Perceptual Learning of Categorical Colour Constancy, and the Role of Illuminant Familiarity

J. A. Richardson and I. Davies
Department of Psychology, University of Surrey, Guildford GU2 5XH, Surrey, United Kingdom

Abstract

It is known that colour constancy is more robust when the changes in illumination are restricted to the phases of daylight than it is for changes in most artificial light sources, suggesting that the ability to correctly identify surface colours may depend in part, on the observers familiarity with the light source.

The present study examines whether a relatively short period of practice in judging surface colours under different illuminants leads to an improvement in colour constancy, and if so whether the improvement is restricted to the illuminants under which the judgements were made.

Five subjects were asked to identify by name (chosen from 11 basic colour terms) a total of 70 colour patches under 4 different broad band illuminants.

Subjects then named each colour patch a further 20 times distributed over a 2 week period, 10 times under each of two of the broad band illuminants. Finally, subjects again named the patches under all 4 illuminants.

It was found that the degree of categorical colour constancy under broad band illumination was significantly better after the learning trials, and that the improvement was greater for the illuminants used in the learning trials.

1. Introduction

Colour constancy is defined as the invariant appearance of surface colours under changes in the spectral composition of the incident illumination.

The visual system is apparently better at compensating for some illuminant changes than others, eg. colour constancy is most complete when the colorimetric shift lies along the blue-yellow axis,[1,2] and is more robust when the changes in illumination are restricted to the phases of daylight than it is for changes in most artificial light sources,[3] which suggests that the ability to correctly identify surface colours may depend in part, on the observers familiarity with the light source.

The present study examines whether a relatively short period of practice in judging surface colours under different illuminants leads to an improvement in colour constancy, and if so whether the improvement is restricted to the illuminants under which the judgements were made.

Colour appearance was examined using a colour naming method which involves subjects naming a large selection of colour surfaces under a number of different illuminants (which vary in chromaticity and/or intensity). This method allows the examination of real surface colours seen without a comparison field, and has been found to provide a reliable measure of colour constancy that does not require the separation of illuminant and surface colour to be made clear explicitly to the subjects.[4]

2. Method

2.1. Subjects

Five subjects (3 undergraduate and two postgraduate students at The University of Surrey) participated in the experiment. All subjects had normal or corrected to normal vision, and were naive as to the purpose of the experiment.

2.2. Stimuli

At a viewing distance of 520mm, sixty-eight colour patches (30mm × 30mm) were presented in the centre of a Mondrian surround (120mm horizontally by 60mm vertically). Under a standard 'white' illuminant, the colour set was representative of the whole u, v chromaticity diagram.

The Mondrian surround was composed of squares of various chromaticities. There were four versions of the surround which were presented in approximately a quarter of the trials each in a pseudo-random order: a basic Mondrian pattern, its mirror image, the basic pattern upside down, and the mirror image upside down. This insured that the average chromaticity and contrast remained constant while at the same time preventing subjects adapting to the background pattern or using chromatic changes in individual squares in the surround as a reference.

2.3. Equipment

The stimuli were presented in a tachistoscope which allowed the light source and display time to be controlled. The stimuli were place in a card holder inside a lamp compartment, opposite a viewing appature. Viewing distance was approximately 510mm, and the stimulus displays subtended a visual angle of 16° horizontally, and 10° vertically. The displays were illuminated by two tube bulbs one aimed downward, and one aimed upward toward the displays at an angle of about 45°.

2.4. Procedure

Subjects first familiarized themselves with the eleven basic colour terms which were used as response categories. The colour samples were presented one at a time in a random order which differed for each trial. Each stimulus was presented for 750 msec. On each trial 0subjects were asked to choose the most appropriate colour category for each of the 68 target patches. In the first set of trials each colour patch was presented four times once under each of four different illuminants : white, u' = 0.22, v' = 0.48; green, u' = 0.19, v' = 0.52; blue, u' = 0.18, v' = 0.52; orange, u' = 0.26, v' = 0.53.

Four subjects then named each colour patch a further 20 times distributed over a 2 week period, 10 times under each of the green and blue illuminants. Finally, all subjects again named the patches under all 4 illuminants.

3. Results

For each subject the colour name assigned to each colour patch served as the standard colour name. The deviations from the standard name when the same patch is viewed under the test illuminants was calculated and used as a measure of colour constancy. Figures 1, 2, and 3 show the number of deviations from the standard colour names for each subject under the green, blue and orange illuminants respectively, before and after training.

It was found that the degree of colour constancy-assigning the same name to the same colour patch under different illuminants—for the light sources under which subjects trained (blue and green) was significantly better after the learning trials than before them, (blue: $t = 7.78$, df 4, $p < 0.001$; green: $t = 4.05$, $p < 0.01$). However, this improvement was not evident for the orange illuminant which subjects did not train under ($t = 0.57$, df 4, $p > 0.05$).

In order to show the colour category shifts caused by the different light sources before and after the practice trials, the centroid locations for each category in u', v' colour space were calculated for each observer. The centroids for all 5 observers under the three test illuminants are plotted in Figures 4, 5 and 6.

As a further measure of the degree of colour constancy the centroid values were used to calculate a two dimensional version of the Brunswik ratio[5]:

$$br = d_{obs}/d_{prf}$$

where d_{obs} = and d_{prf} are the Euclidean distances between the location of the standard and the observed locations, and between the standard and perfect constancy respectively. A ratio of 0 indicates a complete lack of constancy, a ratio of 1 indicates perfect constancy, and a ratio of above 1 indicates overconstancy.

Table 1. Means and Standard Deviations of Bruswik Ratios for all 5 subjects for the Three Test Illuminants Before and After Training.

	Before Training		After Training	
Illuminant	Mean	SD	Mean	SD
Green	0.809	0.221	0.922	0.145
Blue	0.754	0.252	0.910	0.080
Orange	0.895	0.144	0.923	0.143

Table l shows the Brunswik Ratios for the three test illuminants.

The Brunswik ratios also show that there is an improvement in colour constancy for all three test illuminants after the learning trials, and that the improvement is greater for the illuminants under which the trials took place. It should be noted however that the Brunswik ratio for the orange illuminant is nearer to 1.0 (perfect constancy) than it is for the green and blue illuminants before the learning trials.

4. Discussion

In sum, it was found that the degree of colour constancy—assigning the same name to the same colour patch under different broad band illuminants—was significantly better after a relatively short period of practice in categorizing surface colours, and that the improvement was greater for the illuminants which practice took place.

Explanations of colour constancy have ranged from sensory accounts, such as chromatic and contrast adaptation, to higher level, cognitively oriented explanations which emphasize the role of learning and memory for object colours.

The results reported here suggest the importance of learning and memory, not only for object/surface colours, but also for the light source under which the surface colour is being judged.

With regard to perceptual learning, the fact that subjects were not provided with feedback as to the accuracy of their responses, is consistent with Gibson's argument that mere exposure to the relevant stimuli in the absence of feedback is sufficient for learning to occur.

The findings of this study thus suggest that models which attempt to predict which deviations from colour constancy will occur for a given illumination should consider individual observers familiarity with the illuminant.

5. References

1. McCann J., McKee S., & Taylor T. (1976) Quantitative studies in retinex theory. *Vision Research,* **16**, 445-458
2. Worthey J. (1985) Limitations of colour constancy. *Journal of the Optical Society of America A*, **2** 249-258
3. Judd, D. (1940) Hue, Saturation and lightness of Surface colours with chromatic illumination. *Journal of the Optical Society of America* **30**, 2-32
4. Troost J. & deWeert C. (1991) Naming versus matching in colour constancy. *Perception and Psychophysics*, **50** 591-602
5. Brunswik, E. (1928) Zur Entwicklung der Albedowwahnehmung. *Zeitschrift fur Psychologie*. **64** 216-227
6. Gibson E. (1969) *Principles of Perceptual Learning and Development*. Appleton Century Crofts. New York

published previously in SPIE, Vol. 2414, page 50

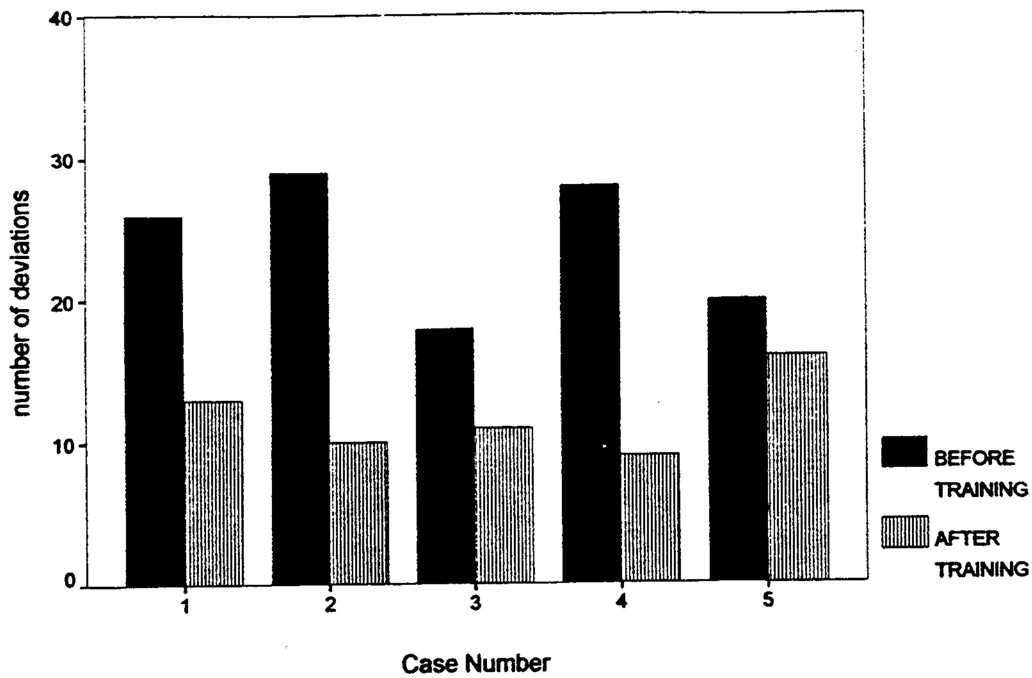
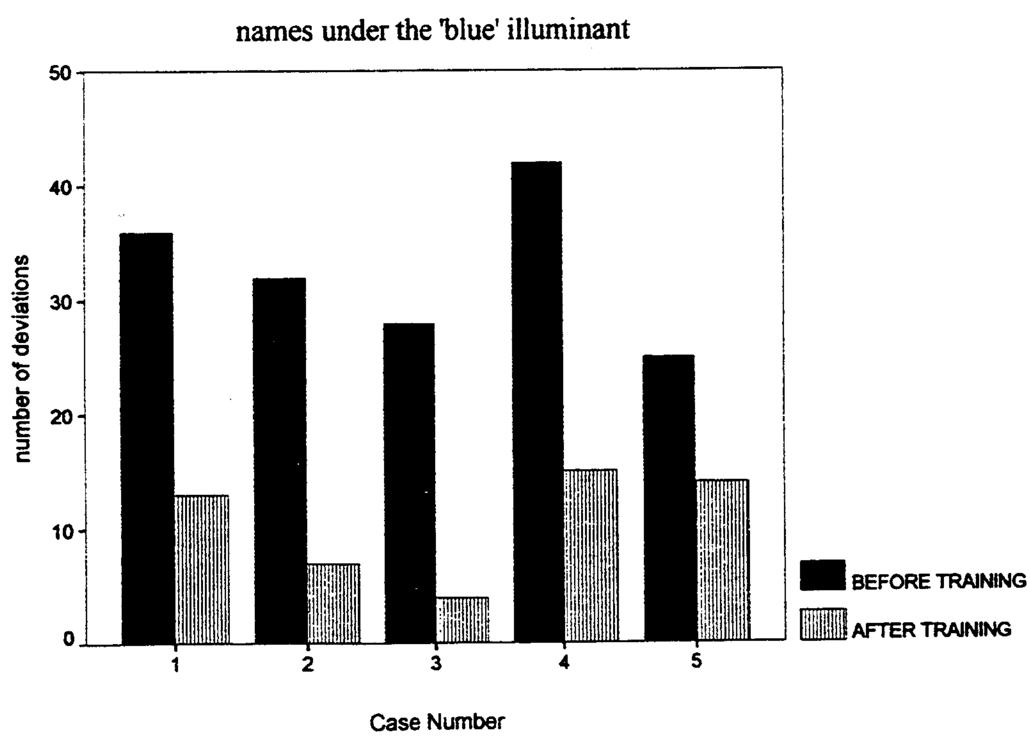


Figure 1. Number of deviations from standard colour names under the green illuminant



Note: case number 5 did not train under the blue illuminant

Figure 2. Number of deviations from standard colour names under the 'blue' illuminant

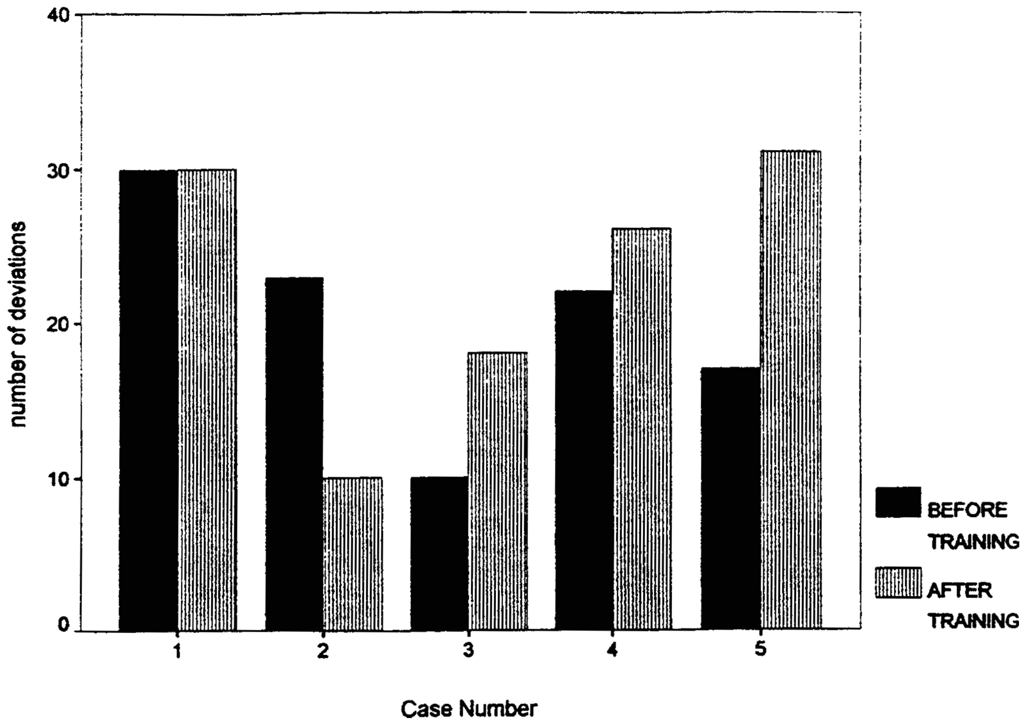


Figure 3. Number of deviations from the standard colour names under the 'orange' illuminant

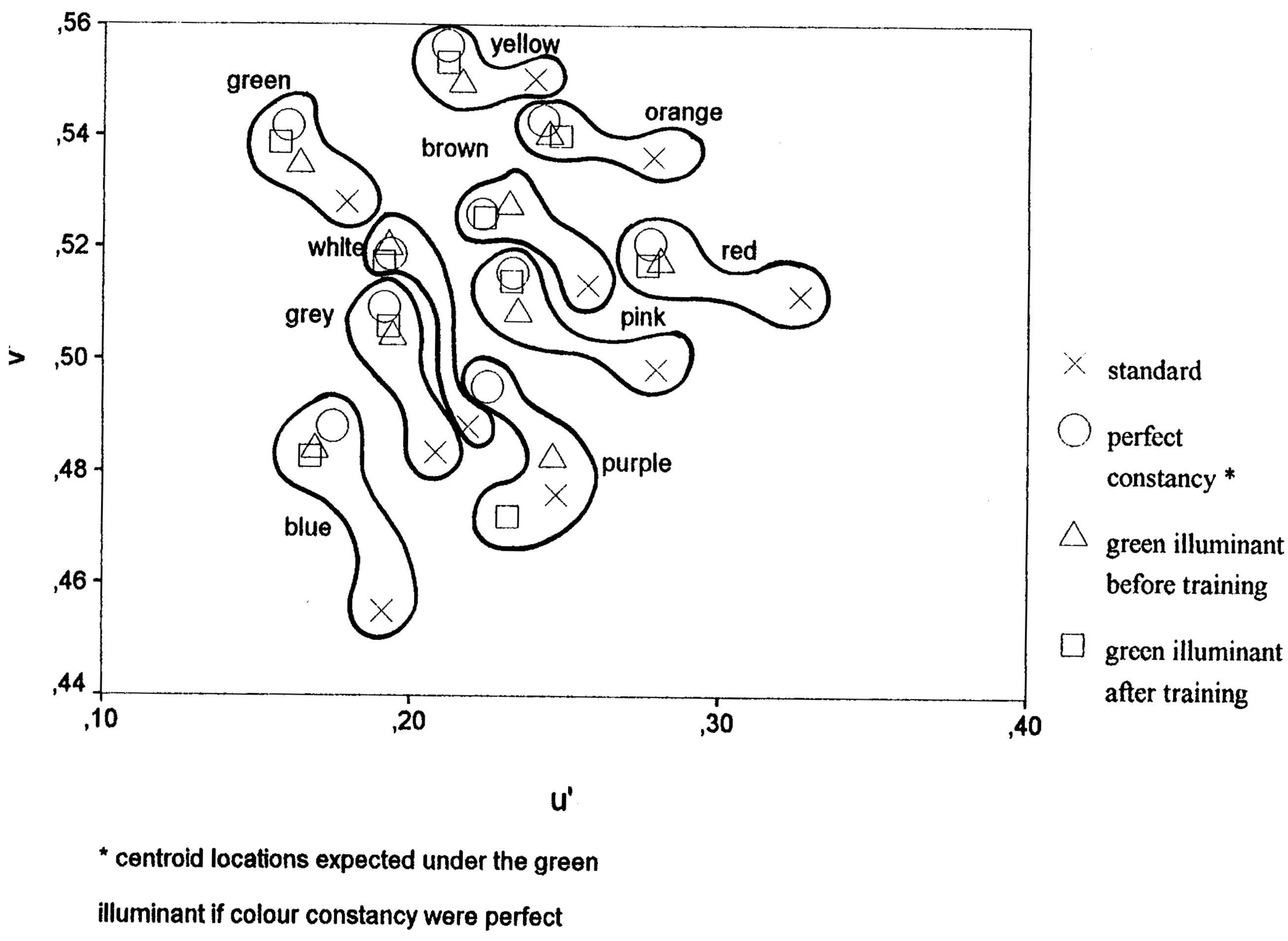


Figure 4. Centroid locations of basic colours under the 'green' and standard illuminants

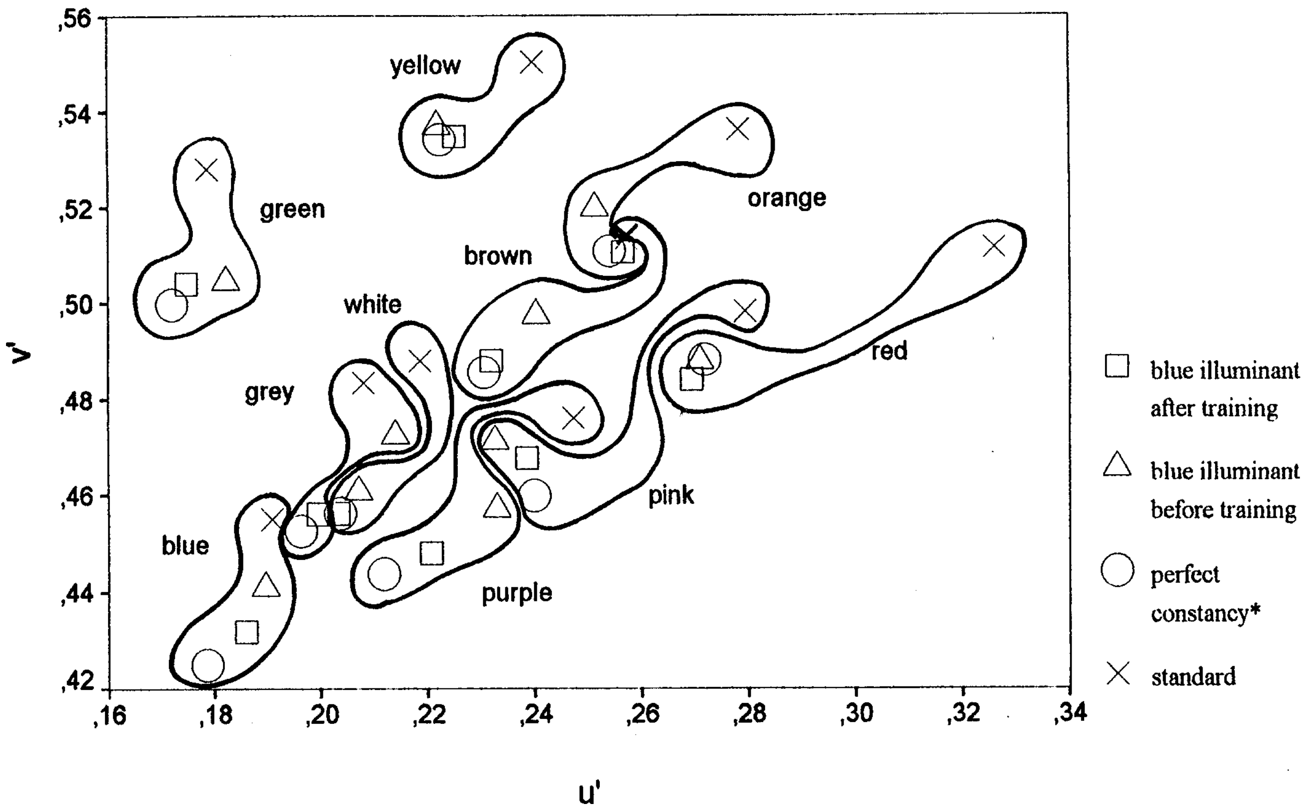


Figure 5. Centroid locations of basic colours under the 'blue' and standard illuminants
* Centroid locations of basic colours expected under the blue illuminant if colour constancy were perfect.

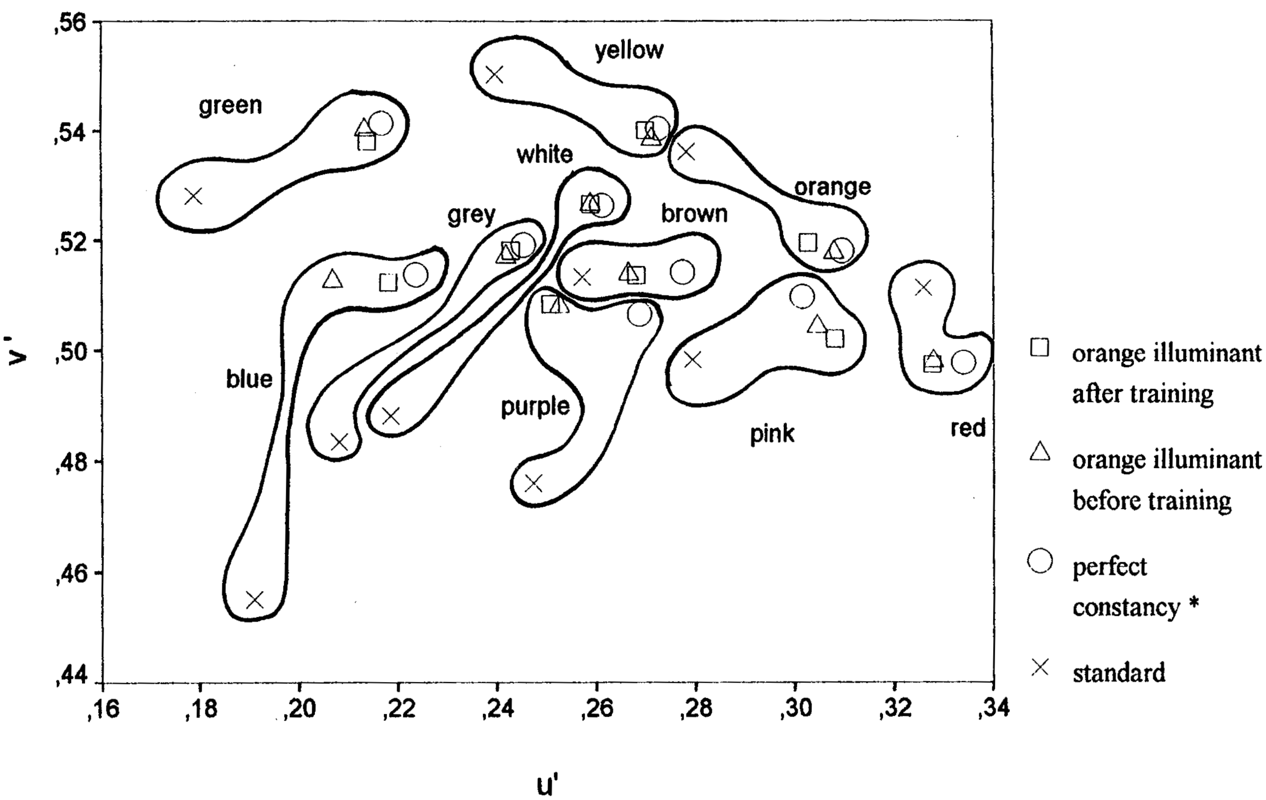


Figure 6. Centroid locations of basic colours under the 'orange' and standard illuminants
* Centroid locations of basic colours expected under the orange illuminant if colour constancy were perfect.