The Extent of Metamer Mismatching

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ABSTRACT

Metamer mismatching refers to the fact that two objects reflecting light causing identical colour signals (i.e., cone response or XYZ) under one illumination may reflect light causing non-identical colour signals under a second illumination. As a consequence of metamer mismatching, two objects appearing the same under one illuminant can be expected to appear different under the second illuminant. To investigate the potential extent of metamer mismatching, we calculated the metamer mismatching effect for 20 Munsell papers and 8 pairs of illuminants (Logvinenko & Tokunaga, 2011) using the recent method (Logvinenko, Funt, & Godau, 2012) of computing the exact metamer mismatch volume boundary. The results show that metamer mismatching is very significant for some lights. In fact, metamer mismatching was found to be so significant that it can lead to the prediction of some paradoxical phenomena, such as the possibility of 20 objects having the same colour under a neutral ("white") light dispersing into a whole hue circle of colours under a red light, and vice versa.

1. INTRODUCTION

As a result of metamer mismatching two objects appearing as having the same colour under one illuminant can appear as having different colours under a second illuminant. In fact, a single colour signal under a first illuminant projects into a volume of potential colour signals under a second illuminant known as its metamer mismatch volume. It is frequently believed that metamer mismatching is not all that serious, however, we show here the metamer mismatch volumes can be very large. Fig.1 shows an example of a metamer mismatch volume produced by the flat spectral reflectance function (0.5 across the visible spectrum) for the case of a change from a red illuminant to a neutral ("white") illuminant.

2. METAMER MISMATCH VOLUMES UNDER 6 ILLUMINANT CONDITIONS

A metamer mismatch volume is a convex body, and therefore can be specified by its boundary. The boundary can be computed precisely using the code of Logvinenko et al. 2012 (Logvinenko et al., 2012), which determines the maximum amount of potential metamer mismatching that can occur for any given colour signal. In order to look into the implications of metamer mismatching, we computed the metamer mismatch boundary surfaces for the colour papers used by Logvinenko & Tokunaga (2011). Specifically, they used 20 chromatic Munsell papers [(i) 10RP5/14, (ii) 5R4/14, (iii) 10R5/16, (iv) 5YR7/14, (v) 10YR7/14, (vi) 5Y8/14, (vii) 10Y8.5/12, (viii) 5GY7/12, (ix) 10GY6/12, (x) 5G5/10, (xi) 10G5/10, (xii) 5BG6/10, (xiii) 10BG5/10, (xiv) 5B5/10, (xv) 10B5/12, (xvi) 5PB5/12, (xvii) 10PB4/12, (xviii) 5P4/12, (xix) 10P4/12, (xx) 5RP5/12] along with a grey (N5/) and a black (N1/) paper. They also used six different lights to illuminate the papers: neutral (N), yellow (Y), blue (B), green (G), and two reds (R1 and R2) of which we will only consider R1 and label it R. Their spectral power distributions are plotted in Logvinenko et al. (Logvinenko & Tokunaga, 2011).

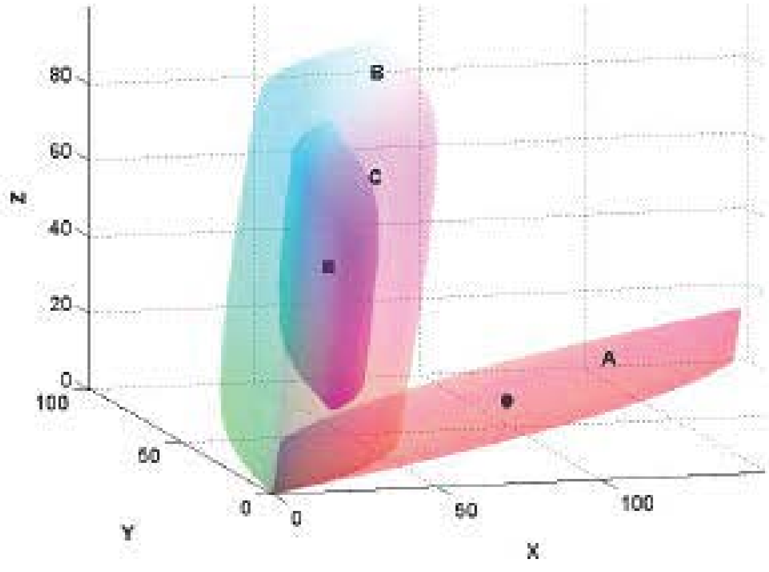

Figure 1: Label A indicates the object colour solid under red light (R). Label B indicates the object colour solid under neutral light (N). The black dot indicates the XYZ of flat grey under red. The black square shows its XYZ under neutral. C indicates the metamer mismatch volume of the flat grey for a change in illumination from red to neutral.

Each illumination condition is described by a pair of illuminants, for example N and Y, and written as NY. We evaluated the metamer mismatch boundary surfaces for the 20 chromatic Munsell papers under the 8 illuminant pairings NR, NY, NG, NB, RN, YN, GN, BN based on the CIE 1931 colour matching functions (Wyszecki & Stiles, 1982). The intersection of mismatch volumes can be hard to see in a 3D plot, so instead we will plot 2D projections of the volumes in the CIE 1931 chromaticity diagram. The set of the xy chromaticity coordinates of the points in a metamer mismatch volume forms the *chromaticity mismatch area* in the CIE chromaticity plane showing how the initial chromaticity disperses due to metamer mismatching. Fig. 2 shows the chromaticity mismatch areas for the NY and NB illumination conditions. Clearly, the chromaticity mismatch areas are significant, even for the NY illumination condition. Note that not only are the areas big, the chromaticity mismatch area for a single paper covers the chromaticities of many other papers. For example, for B, the metamer mismatch area of paper *ii* covers the chromaticities of 18 of the 20 Munsell papers. For the G and R illuminants, some of metamer mismatch areas cover all 20 Munsell papers.

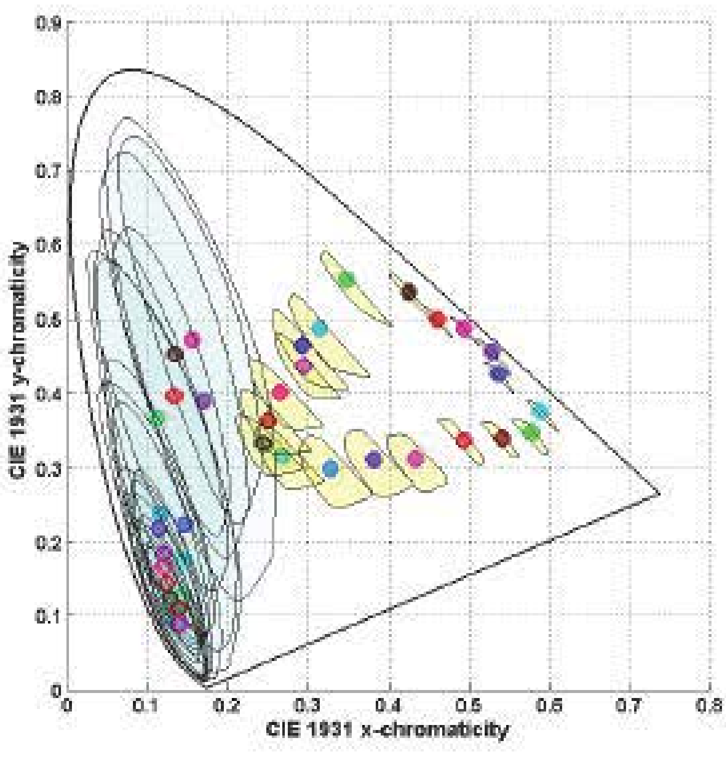

Figure 2: Chromaticity mismatch areas for the shifts from N to the Y and B illuminants. The circular markers are the chromaticities of the 20 Munsell papers under the corresponding illuminant. The mismatch areas for NY are the smaller yellow areas on the right, and for the NB are the larger bluish areas on the left.

3. METAMERIC HUE CIRCLE

The seriousness of metamer mismatching leads to some paradoxical phenomena. For example, for each point in the metamer mismatch volume in the red-light-changed-to-neutral-light condition there exists a reflecting object such that the CIE XYZ tristimulus coordinate of the light reflected by it under the red illumination is equal to that reflected by the flat grey, while the CIE XYZ tristimulus coordinate of the light reflected by it under the neutral illumination differs from that reflected by the flat grey. Consider a sample of such objects representing each point in the metamer mismatch volume. The following question arises: How large is the difference in colour signals within this sample under the neutral light? To answer this question we ascertained which Munsell papers fell into the corresponding metamer mismatch volume. It turns out that, being illuminated by the neutral light, 28% of the 1600 Munsell papers reflect light having CIE XYZ tristimulus values that fall into the metamer mismatch volume in question. While papers from this subset of the Munsell collection are not themselves metameric to the flat gray under the red illumination, they represent the colour of some real objects whose XYZs fall within the metamer mismatch volume. In other words, they give an indication as to the range of colours the flat grey reflectance potentially can become under the neutral illumination. As can be seen from Fig. 3, this range is very large. This figure includes 20 Munsell papers coming from every other page of the Munsell book of Colour. Note their significant Munsell chroma. It is quite a paradoxical phenomenon that metamer mismatching can occur to such a large degree that it can lead to the possibility of 20 objects having the same colour as the flat grey reflectance under a red light that then disperse into a whole hue circle of colours under a neutral light, and vice versa.

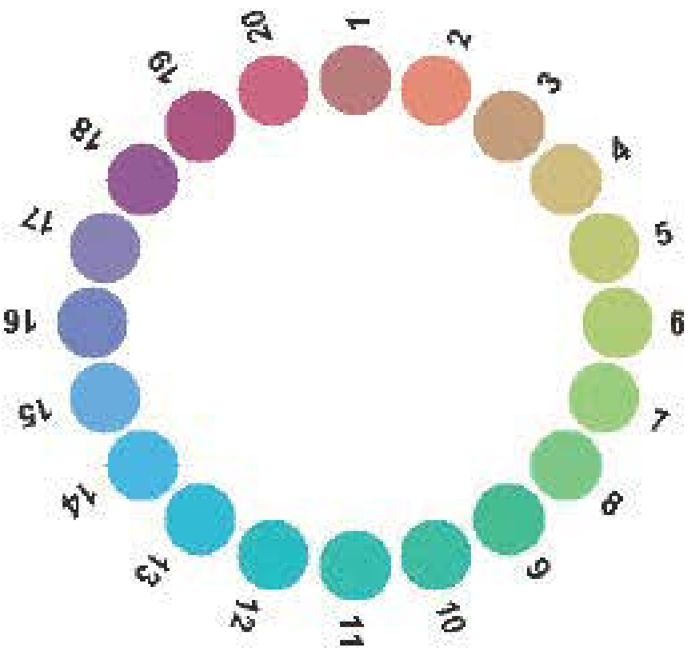

Figure 3: Pictorial representation of the 20 Munsell papers lying inside the metamer mismatch volume for the RN illumination condition (5R6/8, 10R7/10, 5Y7/6, 10YR8/6, 5Y8/6, 10Y8/6, 5GY8/6, 10GY8/8, 5G7/8, 10G7/8, 5BG7/8, 10BG7/8, 5B7/8, 10B7/8, 5PB7/8, 10PB6/10, 5P6/8, 10P5/12, 5RP5/12, and 10RP6/12).

4. CONCLUSION

The extent of metamer mismatching is shown to be greater than might be initially expected. In some cases, the metamer mismatch volume fills more than half the object-colour solid. The effect is large enough that the flat grey reflectance under a red light disperses into a hue circle under a neutral light that can be represented by an appropriate selection of Munsell papers.

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