Colour perception: contrast and adaptation

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The effects of chromatic adaptation on colour constancy were studied under six illuminants, using Munsell samples and asymmetric colour matching. In our colour constancy studies we used test stimulus within a neutral background field and additional blank surround in a region outside the background. We did experiments with a different time (200 ms, 1 s, 5 s, 30 s) of exposure of stimuli. The longer the adaptation time the greater the shift of perceived test colour, but not in our case. It was found that the length of the perceptual shift does not continuously depend on the duration of adaptation, and there is no considerable difference between the size and shape of perceived ellipses. We could make an assumption that introducing a remote blank surround reduces chromatic adaptation.

Key words: colour perception, colour constancy, chromatic adaptation

INTRODUCTION

The perceived colour of an object depends on the spectral distribution of the light reflected from it and on the incident illumination. Despite the fact that the spectral content of light illuminating receptors depends on the "colour" of illumination, the perceived colour of the object is stable. The mechanism of this phenomenon, called colour constancy, is still unknown. For example, an object which appears to be white in daylight, will be so at indoors yellowish incandescent or bluish illumination, as well as at a wide range of other coloured illuminations. We are aware that surfaces in general change their colour appearance in artificial lighting as compared to daylight, but the colour shifts are smaller than would be expected from the spectral properties of the reflected light.

Colour constancy is usually described in terms of the von Kries hypothesis [1] which states that the sensitivity of a cone type is reduced by a factor which is proportional to its excitation by adaptation light (for example, in the red light, the long-wave sensitive L-cones become less sensitive than middle M- and short S-wave sensitive cones, and the "redness" is reduced). Chromatic adaptation has been a subject of prime interest throughout the history of vision research; but still this phenomenon is only partly understood. Many investigators have examined various properties and theories of chromatic adaptation. These studies have been reviewed by Wright, Terstiege, and Lennie and D'Zmura [2–4]. However, the simple von Kries hypothesis fails to describe the experimental data presented by Brainard, Wandell and Worthey, Brill [5, 6]. There is at present no consensus as to a theory that describes this colour constancy. Thus, the mechanisms are is still unknown and the von Kries hypothesis cannot explain this phenomenon. We know that changes in illumination may cause large changes in the perceived colour [7], and although the visual system is capable of cancelling some of physical chromaticity, considerable colour shifts still remain.

It is well-known that chromatic adaptation is a change in the perceived colour of a light, caused by closely located stimuli. Spatially or temporally related surrounds can have profound effects on the colour appearance of illuminated objects [8, 9]. A problem for understanding both chromatic adaptation and colour constancy is the influence of remote lights in a scene, especially when the background is more complex than a single uniform region. A visual stimulus in a noncontiguous remote region (context) can affect the colour appearance of a light in a different way than the same stimulus presented in a contiguous region (contrast), so that a given stimulus may have different effects depending on whether it is adjacent to the test patch or remote from it [10–13].

The aim of our experiment was to check how chromatic adaptation influences colour shifts, how the effect of stimulus test-parameters is determined by different adaptation-times (between 200 ms and 30 s). In our colour constancy studies we used a test stimulus within a neutral background field and additional blank surround in a region outside the background (see Fig. 1).

METHODS

Subjects

Four subjects participated in the experiments, all with normal colour vision, normal or corrected to normal visual acuity, and all were experienced observers.

Apparatus

The experiments were conducted in a dark room. The stimuli were generated with a 3 × 12-bit colour processor (Cambridge Research Systems) and presented on a 20 in. calibrated colour monitor (Barco Reference Calibrator ©) driven by a VSG card. The monitor was warmed up 2 h before the beginning of the experiments and it was re-calibrated with inbuilt routine before each experimental session. The outcome of this re-calibration was checked before and after the experiments with a spectral photometer (SpectraScan PR650). The screen was viewed from the distance of 30 cm with head fixated in a box (75 × 75 × 100 cm) enclosing the front of the monitor.

Stimuli

One complete set of Munsell samples was used in testing tasks. The samples are classified in terms of Munsell hues, value (brightness) and chroma (saturation). Constancy was tested for 40 Munsell samples 7/4 (value 7, chroma 4) on a neutral background N7. The hues of Munsell samples were arranged from numbers 1 to 40, starting with purple (P), then purple-blue (PB), blue (B), blue-green (BG), green (G), green-yellow (GY), yellow (Y), yellow-red (YR), red (R), and finally red purple (RP) completing the full colour circle. For each colour group there were four levels: 2.5, 5, 7.5, and 10 (for example: 10P, 7.5P, 5P, 2.5P, 10B, … 10RP, 7.5RP, 5RP, 2.5RP), hence totalling to 40 Munsell hues.

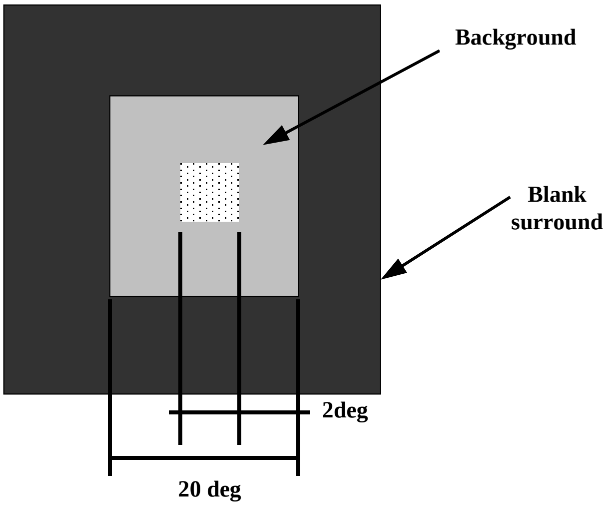

Fig. 1. Stimuli used in experiments.
TM marks the position of the test Munsell sample. The underlying dot-pattern is not present in the actual test-stimulus and is shown here only to indicate the presence of colour. N7 is background

All 40 Munsell samples were simulated as colour test-patterns and were presented in the centre of the screen, subtending diameter 2 deg, surrounded by a 20 deg diameter neutral background N7 (Fig. 1).

Procedure

After spending some time (at least 15 min) in a dim room, a subject initially was pre-adapted for over 1 min to the uniform N7 background under standard illuminant C, average daylight with correlated colour temperature of 6774 K (co-ordinates u’ = 0.200901; v’ = 0.460918). The test sample within the background was exposed for 0.2, 1, 5 and 30 s under one of six illuminants (see below). After the test-stimulus exposure, the subject readapted for 1 s to illuminant C and only then the matching sample appeared (Fig. 2). The subject adjusted the hue, chromas, and values of this sample under standard illuminant C to match the appearance of the test sample. The duration for making this match was not restricted, but generally it took well over 30 s. The presentation cycle (adaptation to illuminant C, test, re-adaptation to C and matching under C) could be repeated until matching of colour appearance was satisfactory. The subject frequently re-

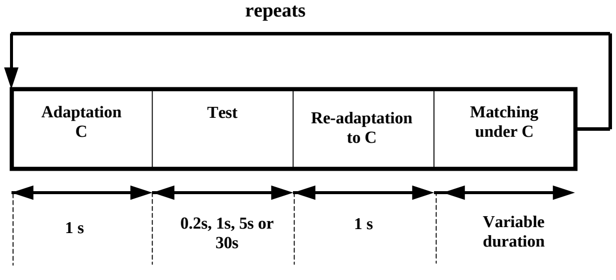

Fig. 2. Layout of experimental sequence.
Adaptation C: neutral background under C illuminant was presented for 1 s; test: time interval of 0.2 s, 1 s, 5 s or 30 s during which the subject could see the test Munsell sample under one of six test illuminants (A, s, r, g, y, b); re-adaptation to C: neutral background under C illuminant was presented for 1 s to ensure stable receptoral adaptation; matching under C: the subject made his/her judgement, the time for making this match was not restricted

adapted to the neutral background (N7) under C, thereby ensuring stable receptoral adaptation and maintaining the influence of post-receptoral mechanisms.

The following illuminants were tested (u'/v' co-ordinates in brackets): illuminant A, black body radiation at a temperature of 2856 K (0.255962/ 0.524318), illuminant S, illumination of extremely blue sky chromaticity, co-ordinates close to the infinite temperature locus of the Plankian curve (0.174433/0.392305); four illuminants placed on red-green and yellow-blue cardinal axes: red r (0.261846/ 0.453317), green g (0.151799/0.466737), violet v (0.21167/0.37666), and yellow y (0.193933/0.518012), as shown in Fig. 3. The spectral content of these sources of light was described by Breivė et al. [14].

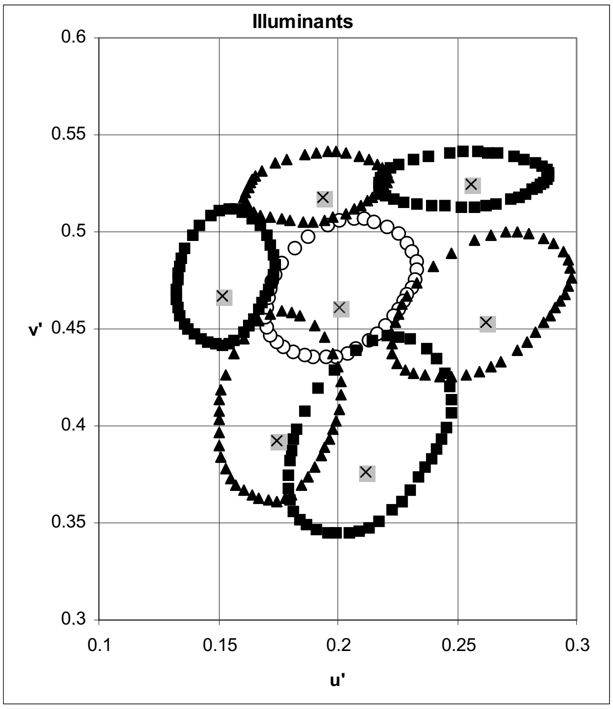

Fig. 3. Layout of samples under reference illuminant C (open circles) and test illuminants A, g, b (filled squares) and r, y, s (filled triangles) plotted in CIE 1976 (u'v') chromaticity diagram

Analysis

We presented the data in which the colour constancy was evaluated by comparing perceptual to physical changes of chromaticity co-ordinates (CIE (1976) u'v' plane), according to the methods described by Kulikowski et al. [15, 16].

RESULTS AND DISCUSSSION

The results of matching by each of the four subjects were analysed separately and all repeats under separate illuminant were averaged in terms of chromaticity (u'/v').

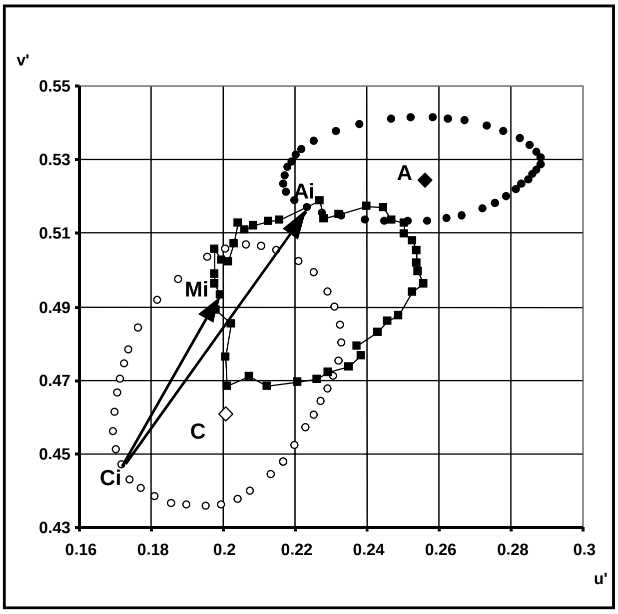

Fig. 4. Loci of 40 simulated Munsell samples.
Open circles u'v' parameters under standard illuminant C; filled circles – u'v' parameters under test illuminant A; filled squares – subjective settings. Filled and empty diamonds indicate u'v' locations for neutral backgrounds under C and A. Vector CiMi shows the perceptual shift of one Munsell sample (10BG 7/4) and vector CiAi shows the physical shift

Figure 4 shows the three loci of 40 Munsell samples, u'/v' parameters of which were determined for illuminant C (empty circles) and for illuminant A (filled circles). The third locus shows the subjective (perceptual colour) matched by one subject (filled squares) (Fig. 4). The matching loci are not as regular as the two others. The objects (in our case Munsell samples) change colour with illumination, but the perceptual changes are much smaller than expected from their physical reflectance. In our case, the perceptual shift (vector CiMi) is shorter than the physical shift (vector CiAi) (Fig. 4). This relevant invariance, or colour constancy, is important for object identification.

We decided that complete perceptual constancy is impossible under brief presentation of test samples in our colour constancy experiments (as a result of weak or absent adaptation). The colour of the test stimulus and the colour of the neutral background must change during adaptation. The longer the adaptation time the greater the shift of the perceived test colour. But that was not our case. As may be seen from Figs. 5 and 6, our results contradict this finding. Firstly, the length of the perceptual shift does not continuously depend on the duration of adaptation. Secondly, our results have shown that large perceived

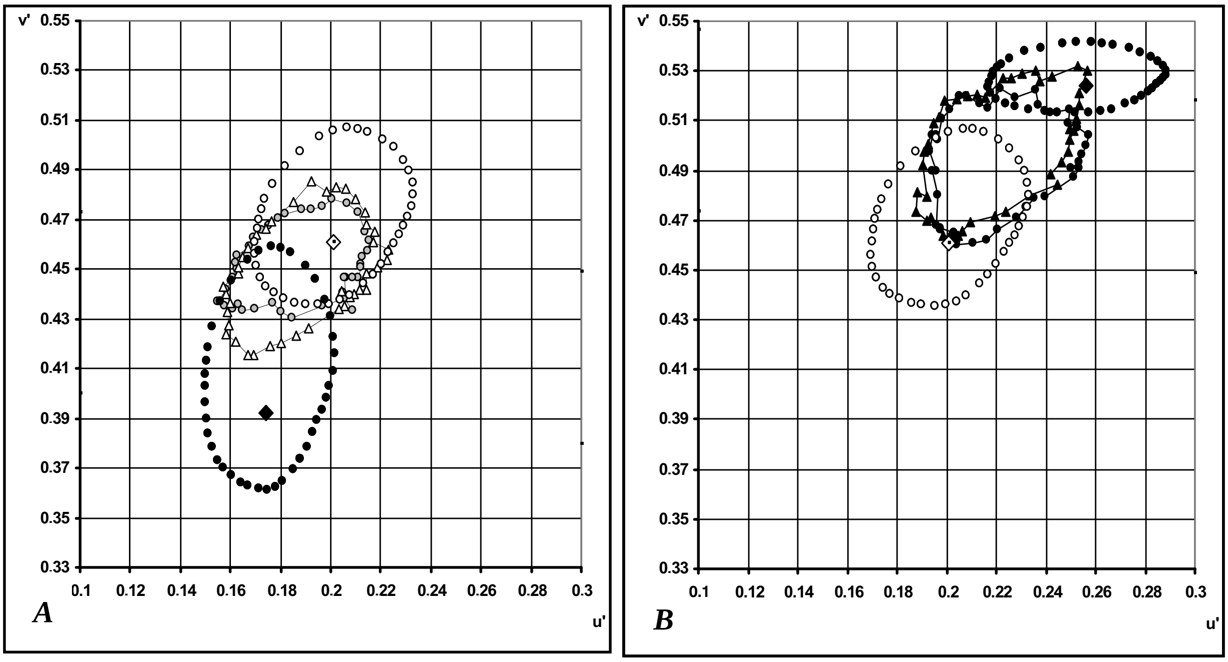

Fig. 5. A Subjective colour matching of Munsell samples under illuminant s as a mean of 4 subjects, when presentation times are 200 ms and 1 s. Open circles – u'v' parameters under standard illuminant C; Filled circles – u'v' parameters under test illuminants s; filled grey circles – subjective settings when presentation time is 200 ms; empty triangles – subjective settings, when presentation time is 1 s

B Subjective colour matching of Munsell samples under illuminant A as a mean of 4 subjects, when presentation times are 200 ms and 1s. Open circles – u'v' parameters under standard illuminant C; filled circles – u'v' parameters under test illuminants A; filled circles – subjective settings, when presentation time is 200 ms; filled triangles – subjective settings when presentation time is 1 s

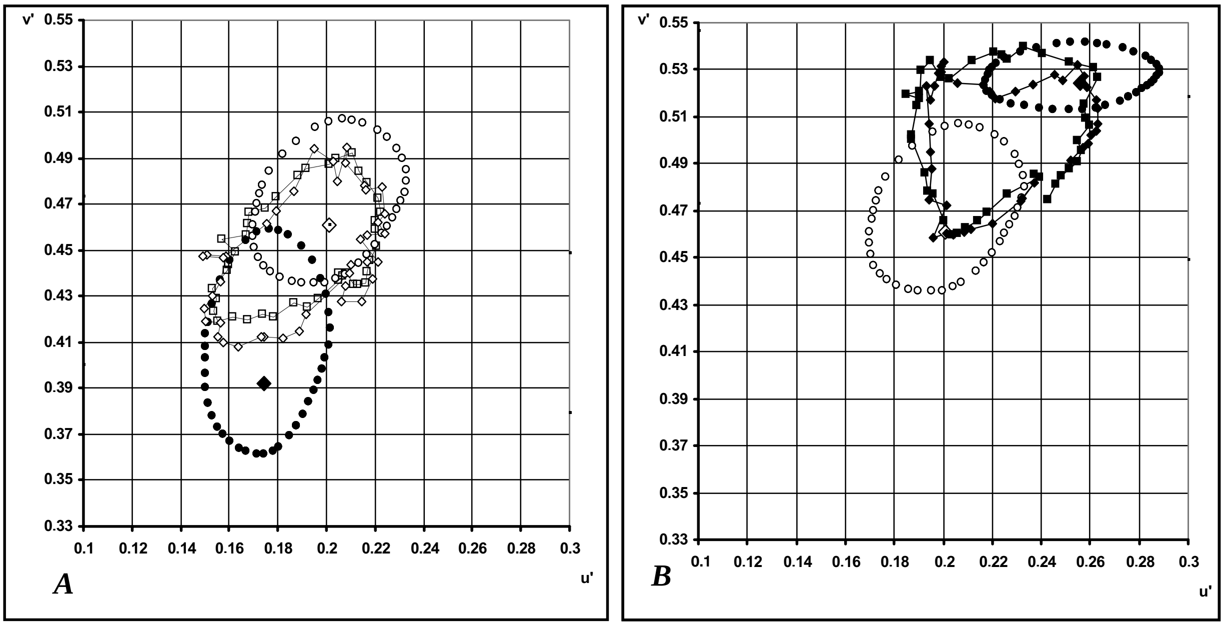

Fig. 6. A Subjective colour matching of Munsell samples under illuminant s as a mean of 4 subjects, when presentation times are 5 s and 30 s. Open circles – u'v' parameters under standard illuminant C; filled circles – u'v' parameters under test illuminants s; empty diamonds – subjective settings, when presentation time is 5 s; empty squares – subjective settings when presentation time is 30 s

B Subjective colour matching of Munsell samples under illuminant A as a mean of 4 subjects, when presentation times are 5 s and 30 s. Open circles – u'v' parameters under standard illuminant C; filled circles – u'v' parameters under test illuminants A; filled diamonds – subjective settings, when presentation time is 5 s; filled squares – subjective settings when presentation time is 30 s colour shifts are not correlated with the duration of adaptation. That is valid for all six illuminations tested. Thirdly, there is no considerable difference between the size and shape of ellipses corresponding to the perceived test-samples under short (200 ms) and longer (1 s) presentation (compare: filled grey circles with empty triangles, and filled circles with filled triangles, Fig. 5) or long (5 s and 30 s) (compare: empty diamonds with empty squares, and filled diamonds with filled squares, Fig. 6). What is the reason for that? Contrary to our expectations, the obtained results imply that the perceived colour depends upon both the difference between the test and the background colours and the colour of the background. Hence follows that the perceived colour is determined by both colour difference of test stimulus relatively to the background and the colour of the background itself [17–19].

We could suggest that the results in Fig. 5 and in Fig. 6 show that introducing a remote blank surround reduces the chromatic adaptation to the background. The colour of test samples is determined by the difference in colour of test samples and the background and the colour of the background. In turn, the colour of the background is also determined by a difference in colour between the background and the blank surround. Since there is no adaptation in the blank surround, nothing changes. (Dark regions normally represent areas of very low reflectance, so they provide little or no information about the illuminant.) Thus there is no influence of the observation time on the perceived colour. Our results coincide with Valberg, Lange-Malecki conclusions [7]. However, there are no data how the blank surround influences the adaptation.

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SPALVŲ SUVOKIMAS: KONTRASTAS IR ADAPTACIJA

Santrauka

Darbe tiriama, kaip tarpusavyje yra susijęs spalvinis konstantiškumas (pastovumas) ir spalvinė adaptacija, kokią įtaką spalvų suvokimui, esant įvairiems apšvietimams, turi jų stebėjimo laikas ir stimulų erdvinės savybės. Spalvų konstantiškumo eksperimentuose spalvinės adaptacijos procesus tyrėme asimetriniu stimulų lyginimo metodu panaudodami 7 skirtingus plataus spektro apšvietimo šaltinius. Testiniais stimulais buvo ant neutralaus (N7) 20° dydžio fono generuojami 2° dydžio keturiasdešimt Manselio pavyzdėlių. Likusią monitoriaus dalį užpildė tuščioji aplinka, kuri atrodė kaip juodas laukas. Testinis stimulas tiriamajam buvo rodomas 200 ms, 1 s, 5 s, 30 s.

Kuo ilgesnė adaptacija esant testiniam stimului, tuo turėtų būti didesnis suvoktos spalvos poslinkis, bet mūsų eksperimentai to nepatvirtino. Mūsų atveju suvoktos spalvos poslinkis nepriklauso nuo adaptacijos trukmės. Be to, nėra didelio skirtumo tarp suvoktų spalvų elipsių formų ir dydžių. Todėl manome, kad eksperimento metu monitoriaus ekrane matoma tuščioji aplinka mažina spalvinę adaptaciją.