# Does realistic rendering of a gradient in illumination increase chromatic induction?

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**ABSTRACT**

Placing a background consisting of two parts with a different surface reflectance behind two physically identical surfaces makes the two surfaces look different from each other. This is a phenomenon known as chromatic induction. Chromatic induction can be seen as a misdirected attempt to maintain color constancy: the visual system erroneously attributes (part of) the difference in the light reaching the eye from the two parts of the background to a difference in illumination instead of a difference in reflectance. In the present paper we examine whether subjects attribute more of the differences between light from different parts of the background to the illumination if the scene is rendered in a manner that suggests that there is a difference in illumination. We simulated a single surface illuminated by an ambient illumination and a lamp with a different spectral power distribution near one of the two surfaces that subjects had to match. We found a very modest level of chromatic induction. Thus realistic rendering of a gradient in illumination does not increase chromatic induction.

## 1. INTRODUCTION

The color of the light that reaches our eyes depends on the spectral properties of the reflectance of the surfaces that we look at, as well as on the spectral power distribution of the illumination. Nevertheless, surfaces hardly change in color appearance when the spectral power distribution of the illumination changes: a phenomenon known as color constancy[1]. How does the visual system succeed in discounting the contribution of the illumination? There being a dominant color in the light coming from a scene can be the consequence of a bias in the illumination or of a bias in the reflectance of the surfaces in the scene. If the visual system assumes correctly that a bias in the dominant color of the light coming from the scene is the consequence of a bias in the spectral power distribution of the illumination, and consequently compensates for this bias, color constancy is achieved[2]. On the other hand, if the visual system erroneously assumes that a bias in the dominant color of the light coming from the scene is the consequence of a bias in the spectral power distribution of the illumination, and compensates for this bias, we experience chromatic induction. In accordance with this interpretation[3], chromatic induction appears to be weaker in simple displays, in which it is evident that the surrounding surfaces have different reflectances, than in more complex displays, in which pictorial depth cues suggest that the illumination rather than the reflectance of the background is different[4].

It is reasonable to assume that if the experimental stimulus contains many indications that it is correct to assume that the illuminant is chromatically biased, as is the case with real scenes, subjects will exhibit strong color constancy. In real scenes, about 80% of the illumination-induced bias in the color of the light reaching the eye is attributed to the illumination and ignored[5-8]. Could the reason why only about 40% is attributed to the illumination in simulated scenes[9-13] be that in real scenes efforts are seldom made to remove direct information about the illumination, whereas simulated scenes do not contain such information unless it is specifically added, which it seldom is?

The classical way to measure chromatic induction is with a simple stimulus consisting of two disks each surrounded by an annulus[14-16]. The stimulus itself is totally devoid of any indication that the differences between the dominant color in the light coming from the two annuli is a consequence of differences in illumination rather than of differences in reflectance. We wanted to investigate whether we could increase chromatic induction in rendered scenes by introducing a gradient of illumination and specular highlights to give the impression that the difference in the light from the background is caused by a difference in illumination. We asked subjects to match the appearance of two disks. We used various backgrounds, illuminants and intensities of the gradient to see whether any of these factors had an effect on the magnitude of chromatic (and luminance) induction.

## 2. METHOD

**Apparatus**

The stimuli were presented on a calibrated Sony GDM –F520 monitor (39.2 by 29.3 cm; 1024 by 768 pixels; 120 Hz; 8 bits per gun) in an otherwise dark room. Subjects sat 100 cm from the screen with their chins and foreheads supported.

**The background**

The 16 by 16 degree square background consisted of an array of 30 by 30 squares. In the 'fixed pattern' condition, there were only four different simulated surface reflectance's in the background, and they were arranged systematically (see Figure 1). In the 'random pattern' condition the same reflectances were arranged irregularly. In the 'random colors' condition each background square had a different simulated reflectance. In the 'grey background' condition the background had a uniform achromatic reflectance. The space averaged simulated reflectance of all the background conditions was the same.

**The illumination**

The simulated scene was always illuminated by a distant lamp (ambient illumination) and a near lamp (simulated to be 40 cm above the surface, 7 cm from the left and upper borders of the screen). We had two illumination conditions: one more or less natural illumination condition combining 1931 CIE standard illuminant C as a distant lamp with CIE standard illuminant A as a local lamp (shown in Figure 1), and a second condition with a green (x= 0.38, y= 0.33) distant lamp and a red (x=0.30, y=0.40) local lamp. The simulated local illumination caused a gradient of luminance and chromaticity across the screen. We used two different ratios between the intensities of the two sources of illumination: a bright local lamp (the luminance directly under the lamp is 166% higher than the ambient value; Figure 1) and a much dimmer local lamp (the luminance directly under the lamp is only 37% higher than the ambient value).

**The test & reference disks**

A 1 degree diameter reference disk was presented at the top left corner (see Figure 1). Its reflectance was chosen so that the light that reached the eyes from that surface had a luminance of 12.5 cd/m$^2$ and a chromaticity of [x= .317, y= .367], [x= .350, y= .367] or [x= .333, y= .333]. Subjects adjusted the luminance and chromaticity of a 1 degree diameter test disk at the bottom right to appear to have the same hue and brightness as the reference disk. They could vary the test disk's hue (within the part of the two-dimensional 1931 CIE color space that we could render on the monitor) by moving a computer mouse. They could increase or decrease the luminance by pressing the arrow keys of the computer keyboard. Subjects indicated that they were content with the set value by pressing the mouse button. Once they did so, a new stimulus appeared. The initial hue and luminance of the test disk was determined at random from within the range that could be set.

**Subjects**

Two authors (JG and JS) and six naive subjects each took part in a session with the bright lamps and then in a session with the dim lamps. All subjects had normal color vision as tested with Ishihara color plates[17]. In each session subjects dark-adapted for 10 minutes and then made 5 settings for each combination of the 3 reference reflectances; 4 background conditions and 2 illumination conditions. The 120 settings within a session were presented in random order.

**Analysis**

We first determined the median (x, y) and the median luminance values of each subject's setting for each of the eight experimental conditions and three different references. A total of 24 median values were calculated for each session per subject. We defined a color induction index as the difference between the set color of the test disk and the color of the reference disk, as a percentage of the difference that we would expect if subjects attributed all differences in the background to differences in illumination; perfect color constancy. So 100% indicates a perfect reflectance match and 0% indicates a perfect match between the light from the test and reference disks (no chromatic induction). The differences were expressed as distances in CIE color space. Only the component of the differences in the direction that would give perfect color constancy were considered. We defined a luminance induction index as the difference between the set luminance and the reference, as a percentage of the difference that we would expect if subjects had attributed all differences in the background luminance to differences in illumination. We averaged the induction indices across the three references to obtain mean induction indices for each subject, for each of the 16 experimental conditions. Repeated measures analyses of variance were used to evaluate the influence of the within-subjects factors 'background condition', 'illuminant condition' and 'illuminant ratio'.

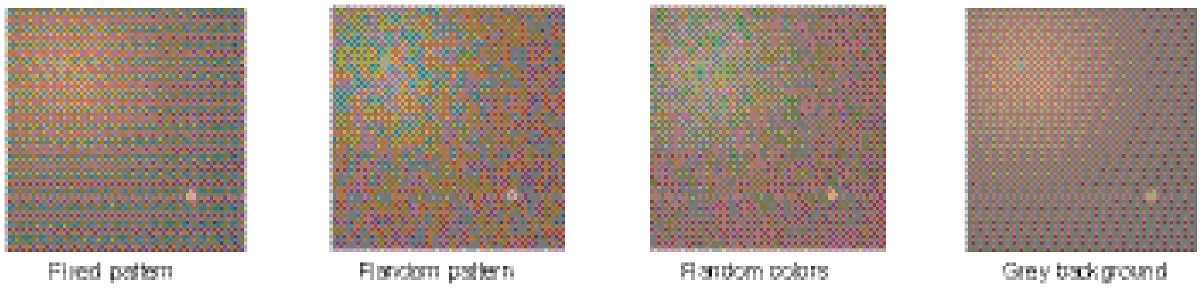


**Figure 1:** The four kinds of background illuminated by standard illuminants C (ambient illumination by an overcast sky) and A (a tungsten filament lamp near the top left corner).

## 3. RESULTS

The overall average index of chromatic induction was only 10%. The overall average index of luminance induction was 55%. A significant effect of the background condition was found on both chromatic induction ($F_{1,3}$=11.01; p<0.01) and luminance induction ($F_{1,3}$=25.54; p<0.01). The magnitude of the chromatic induction was larger and that of luminance induction was smaller for the grey background than for the other three background conditions (see figure 2). The chromatic ($F_{1,1}$= 30.06, p<0.01) and luminance ($F_{1,1}$=64,40; p<0.01) induction were both significantly smaller for the dim lamp than for the bright lamp (18% versus 1% for color and 67% versus 43% for luminance). For luminance induction, there was also an interaction between the factors background condition and illuminant ratio ($F_{1,3}$=9.59; p<0.01). Luminance induction was particularly weak with the dim lamp for the grey background condition. A significant main effect of illuminant condition was found for luminance induction ($F_{1,1}$=6.40; p<0.05), but not for chromatic induction. The luminance induction was higher for the A-C illuminant condition than for the red-green illuminant condition.

## 4. CONCLUSIONS

Our attempts to obtain a high level of chromatic induction by recruiting mechanisms designed to achieve color constancy[18] clearly failed. The level of chromatic induction was similar to that in simple displays, where there is no reason to believe that the different surfaces are under different illuminations[14-16]. The only clear effect of the background was that there was less induction with more chromatic variability, which has been demonstrated before[15]. A possibly important difference between our study and the studies that have shown near perfect color constancy in real scenes[5-8], is that we have an 'unexplained' transition at the borders of the screen. We also presented a single (patterned) surface and our subjects were fully aware that they were judging emitted rather than reflected light. We cannot tell which, if any, of these factors is important[5-8], but we here show that making the difference in background chromaticity in different parts of the scene consistent with a realistic gradient in illumination has very little -if any- effect on chromatic induction.

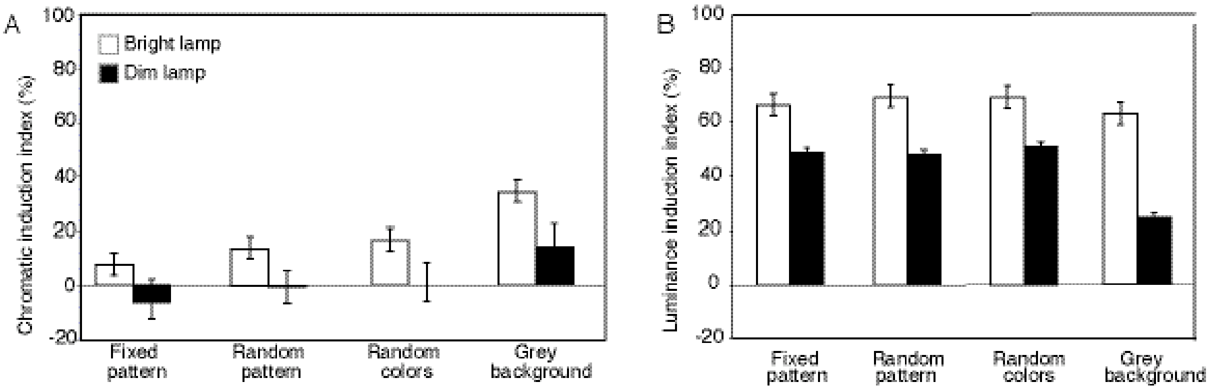


**Figure 2:** Overall average chromatic (A) and luminance (B) induction for each of the four background conditions, for the bright (white bars) and dim (black bars) lamps. Bars show averages across 8 subjects, 3 references and 2 illumination conditions. Error bars show the Standard Error between subjects.

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