

A Direct Test Of The ‘Grey World Hypothesis’; A Comparison Of Different Matching Methods.

J.J. M. Granzier., J.B.J. Smeets., E. Brenner; ErasmusMc ; Rotterdam, The Netherlands. Current address: Faculty of Human Movement Sciences, Vrije Universiteit, Amsterdam, The Netherlands. mailto: j.granzier@fbw.vu.nl

Abstract

Many of the proposed ways in which the visual system could disentangle influences of illumination from influences of reflection on the colour of the light that reaches our eyes, are implicitly or explicitly based on the assumption that the average reflectance of our environment is grey; the ‘Grey World Hypothesis’. Here we investigate whether subjects make large errors when this assumption is not true. Subjects performed matching tasks in which they matched the colour and luminance of a test plate, either by setting the colour of an adjustable patch on a monitor or by selecting a sample from a large set of printed colour samples ‘(Pantone Colour Specifier)’. Matches were made with the test plates embedded in scenes either containing only red or only green objects. Matches hardly differed between the red and green scenes. Thus, the average colour of the scene cannot be the primary scene statistic underlying colour constancy. We found that the matches were most consistent both across and within subjects when using the Pantone Specifier.

Introduction

Because the light reflected from an object to the eye depends both on the object’s surface reflectance and on the illumination, and the observer is usually only interested in the former, the visual system needs some way to compensate for changes in the illumination [1]. To accomplish this, the visual system is likely to consider the light coming from other surfaces [2]. If the illumination of a scene changes so that there is more energy at long wavelengths, the light reflected from all surfaces changes correspondingly, so that the chromaticity averaged over the entire image becomes more reddish. A simple approach to colour constancy could therefore be to take the space averaged chromaticity as a measure of the chromaticity of the illumination. Doing so is based on the assumption known as the ‘Grey World Hypothesis’ [3]. It could easily be implemented early in the visual system as a cone-specific multiplicative gain control (von Kries adaptation) [4], which either extends across the retina [5] or is spread spatially through eye movements [6]. Relying exclusively on transitions at borders [2] also indirectly relies on the Grey World Hypothesis. There is no general agreement about the status of the Grey World Hypothesis in colour constancy; several studies find that the average background colour influences illuminant colour estimation consistently [7, 8], while others do not [9-12]. Most studies [7-9,12] that examined the influence of the average chromaticity in the scene used virtual scenes. It is not certain that such data can be generalized to real surfaces and real illuminants [13].

The Grey World Hypothesis obviously must lead to large errors in colour judgment if the visual background mainly contains surfaces of a certain colour (blue sky, green leaves,

red brick houses) [14, 15]. We here examine whether colours are indeed misperceived under such conditions.



Figure 1: An impression of the objects used for the ‘green scene’ condition (top) and the ‘red scene’ condition (bottom) of experiment 1. One of the two test plates is shown at its position at the back of the scene.

Experiment 1

Methods

Scene

In order to manipulate the average colour of the scene independently of local contrast, test plates were placed in front of a very dark background, with coloured objects at a

distance from the test plate that ensured that they were separated by at least 1.37 deg. They were common household objects (waste paper basket, towel, cup, etc) that we could obtain in both colours. We used ten objects for each scene. Subjects sat 250 cm from the test plates, and 200 cm from the nearest of the surrounding objects.

We used two scenes: one with only green objects and one with only red objects (figure 1). We will refer to the former as a ‘green scene’, although actually only the objects were green. We will refer to the scene with red objects as a ‘red scene’. If people rely on some version of the ‘Grey World Hypothesis’ to deal with changes in illumination, we expect subjects’ matches of the colour of the test plates to be shifted substantially towards ‘red’ when the plates are presented amongst green objects and to be shifted towards ‘green’ when the plates are presented amongst red objects. There were only two test plates, and they were both used in all conditions. However subjects were not aware that there were only two test plates, even after running the experiment. Under daylight illumination, one plate looked orange and the other looked green (both of low saturation).

Lamps

In order to be able to estimate the magnitude of colour constancy, and to make it clear to the subjects that biases could be due to the illumination, we used two different lamps to illuminate the scene. Only one lamp was on at a time. Its brightness was set (by manipulating the voltage driving the lamps) so that the light reflected from a white piece of paper at the centre of the experimental scene was 25 cd/m². The lamps had 1931 CIE x, y coordinates of (0.514, 0.412) and (0.485, 0.413) as measured directly with a Minolta CS-100A chroma meter after the voltage driving the lamps had been set. The lamps were positioned between the subject and the scene, slightly to the left of the subject, and were hidden from view at all time.

Matching Conditions

We asked subjects to match the surface in two ways: by selecting the matching surface from a Pantone Colour Specifier [16] (figure 2a) and by setting a colour on a CRT (see figures 2 b-d). The matching stimulus (The Pantone Specifier under a lamp or an image on a CRT) was presented in another part of the room. When setting the colour (and luminance) on the CRT we had good control of the surrounding image, but there is no real distinction between reflectance and illumination, so subjects could interpret the task as to match the light coming from the two surfaces. For the Pantone Specifier the contribution of surface reflectance is clear, but we have little control of the surrounding. We therefore used both the Pantone Specifier and the CRT and compared the results.

The Pantone Specifier

The Pantone colour specifier was illuminated by a ‘reference lamp’ (0.456, 0.413) that was very similar to one of the two lamps illuminating the scene. It was set to reflect 25 cd/m² to the subject’s eye when a white piece of paper was placed at the position at which subjects held the Pantone Specifier. Under this lamp the two test plates reflect light with coordinates (0.446, 0.430) and (0.485, 0.416). Subjects had to select the sample from the Pantone Colour Specifier that best matched the paint of the test plate. They

were free to leaf through the ‘pages’ until they found a suitable sample.

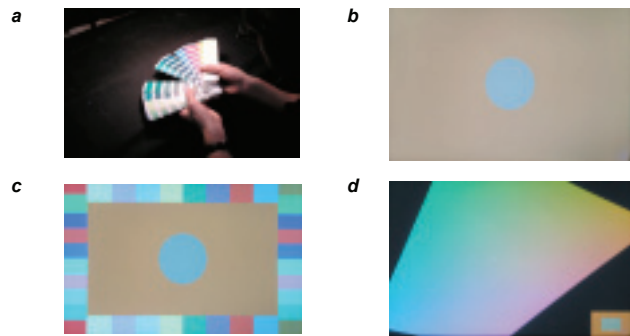


Figure 2: The four matching stimuli used in experiment 1. The Pantone Colour Specifier (a), The simple matching stimulus (b), The stimulus with saturated colours (c) and the visualized CIE matching stimulus (d).

CRT images

The CRT screen (a calibrated Sony GDM-FW 900 Trinitron monitor, 48 cm x 31 cm; 1920 x 1200 pixels; 90 Hz; 8 bits per gun) was 100 cm from the subject. Subjects had to match the colour and luminance of a part of the screen to the colour and luminance of the test plate. The part’s chromaticity was manipulated (within the part of the CIE colour space that we could render on the monitor) by moving the computer mouse. Subjects could set the luminance by pressing the arrow keys of the computer keyboard. They indicated that they were content with the set value by pressing the mouse button. The initial hue of the adjustable patch was determined at random from within the range that could be set for each match. The luminance of the adjustable patch was 10 cd/m² for the first match, but it remained at whatever value the subject set on the next trial. In the ‘simple matching condition’ (see figure 2b) there were only two colours on the screen: the colour set by the subject (within a 5 deg diameter disk at the center of the screen) and a uniform background (10 cd/m²) with the same coordinates (0.47, 0.42) as the light from the ‘white’ background of the Pantone colour specifier (when illuminated by the reference lamp).

We know that the perceived saturation is influenced by the saturation of other colours in the scene [17, 18]. When matching surfaces using the Pantone Specifier, the subject is exposed to a wide variety of colours. We therefore also used a CRT matching condition in which a variety of saturated colours surrounded the background (see figure 2c). In this ‘saturated colours matching condition’, the background on the screen was the same as in the ‘simple matching condition’, but with saturated colours (mean luminance of 16.9 cd/m² with a standard deviation of 8.6 cd/m²) around the borders of the screen.

Another difference between the Pantone Specifier and a CRT matching task is that with the former the subject can instantaneously choose from the whole colour gamut of matching colours. This is not the case for the two above-mentioned CRT matching conditions. In order to test whether this makes any difference, we displayed a part of the 1931 CIE colour space (x: 0.215-0.465; y: 0.25-0.5; 20 cd/m²) on a black background on the monitor. Subjects could choose the matching colour by moving a cursor (open white ring) to the appropriate position in this CIE colour space (see figure 2d). All colours within the range that could be rendered on the

CRT were visualized. A patch at the bottom right of the screen showed the chosen colour and luminance. The background of the patch had the same colour (0.47, 0.42) and luminance (10 cd/m²) as the colour and luminance of the background in the ‘Simple matching condition’. The luminance of the disk at the bottom right was set by pressing the arrow keys. We will refer to this condition as the ‘Visualized CIE’ matching condition.

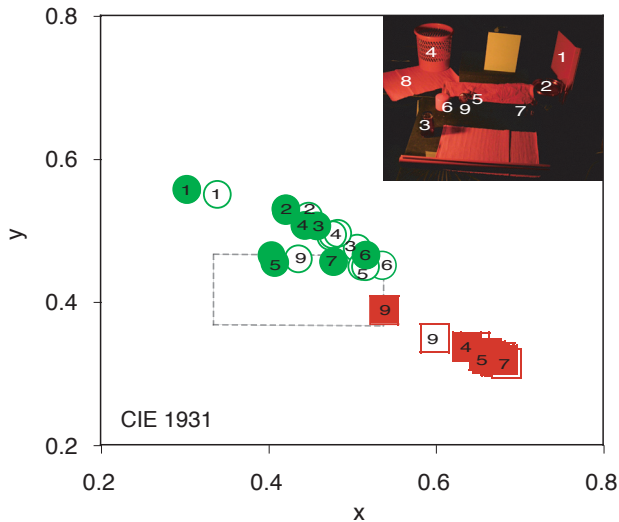


Figure 3: CIE x, y coordinates of the objects found in the ‘red scene’ (squares) and ‘green scene’ (circles). The numbers refer to the objects as indicated. The CIE coordinates are given both for lamp 1 (open symbols) and lamp 2 (solid symbols). The dashed rectangle represents the colour space of figures 4 and 6.

Subjects and Procedure

Six naïve subjects with normal colour vision (as tested with Ishihara colour plates [19]) participated in the experiment. After dark adapting for 5 minutes, each subject made 12 settings (2 test plates x 2 lamps, each presented 3 times). This was done in a separate session for each scene and matching condition. Within each session the lamps and test plates were presented in an arbitrary order. The experimenter changed the illumination and test plates manually after a match had been made. The lamps were switched off and a new test plate was set in the scene before the new lamp was switched on.

Analysis

We converted the chosen samples of the Pantone Specifier into CIE coordinates by measuring the light that they reflect when illuminated by the reference lamp. We determined each subject’s mean CIE (x, y) value for each of the 32 (2 lamps x 2 test plates x 2 scenes x 4 matching conditions) experimental conditions. We then averaged across subjects and calculated the standard errors in these averages. We used these averages to evaluate the influence of the bias in the colour of the surrounding due to the selection of objects and to the lamp used to illuminate the scene (figure 3).

Results

Figure 4 shows subjects’ average settings for the four matching conditions. The effect of the colour of the scene on subjects’ colour matches was quite small (compare squares with circles) and they were often not even really in the expected direction (opposite the direction in figure 3). The difference between the settings under the two lamps was large (compare open and solid symbols), indicating that colour constancy was poor. However, at least for the samples chosen from the Pantone Colour Specifier, there was clearly a tendency towards colour constancy (for perfect colour constancy all circles and squares would lie on the cross). When matching with an image on a CRT, subjects clearly did not simply match the light reaching their eyes (in which case the squares and circles would coincide with the triangles). Table 1 shows that both the standard deviation between subjects’ matches (between-subjects) and the average standard deviations between replications by the same subject (within-subjects) are markedly smaller for the Pantone Specifier than for the CRT.

Table 1: Standard deviations in matches of experiment 1 (distance in 1931 CIE colour space)

	between subjects		within subjects	
	x	y	x	y
	0.006	0.003	0.006	0.003
	0.019	0.013	0.013	0.008
	0.021	0.018	0.021	0.012
	0.020	0.015	0.016	0.009

Discussion

We show that the perceived colour was hardly affected by the fact that the scene only contained objects of a certain colour, so subjects apparently did not rely heavily on the Grey World Hypothesis. At the same time, subjects’ matches were quite different for the different lamps, indicating that colour constancy was poor under these conditions (even for the matches with the Pantone Specifier, for which colour constancy can be estimated to be about 50% [20]). Thus the lack of effect of the scene colour was not due to subjects using a more elaborate strategy to achieve colour constancy. A simple explanation of these results could be that local chromatic contrast plays a crucial role in colour constancy, and that our black scene was dark enough (0.40 cd/m²) to disrupt this source of information (as intended). Moreover, in our experiment only about 20% of the visual field was filled with either green or red objects. The remaining 80% of the visual field was black. It could therefore be that the average colour of both scenes was still too similar. We therefore repeated the experiment, but now covering the whole scene with either red or green fabric. This should increase the influence of the scene both if local contrast plays a critical role for obtaining colour constancy and if the average colour of the scene is important.

We found a clear difference between the matches using the Pantone colour Specifier and those using a computer

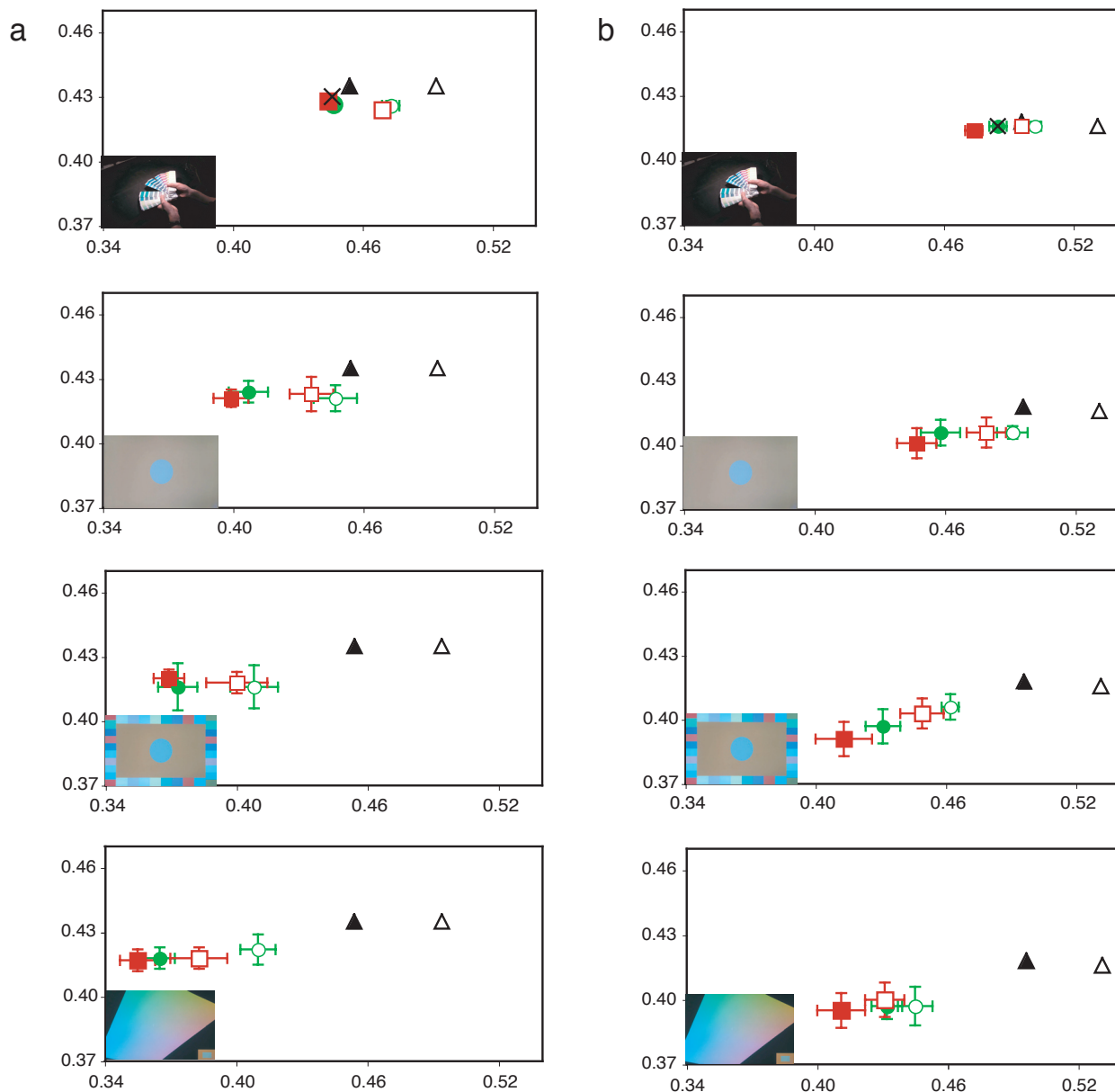


Figure 4: Average colour settings (with standard errors across subjects) for the four matching conditions (see inserts) and two test plates (a, b) of experiment 1. Plots show x and y CIE coordinates on the horizontal and vertical axes respectively. Squares represent matches made for the 'red scene' and circles represent matches for the 'green scene'. Open and solid symbols show data for the two lamps. Triangles show the settings that subjects would have made if they had perfectly matched the light reaching their eyes. The cross (only shown for the Pantone Specifier) indicates the value for perfect colour constancy (obviously independent of the lamp).

monitor. These differences were present even though we took care to match the tasks in various ways. The conclusion with respect to the Grey World Hypothesis, however, is the same for both tasks. Because the Pantone Specifier showed the most reliable matching data, we only used this matching method in our second experiment.

Experiment 2

Methods

The methods, procedure and analyses were identical to those used for the Pantone Specifier matching condition in experiment 1. The only difference was that we draped a large red or green cloth across the whole scene. We will refer to the scene in which everything was green or red as the 'uniform green' and the 'uniform red' scene respectively. We used the same red and green objects, positioned at roughly the same locations as in experiment 1 (see figure 5). The same two lamps and two test plates of experiment 1 were used. The same six subjects also participated in experiment 2.



Figure 5: Scene used for the 'uniform green' (top) and the 'uniform red' (bottom) conditions of experiment 2.

Results

The results are shown in figure 6. Filling the whole scene with one colour hardly made a difference (compare figure 6 with the upper row of figure 4). There was still only a very small difference between matches for the red and green scenes (compare squares with circles). Colour constancy was also still far from complete: subjects' matches clearly depended on the illumination (compare open and solid symbols).

General Discussion

Even when we filled the whole scene with either green or red surfaces, the bias in subjects' colour perception was very modest. The Grey World assumption predicts a very large effect: corresponding with the differences between the colours shown in figure 3 (note that figures 4 and 6 only show the region within the dashed rectangle in figure 3). This could imply that the visual system managed to recognize the fact that the objects were biased in chromaticity, rather than the differences arising from differences in illumination. The information with which to do so is available from highlights, shadows and mutual reflections [21]. This would explain why colour constancy was quite poor in our experiments, although we used real scenes, which could be expected to lead to good colour constancy [22]. Subjects may have noticed that the objects were chromatically biased, and therefore avoided relying on the Grey World Hypothesis.

Thus subjects may rely on the Grey World Hypothesis to achieve colour constancy under some conditions, but recognize that they should not do so in others, such as the present ones. In any case, the present study shows that we do not automatically rely on the Grey World Hypothesis to isolate surface reflectance from influences of the illumination.

We found differences in reliability between subjects' matches with the Pantone Specifier and with a CRT. The Pantone Specifier provided the most reliable matches. There were also large systematic differences (see figure 4). This suggests that there is some fundamental difference between the matching tasks [23, but see 24]. We were able to exclude some low-level explanations for the differences in results found between the Pantone Specifier and the CRT matching condition. We conclude that there must be some more subtle or fundamental difference between the matching conditions.

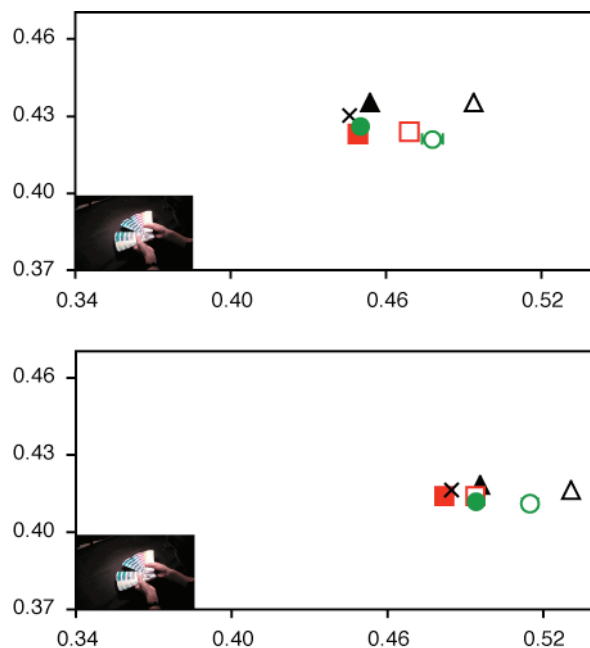


Figure 6: The top and bottom figures show the means and standard errors (mostly smaller than the symbols) of the matches made for the two test plates in experiment 2. For further details, see figure 4.

Acknowledgements

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Authors Biography

Jeroen Granzier works as a PhD student at the Vrije Universiteit in Amsterdam (The Netherlands) where he studies colour constancy using psychophysics under supervision of Jeroen Smeets and Eli Brenner, who are both co-authors of this manuscript.