Rules for colour constancy

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Colours of objects tend to be constant regardless of the colour of the illuminant, therefore, regardless of the quanta catch of the retinal cones. Various mechanisms for this including context recognition, adaptation of retinal sensitivities and independent processing by receptor types have been proposed. These present experiments test the hypothesis that colours are determined by the normalized relationship between all colours in the field of view. In this hypothesis, colours are constant in classical experiments simply because changes of the illuminant do not disrupt the relationship between quanta catches across the field of view. The experiments consist of making sets of colour displays; each with the same relative quanta catches, but different absolute reflectances. 'Colour tatami' arrays of five colour patches were printed using controlled amounts of yellow, magenta, cyan and black toners. The experiment began with a control 'colour tatami' array of reflectances with measured relative quanta catches. New arrays of colours were then chosen that increased (or decreased) the reflectances, and quanta catches, a constant amount for the entire array. These changes were done independently for each receptor type. When these 'colour tatami' are viewed in the room, each array has a different set of colours. When viewed in a restricted field of view, all arrays appear the same. In a further experiment new areas such as white are added to the display. Colour constancy is a field phenomenon controlled by the relative quanta catches in the field of view. Absolute colour constancy is controlled by the relative quanta catches in the field of view and the absolute quantum catches of the receptors.

Contrasts in Vision is a fitting title for the many contributions to vision science made by Fergus Campbell. Contrast is also the central idea in these demonstrations on colour constancy prepared for the Festspiel. The purpose of the demonstrations is to highlight the small changes in appearance produced by global changes in receptor quanta catch, and to compare them with the large changes in appearance produced by local changes in receptor quanta catch. This difference between global and local changes in quanta catch is a basis for understanding colour constancy.

Imagine two complex displays of the same size, which send to the human eye arrays of light measurable pixel by pixel. Imagine that two arrays send to the eye light that causes an identical quanta catch for each corresponding point on the retina. It is not difficult to suppose that these two arrays will look absolutely identical. They will exhibit colour constancy because the human photoreceptors respond to both in the same manner. This is true regardless of the reflectance and illumination spectra. For this argument, the product of reflectance and illluminant is crucial, but either component is unconstrained. Thus, the first hypothesis to be tested in this demonstration is that exact colour constancy is achieved by exactly equal quanta catches everywhere in the field of view.

Next the relative magnitude of colour appearance changes due to local and global display changes is examined. Local changes are defined as changes in quanta catch of different pixels in the field of view by different amounts, and global change is defined as changing the quanta catch of all pixels by the same amount.

These demonstrations show that local and global effects are different. Equal changes in quanta catch do not cause equal changes in appearance for local and global changes.

Method

The viewing apparatus consists of two boxes. Each box was made of a cardboard shoebox approximately 15 x 12 x 32 cm, two black 35 mm plastic film containers, a plastic lens, a 5 x 5 cm piece of black velour paper, a piece of diffuse drafting velum and a Kodak Wratten Color Correction filter, as illustrated in Figure 1.

Light enters the apparatus through a 9 cm square hole cut in the cardbox box top. The diffuse drafting velum is taped over the hole to diffuse the light. Kodak Wratten filters are used to control the intensity and spectral composition of the light inside the viewing box. The displays are attached to the inner wall of the box opposite the viewing aperture. The displays are 7 cm square; with four patches 2.5 x 4.5 cm and a centre patch 2 cm square. The aperture is made by glueing a 1.5 cm thick piece of wood to the end wall of the box and cutting a 2.5 cm diameter hole through it in the centre of the box face. Two black 35 mm film containers with the bottoms removed are force fitted into the hole, one outside and the other inside the box. The black velour paper is rolled with the flocked surface inside and inserted into the film containers. A 1.7 D plastic lens is attached to the outside film container. The black velour lining for the viewing tube is an important part of the apparatus, without it specular reflection of the inside of the tube creates patches of high quanta catch and alters the results of the experiment. It restricted the field of view within the shoe box to a circular field ~ 3 degrees diameter.

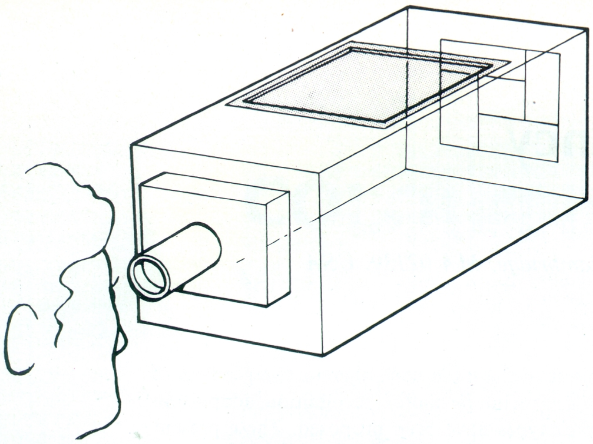

Figure 1 Assembly of the shoebox viewing apparatus (after Maximov)

The displays are illuminated by holding the box at a 45 degree angle near a window.

All displays used in the experiment were made using a Canon Color Laser Copier (CLC 500). The colour of each patch was created by specifying a digit between O and 100 for each of cyan, magenta, yellow and black toners 7 using a Minolta Chroma Meter CR22 1 to measure their chromaticity and L* value.

Experiment I

A Wratten colour correction 40R filter was selected for one box and a 40C for the other. They have chromaticities of x = 0.35, y = 0.32 (40R) and x = 0.27, y = 0.30 for 40C. The shift in character is Ax = 0.08, Ay = 0.02. The observers were asked to hold the filter close to their eye and compare the appearance with no filter, 40R and 40C. They reported that the world looks neutral, warm and cool as a result of the filter shifting the quanta catch of

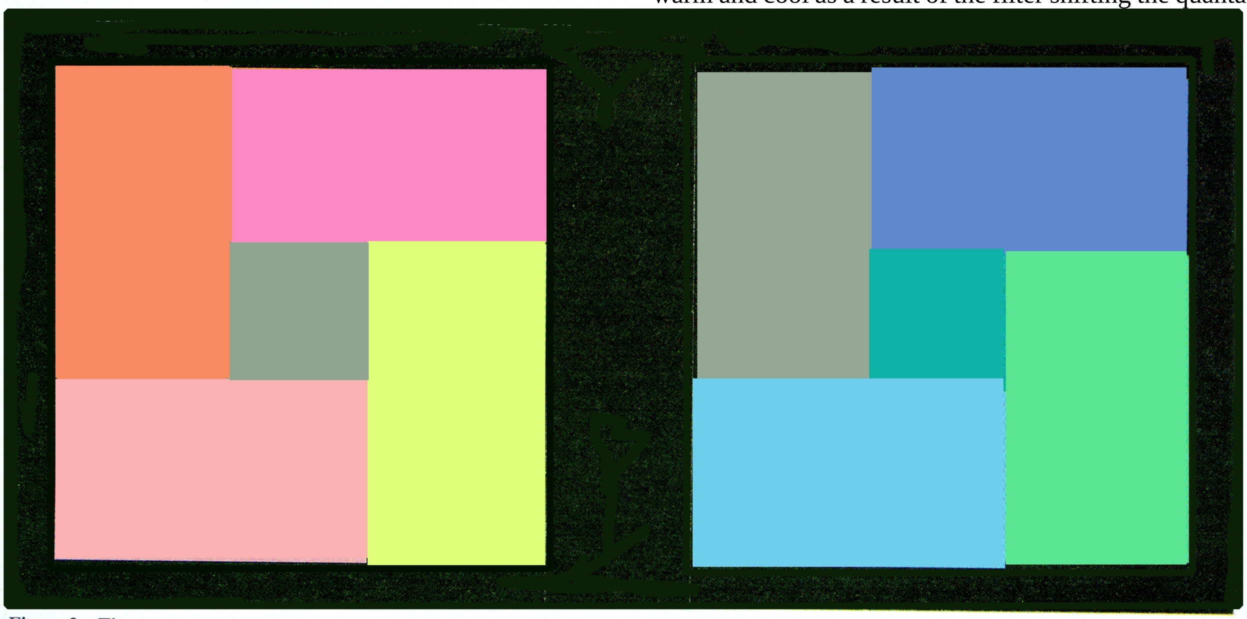

Figure 2 The warm papers make-up tautomi A; the cool papers make-up tautomi B

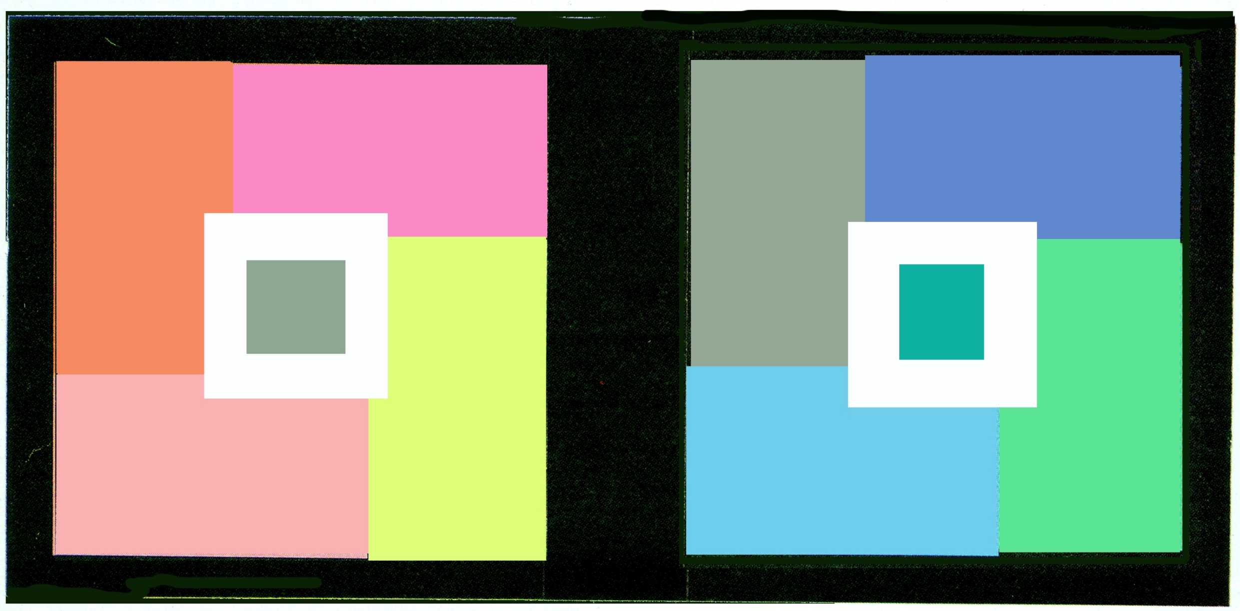

Figure 3 The warm patches make-up tautomi Aw; the cool papers make-up tautomi Bw

Table I Chromaticity data for tatami A and tatami B

	Tautomi A		Tautomi B				
	x	y	x	y	Δx	Δy	ΔL
Top right	0.38	0.33	0.30	0.32	0.08	0.02	10.9
Bottom right	0.34	0.31	0.26	0.29	0.08	0.02	9.2
Bottom left	0.35	0.39	0.28	0.35	0.07	0.04	16.3
Top left	0.33	0.27	0.25	0.25	0.08	0.02	17.0
Centre	0.30	0.32	0.22	0.30	0.08	0.02	14.4

all receptors in the field of view by the same amount. The magnitude of the change is small. Objects do not change their colour names; neutrals take on a warm or a cool cast.`The general conclusion is that these colour filters are relatively weak and do not change colour appearance sign)ficantly.

Experiment 2

Using the CLC 500 Laser Copier and the Minolta Colorimeter, two sets of five papers separated in colour space by x = 0.08, y = 0.02 were made. Table-l lists the chromaticity of all five areas in tatami A and tatami B. This data shows that all of the coloured papers in A are shifted by the same amount in CIE space. The amount of the shift is equal to the shift caused by changing from a Wratten 40R to a Wratten 40C.

Tatamis A and B have particular properties. The relationship of any particular paper in A to all other papers in A is the same as for the corresponding paper in B to all other papers in B. The quantum catch for the cones in the retina for all of A is proportional to that of all of B. Only the absolute values of quanta catch vary. Relatively, they are the same.

When we combine the colour illuminant Wratten 40C filter with the tatami A and the Wratten colour correction 40R with the tatami B, we have two nearly identical displays. The 40R colour correction shifts the reflected light from all of the patches towards higher x values but all the papers in tatami A have lower x reflectance values. The opposite is true for colour correction 40R and tatami B. Since the two displays have identical chromaticities at corresponding points, everywhere in the field of view, they must appear the same.

The experiment is to view tatami A with filter 40C in box 1 and tatami B with filter 40R in box 2 and compare the colour appearance. All observers at the Festspiel, except one, reported that the colour display in box 1 and box 2 were very similar. The table shows small experimental errors and observers reported corresponding small differences between tatami A and tatami B. In general, most observers saw the tatami in their display boxes before they saw them in the room. When they removed the cover of the box they were pleasantly surprised by how different these colours appeared in the room. The tatamis are reproduced in Figure 2.

Regardless of the visual surprise, Experiment 2 like Experiment I is a control. No one should be intellectually surprised by the fact that two displays appear the same when pixel by pixel they send to the eye very nearly the same quanta catch for the cones.

Experiment 3

This experiment replaces tatomis Aand B with tatomis Aw and Bw, (Figure3), these are identical to A and B except that a 0.6 cm band of white (no toner) is added in the centre of the target.

If the white influences the appearance of all colours in the field of view, then the corresponding areas in tatami Aw and Bw should no longer match. If this is the case it is a strong argument for colour appearance, i.e. colour constancy, to be an imagewise relativistic property; colours are constant when they have the same relative value to everything in the field of view.

If the fundamental determinant of colour appearance is quanta catch, then the small white frame should have a small effect on appearance. Except for whites, every other pixel in the field of view is identical in A and Aw; B and Bw. Compare the influence of the white on tatamis A and B in Figure 2 with Aw and Bw in Figure 3.

Results

At the Festspiel observers reported two sign)ficant findings. First, the presence of the white sign)ficantly altered the appearance of the other areas in the display. Instead of appearing nearly identical, they appeared nearly the same as they do in the room. Second, the white in illuminant Wratten 40R did not look the same as the white in Wratten 40C. Just as in viewing the room with these filters (Experiment 1) the whites take on a warm cast with 40R and a cool cast with 40C.

Discussion

The fact that the colour appearances changed significantly after the introduction of the white band, supports the early Retinex mechanisms using a white reference calculation] 2. The fact that the observer noted the change and colour appearance of the white supports mechanisms that recognize small appearance changes due to changes of overall quanta catches2 3. The changes in colour appearances (colour names) are consistent with the colours expected by normalizing each receptor set independently to a white reference. In other words, the colours observed are consistent with the Retinex model.

In summary, the rules for experimental colour constancy are:

1. Exact colour constancy is achieved by exactly equal quanta catches everywhere in the field of view.
2. Global changes in quanta catch cause small appearance changes.
3. Local changes in quanta catch cause large appearance changes.
4. In a complex field of view:

a. Whites manifest subtle global changes (aperture colour)

b. The rest of the image manifests dramatic local changes (object colour). Colours demonstrate normalization of each waveband separately (Retinex).

c. Colours demonstrate normalization of each waveband separately (Retrinex).

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