Perception differences of systematic and statistic colour distortions

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Introduction

Nowadays the LED light sources gain ground, thanks to their favourable operation parameters (e.g. little power consumption, long lifetime, robust construction). However these light sources often distort the illuminated object's colour appearance. Colour compilations that provide a pleasant colour sensation in daylight can induce disturbance in other illuminations. The size of such distortions that are still acceptable to the human observer, is an open question.

My research deals with the question, what kind of distortions and how large distortions are acceptable for an average human observer. To test these I took a coloured image and tested how large systematic or random distortions of the single coloured patches would the observer accept.

I started from the supposition that if the distortion of all coloured patches in a colour composition are systematic, the impression on the human observer will be different from that if the distortions are non-systematic.

Under systematic distortion I understood distortions that move in colour space all in the same direction, e.g. the colour of all patches increases in lightness, or changes by the same hue angle.

Experimental setup

To test above assumption I started from an image used for similar purposes in printing research by John McCann[1]. This test image consists of a number of coloured patches that are arranged is such a form that inner patches seem to resemble a children's pinwheel, see Figure 1.

Figure 1: McCann's children's pinwheel test image

I have prepared an electronic copy of this image on a calibrated CRT monitor. I used a CRT monitor, because this type of monitor permits wider visual angle of observation without any further colour distortion (LCD monitors, even modern types, are still show colour changes if not viewed exactly perpendicularly). My program enabled the setting of the colour of every patch independently. For the original colouration I tried to stay as far as possible near to those tristimulus values as used by McCann as well. The only restriction was, that as I wanted to change afterwards the colour of the single patches, non of the selected colours was set to be very near to the colour boundary of the monitor gamut, so that later one could set colours also in the direction nearer to the gamut boundary.

The next question was, how to define the colour distortions. My intention was to enable equal distortions in every part of the colour gamut, thus I selected a uniform colour space to describe my colours and their change. One of the best such spaces is the CIECAM02 colour space defined by the CIE colour appearance model[2]. In this space one has the possibility to define directions according to perception attributes: lightness/brightness, chroma and hue, as shown in Figure 2. (Lightness is used for surface colours, brightness for self-luminous colours, but the images on the computer screen were presented in a grey background, so the looked like pseudo-surface colours.)

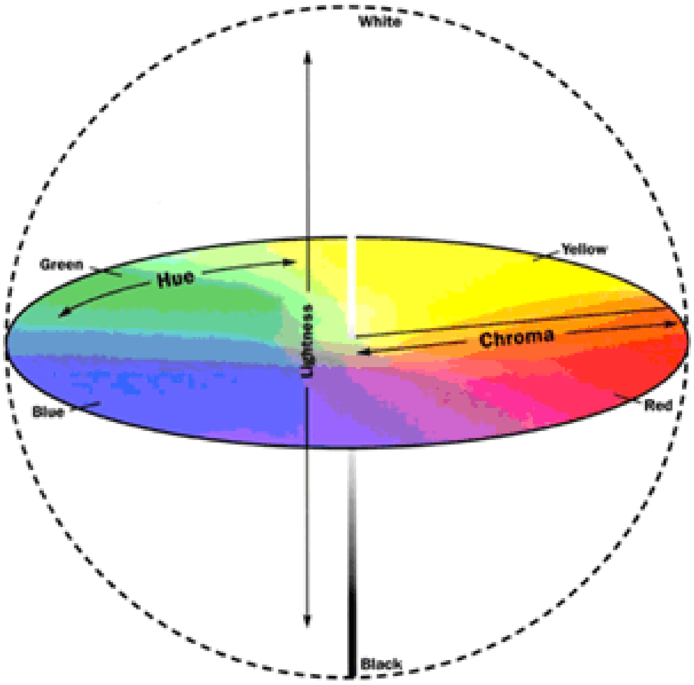

Figure 2: Lightness, chroma and hue angle in the CIECAM02 colour space

My program calculates colour differences in the CIECAM02 model. One can define independently differences in lightness, chroma and hue angle. The program that produces a second picture where the colour of every patch got changed by this amount of lightness, or chroma or hue angle, systematically, if e.g. increase of lightness was defined, the lightness of every patch increased. But at the same time also a third picture was generated, where the lightness, or chroma or hue angle was changed stochastically, for one patch with the same sign, as prescribed, and for an other with the opposite sign. Thus e.g. the lightness of one patch increased, but for an other it decreased by the same amount (and similarly for chroma or hue angle).

Three pictures were shown on a grey background to the observer on the screen: the “original” one, one with the systematic distortions and one with the stochastic distortions. The two images with distorted colours were shown on the two sides of the original one, but again the systematically distorted one was presented stochastically once on the left and once on the right side of the original. Figure 3 shows an example of the presentation.

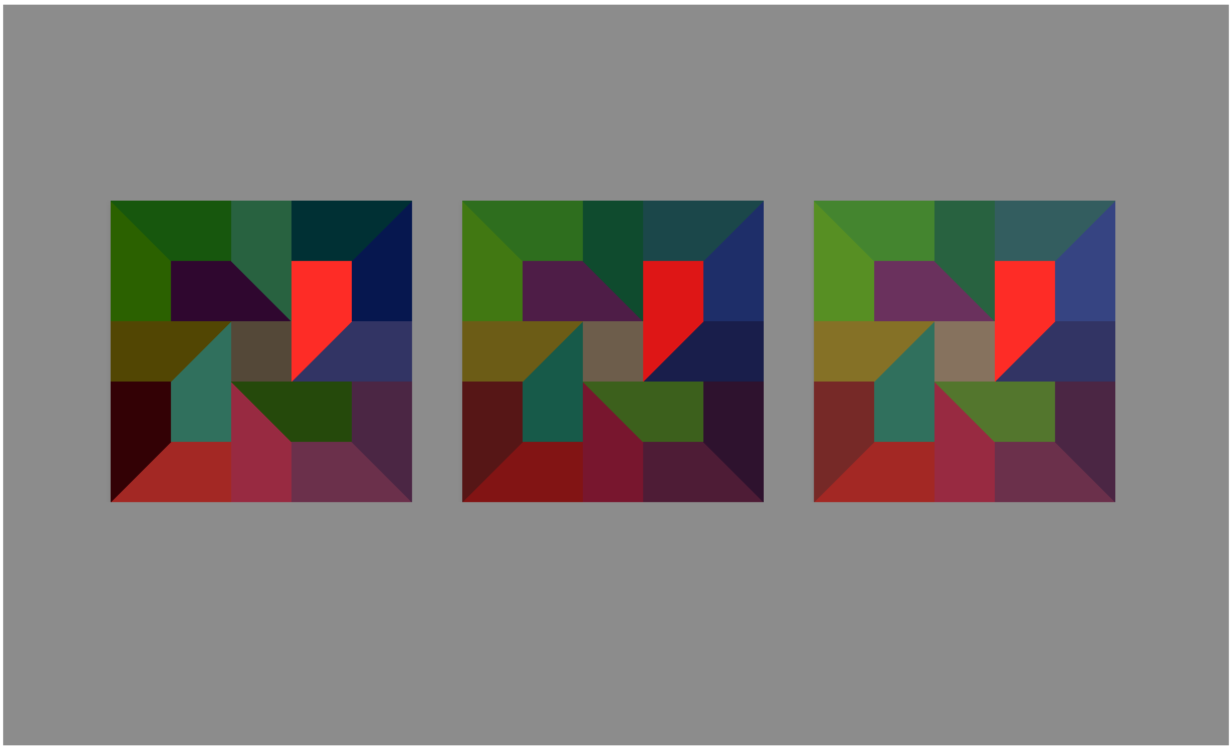

Figure 3: Three copies of the pinwheel image, here left hand side copy has stochastic, the right hand side copy has systematic colour distortion

Experiments

The experiment was set up in a dark room, to exclude the influence of external adaptation light. Observers had to accommodate to the dim light of the monitor screen for 10 minutes before starting the experiment. During this time they got an explanation of the experiment, they were asked not to compare the colouring of the single patches, but evaluate the total impression of the pictures.

Up to now 15 colour normal university students performed the investigations, for all three attribute of colour. The program stores information on the person who performed the investigation, and which component of the colours was changed and to which degree. Observers had to click on the sample that they thought resembled more the original one. If they found the three copies to be very similar and could not decide which one resembled the original better, they had to click the original. This information was also stored.

Results

We conducted three series of measurements, gradually increasing or decreasing the lightness, the chroma and changing the hue angle. Figure 4 shows for the three directions of colour change (lightness, chroma and hue angle) the per cent of selections, when the observers selected the systematically changed image (yellow bars), when they selected the randomly changed image (blue bars) and when they were unable to decide between the two pictures (red bards), for the different amounts of changes.

Figure 4.A show the results for lightness change. As can be seen for a one unit change most of the observers were still undecided which picture they should select (for -1 unit in all cases, for +1 unit in 50 % of the cases they already selected the systematically changed image.

Figure 4.B shows that with increasing chroma difference the observers were more and more certain in their selection, but quite frequently they selected the randomly modified image.

Figure 4.C shows similar behaviour for hue angle change.

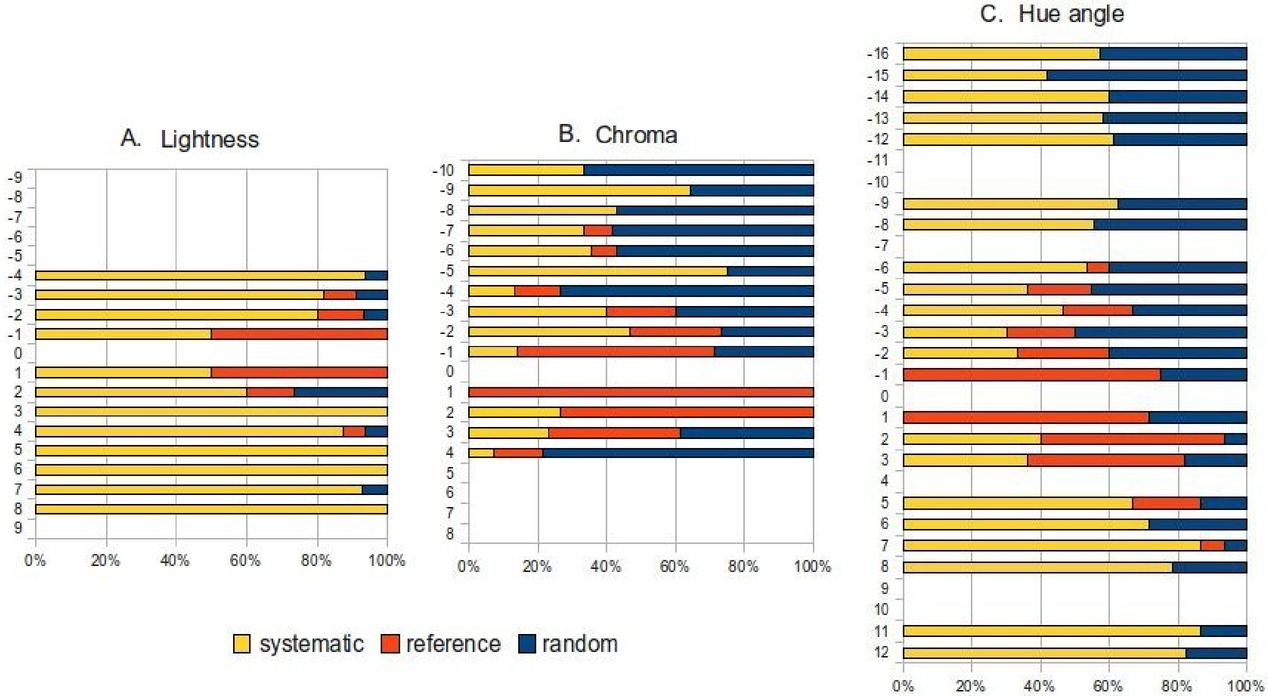

Figure 4: Percent selection of the image with systematic change (yellow), the image with random changes (blue), and where the observer was unable to decide between the images

Discussion and conclusions

Up to now the number of participants was still not high enough to draw statistically significant conclusions, but the first results show already that for lightness change one gets the expected result: after a systematic change of the lightness of all surface elements the resulting picture seems to resemble the original more closely as an other picture where the changes have been made at random.

The situation is quite different for chroma change. The experiments do not show the preference of the systematic change, this is against the general belief that a chroma increase is more preferred. This will have to be investigated using different images, also with real graphical content, as many colour preference studies have shown that people prefer images with higher chroma of the objects[3]. This is in marked disagreement with the generally accepted viewpoint of Evans, who stated that “as long as the chromatic relations within a given scene are consistently like those of the original scene, the colours will actually seem to be the same in both[4].”

The hue angle experiment shows also the very interesting result of an asymmetry of positive and negative change that needs further investigation.

In summary I can state that in contrary to expectations the systematic colour changes are not always preferred by observers.

References

[1] *McCann J (2002) A spatial colour gamut calculation to optimise colour appearance, pp. 213-233 in Colour Image Science, ed.: MacDonald LW & Luo MR, John Wiley & Sons Ltd. 2002.*

[2] *CIE (2004) A colour appearance model for colour management systems: CIECAM02. CIE Publ. 159:2004.*

[3] *Bodrogi P & Tarczali T (2002) Invstigation of colour memory. Pp. 23-47. in Colour Image Science, ed.: MacDonald LW & Luo MR, John Wiley & Sons Ltd. 2002.*

[4] *Evans RM (1974) The perception of color, p. 205. John Wiley, New York (from reference 1).*