Simulated Surface Colour Matching under Conditions of Multiple Illuminants

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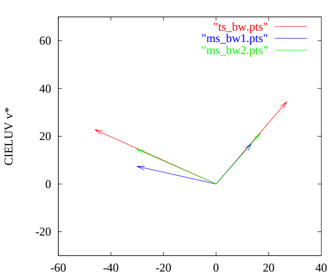
Two house-like images are used to present the stimuli. The top image shows the yellow/blue illuminants for light and shadow, and the bottom shows the green/magenta illuminants. The displays are presented using a mirror stereoscope and two monitors.

Most theories of colour constancy assume a flat coloured surface and a single homogenous light source (Maloney & Wandell, 1986). Natural situations, however, are 3-dimensional, are hardly ever restricted to a single light source and object illumination is never homogenous. Two special cases of secondary light sources with sharp boundaries have been simulated on a computer screen: A house-like 3-D object with colour patches in sunlight and shadow and a Mondrian-type pattern with a coloured transparency covering some of the colour patches.

Experiment I

The stimulus situation is a simulated 3-D-image of a house in sunlight and shadow presented with a mirror stereoscope and two monitors. All surfaces are simulated Munsell chip reflectance functions.

Lighting conditions: A natural pair of sunlight (4502 K) and shadow (16244 K) illuminants with an intensity ratio of 5:1, and an artificial pair of greenish light and magenta shadow illuminant with the same intensity ratio.
Additional conditions: 2 different wall reflectances (5Y 6/2 and 5B 6/2), and each target colour patch as a 1 or 2 Munsell Value step increment or decrement.
5 subjects with variable amount of experience in colour matching.
Subjects' task: Adjust the center patch on the bright right wall such as if it were painted with the same paint as the center patch on the dark left wall.



The red arrows show the average chromaticity shift induced by moving from blue shadow to yellow light and from magenta shadow to green light. The green and blue arrows indicate the adjustments made by the subjects. For the blue arrows targets are on a yellow wall and for the green arrows they are on a blue wall. Mean adjustment vectors are slightly shifted to bluish appearance of shadows.

Experimental Questions

1. Does a natural lighting shift form blue shadow to yellow light allow for better simultanous colour constancy (Arend & Reeves, 1986) than an artificial lighting shift from magenta shadow to greenish light?
2. How do local contrast conditions affect constancy in the simulated 3-D-arrangement of the present experiment?

Results

Effects are computed in CIELUV E*, the difference between perfect surface colour constancy and the actual adjustments. Data are analyzed by an ANOVA with 3 factors (lighting, local Munsell Value contrast, wall colour).
Lighting Effect. There is a small but statistically significant (p=0.029) effect of lighting: Deviation from perfect constancy is smaller for the natural lighting condition (E*=24.8) as compared to the artificial lighting condition (E*=29.5).
Local Intensity Contrast Effect. There is a significant effect (p=0.01) of the local luminance contrast direction: E* is smaller for decrements (E*=21.6) as compared to increments (E*=32.7).
Local Chromaticity Contrast Effect. There is a significant effect (p=0.009) of the wall colour: Constancy is better for the bluish (E*=25.6) as compared to the yellowish (E*=28.8) wall. This, together with a significant effect of the wall on the uv-error indicates a local chromaticity contrast effect.
There are no statistically significant interaction effects.

Discussion

Deviations from perfect constany are almost completely due to chromaticity errors. There is no statistically significant deviation of CIELUV L* from 0.
Are cone excitation ratios (Foster & Nascimento, 1994) between target and homogenous context areas suitable predictors for matches across lighting conditions?
L- and M-cone excitation ratios are preserved rather well across lighting conditions.
S-cone excitation ratios are not preserved. Most adjustments are such as if there was too much S-cone stimulation. This indicates that surfaces in shadows tend to shift appearance more into the blue direction as predicted from the same surface unter a bright illuminant.

Experiment II

The stimulus is a pair of Mondrian-like samples with one center target patch and 2 or 6 context patches. The display is shown in stereo and in front of one of the Mondrians there is a simulated colour filter. Filter transmission functions are identical to Munsell chip reflectance functions.
Partial vs Full Filters: In the partial filter condition the filter covers the center patch completely but covers the context patches only partially. In the full filter condition the filter covers the whole Mondrian completely. There also is a control condition without filter.
Number of Context Patches: One group of Mondrians has 2 context patches and one group has 6 context patches.
Data of 4 subjects are reported.
Subjects' task: Adjust the center patch of the right Mondrian such as if it were painted with the same paint as the center patch of the left Mondrian behind the filter.

Experimental Question

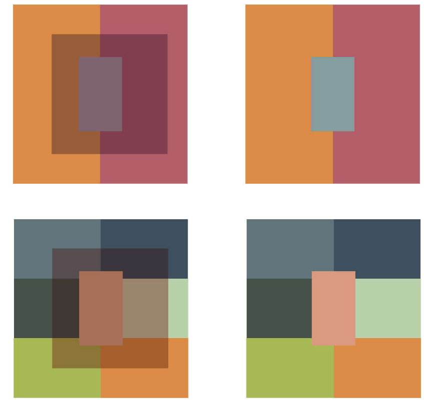
If cone excitation ratios at borders help to recognize the colours of interior fields, then
1. adjustment errors should be smaller for partial filters as compared to full filtering, and
2. additional context fields should reduce the adjustment errors.

	Adjustment Vector		Error Vector	
	CIE *L**	D *E**	CIE *L**	D *E**
Total Mean	23.51	29.54	-1.99	18.05
Full Filter	23.21	29.05	-1.69	17.14
Partial Filter	23.80	30.03	-2.28	18.96
2 Context Colors	22.65	29.00	-1.13	18.49
6 Context Colors	24.37	30.08	-2.84	17.60
No Filter	2.19	4.18	-2.19	4.18

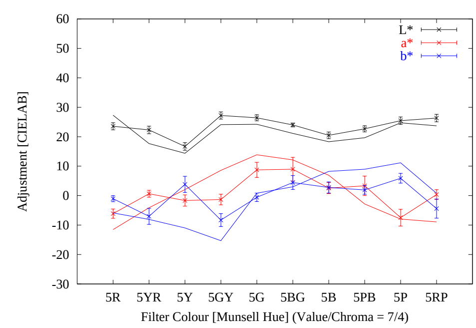
Mean intensity L* and total shift E* for all conditions of the transparency experiment. The small values for L* errors indicate that deviations from perfect constancy are mainly determined by chromaticity errors. Differences in E* errors for full and partial filtering are statistically significant. Differences in E* for the number of context fields exist but are not significant.

Results

Results are computed in terms of CIELAB coordinates. Errors are computed as distances between the actual adjustments and the adjustment expected under full constancy. Matching errors in experimental conditions are about 4 times as large as in the control condition.
Partial vs Full Filters. Deviations from full constancy are slightly but statistically significantly (p=0.047) smaller for the full filter condition (E*=17.14) as compared to the partial filter condition (E*=18.96).
Number of Context Patches. There is no statistically significant effect of the number of context patches. The mean error in the sample is E*=18.49 for 2 context patches and E*=17.60 for 6 context patches. Here also, errors are almost completely due to chromaticity errors. The mean deviation of L* from 0 is not statistically significant.



The subject's task is to adjust the center patch in the right Mondrian such that it looks as if it were cut from the same paper as the center patch in the left Mondrian, covered by the transparent sheet. 4 conditions are used: 2 or 6 context fields and the sheet covering the Mondrian partially or fully.



Adjustments and errors of the means in CIELAB space made by subjects for 10 filter colours. Simple lines indicate perfect constancy. Note the slight overcorrection of intensity and also note that for both chromaticity components the adjustment usually is less than required for constancy.

Discussion

In general, constancy is almost perfect for the lightness component and is rather poor for the chromaticity shift induced by spectral differences between light and shadow illuminants and by filter transmittances.
Matching between shadow and light is slightly better if the lighting condition was natural (yellow light, blue shadow) as compared to artificial (green light, magenta shadow). The simulated 3-D-arrangement is not sufficient to prevent significant local intensity and chromaticity contrast effects.
Th results contradict the hypothesis that a constant cone excitation rule is used to get constancy in the present arrangement. (1) There is a strong variation in S-cone excitation ratios in the 1st experiment. Good constancy of L- and M-cone excitation ratios correlates with almost perfect lightness constancy. (2) The number of context fields in Experiment II had no significant effect and a fully covered Mondrian resulted in better constancy than a partially covered one, although the latter provides more cues to the patch colors.
These results indicate that subjects were able to use local contrast cues at sharp illumination boundaries to discount for the illuminant's intensity but not for its chromaticity.

References

Arend, L., & Reeves, A. (1986). Simultanous color constancy. *Journal of the Optical Society of America A*, 3, 1743-1751.
Foster, D. H., & Nascimento, S. M. C. (1994). Relational colour constancy from invariant cone-excitation codes. *Proceedings of the Royal Society of London, B*, 257, 115-121.
Maloney, L. T., & Wandell, B. A. (1986). Color constancy: A method for recovering surface spectral reflectance. *Journal of the Optical Society of America A*, 3, 29-33.