann, McKee and Taylor, as well as the same illumination levels. We used the same telephotometer fitted with spectral filters that allowed us the measure Integrated radiances that were proportional to the quanta catches of the cones in the retina.

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. A computer program calculated the average radiance for all areas in the Mondrian, scaling the contribution of each paper based on its area. The output of this program was AVL, AVM, AVS. - the average quanta catch for each cone type.

The second step is to measure the new average radiances with the new illumination (ILL1, ILM1, ILS1). This second measurement gave new average Quanta Catches AVL1, AVM1, AVS1.

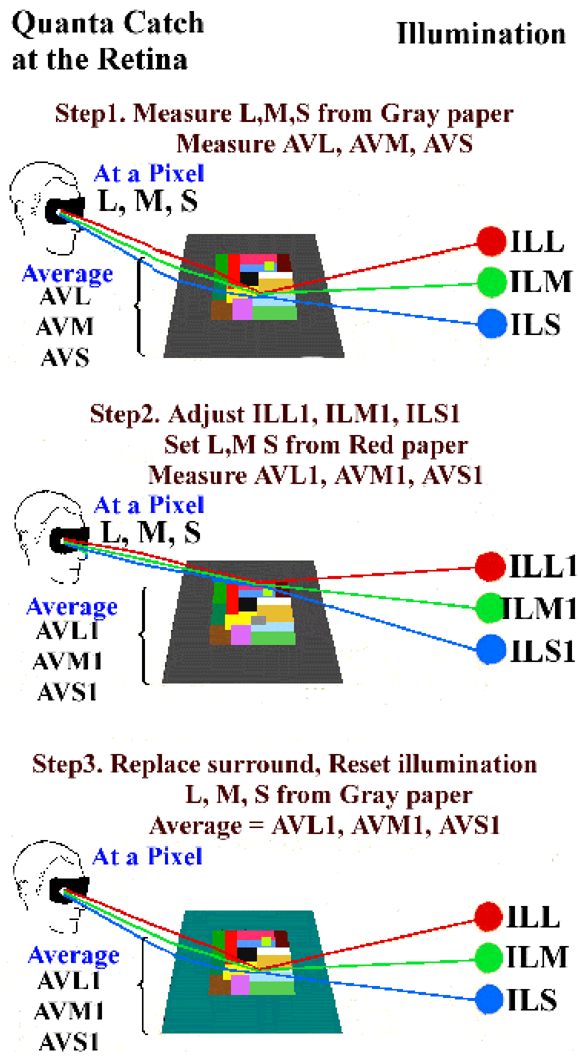

Figure 2. The illustrations of how surround papers were chosen.

The third and final step was to search for a new paper that changed the average quanta catches as much as the illumination did in step 2, but using the illumination in Step 1. We measured the integrated reflectance of several-hundred candidate papers in the five illuminations.

The best papers are listed in Table 2. The papers average radiance for the Gray Mondrian in Red illumination (AVL1, AVM1, AVS1) was the aim for the Red Experiment. The average radiance for the aim and for the best fit (G Tint 1) are listed. The difference and percent aim are listed as well. In the red experiment the aim and fit are very close (107%, 95%and 108%). We were able to find five papers, one for each target that were very close to compensating for the change in average due to the change in illuminant (Table 2).

	Surround		Aim	Fit	Differnce	Percent
Gray	ColorAid 8					
Red	G tint1	AVL1	28.91	30.85	-1.94	107%
		AVM1	42.3	40.29	2.01	95%
		AVS1	21.56	23.2	-1.64	108%
Green	CA NavyBlue	AVL2	17.32	14.8	2.52	85%
		AVM2	11.29	13.74	-2.45	122%
		AVS2	15.99	13.23	2.76	83%
Yellow	CA B hue	AVL3	8.2	15.6	-7.4	190%
		AVM3	8.43	16.03	-7.6	190%
		AVS3	34.6	36.44	-1.84	105%
Blue	CA YO Sh3	AVL4	23.96	24.17	-0.21	101%
		AVM4	18.51	22.44	-3.93	121%
		AVS4	9.05	13.75	-4.7	152%

Table 2. The data on the papers used as surrounds. The first column lists the experiment, the second lists the paper designation used in the surround, the third list the illumination designation, fourth lists the aim average radiances from the gray target., the fifth lists the actual measured average radiance, the sixth lists the difference and the seventh lists the percent aim.

Five different surround papers were chosen for each of the five displays. Each surround changes the average radiance. The average radiance change is equivalent to the illumination shifts used in MMT. The long-, middle-, and short-wave reflectances were chosen so that the five triplets of average radiances (AVL, AVM, AVS; AVL1, AVM1,. …AVS4) simulated the changes due to illumination.

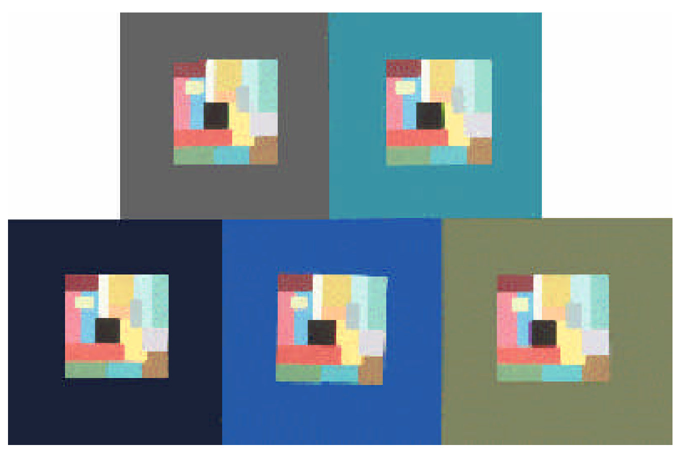

Figure 3. The five different Color Mondrians that change the average Quanta Catch as much as changing the illumination.

Thus, we have constructed a set of five displays that have the five different average quanta catches over the entire field of view. These targets are shown in Figure 3.

Using the same apparatus and procedures described by MMT, we asked two observers to match each area in each of five Mondrians. Any measure of a global average or gray-world average describes these displays as identical to the same display in five different illuminants. To what extent does Average Radiance (AVL, AVM, AVS) influence the observers' choice in matching color sensations?

Results

The experimental measure of the effect of average quanta catch adaptation is zero. If the *illumination equivalent-surrounds* shifted the match as much as the original Mondrian experiments, then we would have expected hue shifts of -3, -16, 11 and 5 pages in the Munsell book. The measured shifts were 0.2, 0.2, -0.1, -0.2 pages. The expected chroma shifts were 6, 4, 4, 8. The measure shifts were -0.2, -0.1, -0.7, -0.1 units of chroma. The detailed results are shown in Table 6.

Two observers matched each area in all five Mondrians. The Gray Mondrian (upper left Fig3) was the baseline. It was sequentially compared to the four other Mondrian matches. The difference between matches of Area B in the Red and Gray experiments was averaged with the difference between matches for Areas C,D…R. These average and standard deviation are shown in Table 3. The data is presented as differences in Hue [Pages], Lightness [Units], and Chroma [Units].

Average Shift in Munsell Space									
	Hue			Lightness			Chroma		
	[Pages]			[Units]			[Units]		
Red	*0.2*	±	*1.6*	*-0.1*	±	*0.6*	*-0.2*	±	*1.4*
Blue	*0.2*	±	*1.1*	*-0.1*	±	*0.5*	*-0.1*	±	*1.1*
Green	*-0.1*	±	*0.7*	*-0.2*	±	*0.6*	*-0.7*	±	*1.6*
Yellow	*-0.2*	±	*1.0*	*-0.1*	±	*0.5*	*-0.1*	±	*1.3*

Table 3. The average shift in match measured in the experiment. The first column lists the Mondrian compared with Gray. The Hue, Lightness, and Chroma columns list the average and standard deviation of color shifts. There is no significant shift from zero. AVL, AVM, AVS have no affect on color appearance.

Local Surrounds

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. Nevertheless, one can develop alternative techniques to test the influence of local averages. Figure 5 shows the Local Surround Target. It is made up of the same papers used in the Surround targets. The papers are 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 2; 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. Each Mondrian paper is 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.

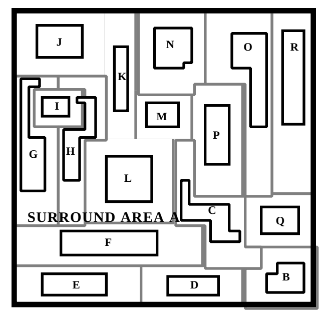

Figure 5. The Local Surround Target. Here the surround is placed around each individual area of the Mondrian. Solid lines show the papers; gray lines show a 2X Mondrian.

Just as in the Unspaced Mondrians described above, two observers matched each area in each of five Local Surround Mondrians. The results are the same as with the Unspaced Mondrians. The results are shown in Figure 5.

Average Shift in Munsell Space									
	Hue			Lightness			Chroma		
	[Pages]			[Units]			[Units]		
Red	*0.2*	±	*1.6*	*-0.1*	±	*0.6*	*-0.2*	±	*1.4*
Blue	*0.2*	±	*1.1*	*-0.1*	±	*0.5*	*-0.1*	±	*1.1*
Green	*-0.1*	±	*0.7*	*-0.2*	±	*0.6*	*-0.7*	±	*1.6*
Yellow	*-0.2*	±	*1.0*	*-0.1*	±	*0.5*	*-0.1*	±	*1.3*

Table 5. The average shift in match measured in the experiment. The first column lists the Mondrian compared with Gray. The Hue, Lightness, and Chroma columns list the average and standard deviation of color shifts. There is no significant shift from zero. AVL, AVM, AVS have no affect on color appearance.

	Gray		USP		*Red*		USP		*Blue*		USP		*Green*		USP		*Yellow*		USP	
AREA	*H*	*Hn*	*L*	*C*	H	Hn	L	C	*H*	*Hn*	*L*	*C*	H	Hn	L	C	*H*	*Hn*	*L*	*C*
A	N	0	8.8	0	2.5 G	17	7	8	2.5 Y	9	6	6	N	0	3	0	5.0 PB	30	5	10
B	5.0 YR	6	6	8	7.5 YR	7	6	10	7.5 YR	7	6	10	7.5 YR	7	6	6	7.5 YR	7	6	10
C	7.5 Y	11	9	10	7.5 Y	11	9	10	5.0 Y	10	9	8	5.0 Y	10	9	8	7.5 Y	11	9	10
D	7.5 G	19	8	6	7.5 G	19	7	4	7.5 G	19	7	6	7.5 G	19	7	6	2.5 G	17	7	6
E	5.0 GY	14	7	10	7.5 Y	11	7	8	5.0 GY	14	7	10	5.0 GY	14	8	6	2.5 GY	13	7	8
F	5.0 R	2	6	10	5.0 R	2	5	12	5.0 R	2	5	12	5.0 R	2	5	12	7.5 R	3	5	12
G	7.5 RP	39	6	10	5.0 R	2	7	8	10.0 RP	40	6	10	10.0 RP	40	6	10	10.0 RP	40	6	10
H	10.0 B	28	7	6	5.0 PB	30	6	6	10.0 B	28	7	6	2.5 PB	29	7	6	10.0 B	28	7	4
I	2.5 GY	13	9	8	7.5 Y	11	9	8	2.5 GY	13	9	6	2.5 GY	13	9	6	10.0 Y	12	9	8
J	10.0 RP	40	4	8	10.0 RP	40	4	8	7.5 RP	39	4	8	7.5 RP	39	4	8	7.5 RP	39	4	6
K	N		9.7	0	N		9.5	0	N		9.7	0	N		10	0	N		9.5	0
L	N		1.3	0	N		1.25	0	N		1.3	0	N		1	0	N		1.8	0
M	5.0 Y	10	8.5	10	5.0 Y	10	8.5	12	5.0 Y	10	8.5	10	2.5 Y	9	9	8	5.0 Y	10	8	12
N	2.5 YR	5	7	10	5.0 YR	6	7	10	2.5 Y	9	7	10	5.0 YR	6	7	10	5.0 YR	6	7	10
O	5.0 B	26	8	4	10.0 B	28	9	1	5.0 B	26	9	2	5.0 B	26	8	2	5.0 B	26	9	2
P	N		7.5	0	N		6.75	0	N		6.5	0	N		7	0	N		6.5	0
Q	10.0 P	36	8	4	5.0 RP	38	8	4	2.5 RP	37	8	4	7.5 P	35	7	6	10.0 P	36	8	4
R	2.5 G	17	8	6	7.5 GY	15	9	6	10.0 GY	16	8.5	6	10.0 GY	16	9	4	7.5 GY	15	8.5	6

	Gray		SPACED		*Red*		SPACED		*Blue*		SPACED		*Green*		SPACED		*Yellow*		SPACED	
AREA	*H*	*Hn*	*L*	*C*	H	Hn	L	C	*H*	*Hn*	*L*	*C*	H	Hn	L	C	*H*	*Hn*	*L*	*C*
A	N	0	6.5	0	2.5 G	17	7	8	2.5 Y	9	6	6	N	0	3	0	5.0 PB	30	5	10
B	5.0 YR	6	6	8	7.5 YR	7	6	10	7.5 YR	7	6	10	7.5 YR	7	6	6	7.5 YR	7	6	10
C	7.5 Y	11	9	10	7.5 Y	11	9	10	5.0 Y	10	9	8	5.0 Y	10	9	8	7.5 Y	11	9	10
D	7.5 G	19	8	6	7.5 G	19	7	4	7.5 G	19	7	6	7.5 G	19	7	6	2.5 G	17	7	6
E	5.0 GY	14	7	10	7.5 Y	11	7	8	5.0 GY	14	7	10	5.0 GY	14	8	6	2.5 GY	13	7	8
F	5.0 R	2	6	10	5.0 R	2	5	12	5.0 R	2	5	12	5.0 R	2	5	12	7.5 R	3	5	12
G	7.5 RP	39	6	10	5.0 R	2	7	8	10.0 RP	40	6	10	10.0 RP	40	6	10	10.0 RP	40	6	10
H	10.0 B	28	7	6	5.0 PB	30	6	6	10.0 B	28	7	6	2.5 PB	29	7	6	10.0 B	28	7	4
I	2.5 GY	13	9	8	7.5 Y	11	9	8	2.5 GY	13	9	6	2.5 GY	13	9	6	10.0 Y	12	9	8
J	10.0 RP	40	4	8	10.0 RP	40	4	8	7.5 RP	39	4	8	7.5 RP	39	4	8	7.5 RP	39	4	6
K	N		9.7	0	N		9.5	0	N		9.7	0	N		10	0	N		9.5	0
L	N		1.3	0	N		1.25	0	N		1.3	0	N		1	0	N		1.8	0
M	5.0 Y	10	8.5	10	5.0 Y	10	8.5	12	5.0 Y	10	8.5	10	2.5 Y	9	9	8	5.0 Y	10	8	12
N	2.5 YR	5	7	10	5.0 YR	6	7	10	2.5 Y	9	7	10	5.0 YR	6	7	10	5.0 YR	6	7	10
O	5.0 B	26	8	4	10.0 B	28	9	1	5.0 B	26	9	2	5.0 B	26	8	2	5.0 B	26	9	2
P	N		7.5	0	N		6.75	0	N		6.5	0	N		7	0	N		6.5	0
Q	10.0 P	36	8	4	5.0 RP	38	8	4	2.5 RP	37	8	4	7.5 P	35	7	6	10.0 P	36	8	4
R	2.5 G	17	8	6	7.5 GY	15	9	6	10.0 GY	16	8.5	6	10.0 GY	16	9	4	7.5 GY	15	8.5	6

Table 6. The average matching data for all ten Mondrians. The top set shows the results for the Surround Experiments illustrated in Figure1. The lower set shows the results from the Local Surround Experiments. Each subsection lists the Hue name, Hue number, Lightness and Chroma.

As with the first set of experiments, we find no evidence of a color shift, despite the fact that the surround encapsulates each area. We again find no evidence that AVL, AVM, AVS controls color appearance.

Discussion

These experiments test two hypotheses. First, they test 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 illumination; but the different surround gave the same adaptation. If adaptation controls color constancy, then there should be significant shifts of color matches. Color constancy is not controlled by adaptation based on the average quanta catch of the receptors.

The second hypothesis is whether the color constancy can be predicted by normalization to the L, M, S maxima. This hypothesis predicts that each patch will remain constant because the maxima did not change. The data supports the L. M, S normalization hypothesis.[2,3]

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

Acknowledgment

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