# Consideration on Hunt Effect Based on Maximum Color Separation Model

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## Abstract

The Hunt effect is an increase in saturation due to increment in the level of luminance. This paper discusses whether the color matching function spectral sensitivities impact the Hunt effect based on the color constancy model called Maximum Color Separation (MCS).

## Introduction

As is well known, the Hunt effect is an increase in saturation due to increment in the level of luminance[1]. In his original paper on the subject, it was suggested by Hunt that this visual effect can be attributed to an artifact of brain information processing. But there remains an unsolved question as to whether the color matching function spectral sensitivities impact the phenomenon? In this paper, this question is discussed based on the color constancy model called Maximum Color Separation (MCS) whose basic idea was proposed by N. Ohta in References 2 and 3. Based on the model, the relationship between the effect and the contribution of adjusting the sensitivities of the color matching functions is discussed.

### Outline of MCS

The human visual system has a capability called chromatic adaptation or color constancy that removes much of the influence of ambient illumination. In computation, the von Kries equation is often employed as a model for chromatic adaptation. The model is based on the assumption that white always remains white regardless of the illuminant. The model explains this effect by adjusting the sensitivity of respective receptors without changing the basic shape of spectral sensitivities. However chromatic adaptation or color constancy occurs even when there are no whites in a viewing field. We have tried to establish a new model different from the von Kries model. We can generally notice that under white illuminants, object colors look more vivid than under colored illuminants. This phenomenon has long been noticed, but it has never been applied directly in the research of chromatic adaptation and color constancy. This phenomenon has been employed to MCS. In MCS, the assumption is that the chromaticity gamut of an image reaches its maximum (maximum color separation) under white illuminant. As in the von Kries model, we assume that color under one illuminant can be transformed to the color under any other arbitrary illuminant through a diagonal transform. We further assume that our visual system adapts when moving to a new ambient illumination in such a way that the separation of respective colors is maximized thus giving the maximum chromaticity gamut.

The color space used is the $(r,g)$ color space in which the following transform is performed from $(R,G,B)$ color space.

$$r=\frac{R}{R+G+B}\ , \tag{1.a}$$

$$g=\frac{G}{R+G+B}\ , \tag{1.b}$$

$$b=\frac{B}{R+G+B}\ . \tag{1.c}$$

The transform framework from one illuminant to another illuminant to give a new $(R',G',B')$ is assumed to be as follows:

$$R'=\eta_R\cdot R\ , \tag{2.a}$$

$$G'=\eta_G\cdot G\ , \tag{2.b}$$

$$B'=\eta_B\cdot B\ , \tag{2.c}$$

where, $\eta_R$, $\eta_G$ and $\eta_B$ are transform coefficients, and applied to the three channels of $R$, $G$, $B$, respectively. The chromaticity coordinates transformed by Eqs. (2.a), (2.b), (2.c) are calculated using Eqs.(1.a)(1.b)(1.c), and are denoted by $(r',g',b')$. When the chromaticity gamut area $S$ becomes maximum by varying $\eta_R$, $\eta_G$ and $\eta_B$, we should obtain

$$\frac{\partial S}{\partial \eta_R}=\frac{\partial S}{\partial \eta_G}=\frac{\partial S}{\partial \eta_B}=0\ . \tag{3}$$

By solving Eq. (3), the coefficients of $\eta_R$, $\eta_G$ and $\eta_B$ to give the maximum chromaticity gamut can be obtained.

The aspect to be considered is the relationship between the assumption that objects will become more vivid under a white illumination and the parameter values of $\eta_R$, $\eta_G$ and $\eta_B$ as derived from Eq.(3). The area of the chromaticity gamut transformed through the diagonal transform is calculated by using the following equation.

$$S = \frac{1}{2}\left( \begin{vmatrix} r'_1 & g'_1 \\ r'_2 & g'_2 \end{vmatrix} + \begin{vmatrix} r'_2 & g'_2 \\ r'_3 & g'_3 \end{vmatrix} + \cdots + \begin{vmatrix} r'_n & g'_n \\ r'_1 & g'_1 \end{vmatrix} \right). \tag{4}$$

A series of transforms lead the numerators of $\partial S / \partial \eta_R$ , $\partial S / \partial \eta_G$ as follows and should be zero.

$$\sum_{i=1}^{n} \left(1 - r'_i - r'_{i+1}\right)\left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right) = 0 , \tag{5.a}$$

$$\sum_{i=1}^{n} \left(1 - g'_i - g'_{i+1}\right)\left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right) = 0 . \tag{5.b}$$

Eqs. (5.a) and (5.b) can be reformatted to produce the following equations.

$$\begin{aligned} &\sum_{i=1}^{n} \left(r'_i + r'_{i+1}\right)\left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right) \\ &\quad = \sum_{i=1}^{n} \left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right) \end{aligned} , \tag{6.a}$$

$$\begin{aligned} &\sum_{i=1}^{n} \left(g'_i + g'_{i+1}\right)\left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right) \\ &\quad = \sum_{i=1}^{n} \left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right) \end{aligned} . \tag{6.b}$$

From the expansion of Eq. (4), the right side of Eqs. (6.a) (6.b) are twice the area of the chromaticity gamut polygon. Then Eqs. (6.a)(6.b) can be reformed as follows:

$$\sum_{i=1}^{n} \left(r'_i + r'_{i+1}\right)\left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right) = 2 \cdot S , \tag{7.a}$$

$$\sum_{i=1}^{n} \left(g'_i + g'_{i+1}\right)\left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right) = 2 \cdot S . \tag{7.b}$$

On the other hand, the coordinates of the centroid of convex polygons are calculated by using the following equations.

$$r'_{centroid} = \frac{1}{6} \frac{\sum_{i=1}^{n} \left(r'_i + r'_{i+1}\right)\left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right)}{S} , \tag{8.a}$$

$$g'_{centroid} = \frac{1}{6} \frac{\sum_{i=1}^{n} \left(g'_i + g'_{i+1}\right)\left(r'_i \cdot g'_{i+1} - r'_{i+1} \cdot g'_i\right)}{S} . \tag{8.b}$$

By applying Eqs. (7.a) (7.b) to Eqs. (8.a) (8.b), respectively, the coordinates of the centroid coincide with $\left(1/3, 1/3\right)$. That is,

$$r'_{centroid} = 1/3 , \tag{9.a}$$

$$g'_{centroid} = 1/3 . \tag{9.b}$$

The result indicates that when representing the chromaticity gamut with a general convex polygon, the centroid of the maximized chromaticity gamut coincides with (1/3, 1/3) of the ideal white. The white point centroid implies the most balanced vivid color reproduction noticed visually under white illuminants. Eqs. (9.a) (9.b) are the backbone of MCS.

## Simulation Results of the Hunt Effect Using MCS and Considerations

Using MCS, simulations of the Hunt effect were performed. Sample color patches were generated by computer simulations, and the results were analyzed by an MCS computer program. A uniform color area and its background composed a color patch, and the background color was ideal gray. In this case, the chromaticity gamut is constructed by two colors and the gamut region becomes to a line segment. A line segment can be considered an area shrunk to its 2-dimensional limit, and maximizing a line segment corresponds to maximizing an area in MCS. The existence of the background in the experiments is reasonable because only one color existence in all over a visual field is almost impossible. Corresponding to this, MCS does not work for one color existence because a point in the chromaticity diagram can not be maximized. MCS works from at least two colors existence. The parameters $\eta_R$, $\eta_G$, $\eta_B$ were optimized using the non-linear simplex method in IDL. Three color patches of red, green, and blue of an 8-bit *RGB* color space were employed in the numerical experiments. The parameter range of $\eta_R$, $\eta_G$, $\eta_B$ has not yet been investigated, and numerical results are shown for $0.5 \leq \eta_R, \eta_G, \eta_B \leq 1.5$ and $0.4 \leq \eta_R, \eta_G, \eta_B \leq 1.8$.

Tables 1(a)(b)(c) show corresponding conditions for each case in Tables 2 and 3. Luminance increments were by $\Delta R = \Delta G = \Delta B$ from case 1 to case 4. Tables 2 and 3 show adjusted sensitivity for $0.5 \leq \eta_R, \eta_G, \eta_B \leq 1.5$ and $0.4 \leq \eta_R, \eta_G, \eta_B \leq 1.8$, respectively. The left side of indices in Tables 2 and 3 are the combinations of *R*, *G*, *B* color patches and the cases of 1 to 4.

**Table 1(a). Corresponding conditions for R color patch.**

| | Color R | Background (R,G,B) |
|---|---|---|
| case 1 | (161,1,1) | (1,1,1) |
| case 2 | (190,30,30) | (30,30,30) |
| case 3 | (220,60,60) | (60,60,60) |
| case 4 | (250,90,90) | (90,90,90) |

**Table 1(b). Corresponding conditions for G color patch.**

| | Color G | Background (R,G,B) |
|---|---|---|
| case 1 | (1,161,1) | (1,1,1) |
| case 2 | (30,190,30) | (30,30,30) |
| case 3 | (60,220,60) | (60,60,60) |
| case 4 | (90,250,90) | (90,90,90) |

**Table 1(c). Corresponding conditions for B color patch.**

| | Color B | Background (R,G,B) |
|---|---|---|
| case 1 | (1,1,161) | (1,1,1) |
| case 2 | (30,30,190) | (30,30,30) |
| case 3 | (60,60,220) | (60,60,60) |
| case 4 | (90,90,250) | (90,90,90) |

Analyses on the results of Tables 2 and 3 indicate that the adjusted sensitivity of the $R$ channel increases as the luminance increments. This implies the increased saturation of $R$. In the same way, for $G$ and $B$ color patches, the adjusted sensitivity of the $G$ channel and the $B$ channel increase as the luminance increases and these imply the increased saturations of $G$ and $B$. The results indicate that MCS model explains the Hunt effect at the color matching functions stage in other words retinal stage. It is reasonable that saturations are increased on the chromaticity diagram in the color constancy framework. Though, a part of the effect might be processed in the brain, at least any contribution of the adjusting sensitivity is explained by using MCS.

**Table 2. Resultant adjusted sensitivities.**

| | $\eta_R$ | $\eta_G$ | $\eta_B$ |
|---|---|---|---|
| *R*, case 1 | **0.50** | 1.50 | 0.50 |
| *R*, case 2 | **0.80** | 1.50 | 0.50 |
| *R*, case 3 | **1.08** | 1.50 | 0.50 |
| *R*, case 4 | **1.23** | 1.50 | 0.50 |
| *G*, case 1 | 1.50 | **0.50** | 0.50 |
| *G*, case 2 | 1.50 | **0.80** | 0.50 |
| *G*, case 3 | 1.49 | **0.96** | 0.50 |
| *G*, case 4 | 1.49 | **1.21** | 0.50 |
| *B*, case 1 | 1.49 | 1.36 | **0.50** |
| *B*, case 2 | 0.50 | 1.50 | **1.07** |
| *B*, case 3 | 0.50 | 1.50 | **1.14** |
| *B*, case 4 | 0.50 | 1.49 | **1.19** |

Though in the experiments above, luminances are incremented for both two areas, the fixed luminance of backgrounds derives the same results of Tables 2 and 3, because the chromaticity coordinates of the backgrounds are the same not depending on the luminance values.

Since the resultant adjusted sensitivities are relatively modified each other that the saturated chromaticity coordinates by the color constancy are invariantly appeared on the chromaticity coordinate even if a normalization of the $RGB$ color coordinate is performed.

From the results of experiments and the considerations, it can be said that the Hunt effect is impacted by retinal processing.

An auxiliary consideration is that the opponent color sensitivity is enhanced especially for each color patch of red, green and blue with the complete black background $(1,1,1)$ in Tables 2 and 3. In other words the Helson-Judd effect appears especially in the patch that includes the complete black background in Tables 2 and 3. In Table 2, the sensitivity of $G$ is enhanced in the columns of $R$, the sensitivity of $R$ is enhanced in the columns of $G$, and the sensitivity of $R$ and $G$ (Yellow) are enhanced in the columns of $B$. These results are the same with the results in Table 3. These results indicate that MCS also explains the Helson-Judd effect other than the Hunt effect.

**Table 3. Resultant adjusted sensitivities.**

| | $\eta_R$ | $\eta_G$ | $\eta_B$ |
|---|---|---|---|
| *R*, case 1 | **0.40** | 1.80 | 0.40 |
| *R*, case 2 | **0.88** | 1.80 | 0.40 |
| *R*, case 3 | **1.16** | 1.80 | 0.40 |
| *R*, case 4 | **1.32** | 1.79 | 0.40 |
| *G*, case 1 | 1.80 | **0.40** | 0.40 |
| *G*, case 2 | 1.80 | **0.89** | 0.40 |
| *G*, case 3 | 1.80 | **1.13** | 0.40 |
| *G*, case 4 | 1.78 | **1.33** | 0.40 |
| *B*, case 1 | 1.70 | 1.80 | **0.40** |
| *B*, case 2 | 0.40 | 1.80 | **1.13** |
| *B*, case 3 | 0.40 | 1.80 | **1.14** |
| *B*, case 4 | 0.40 | 1.80 | **1.34** |

## Conclusion

As is well known, the Hunt effect is that saturation increases with luminance increment. Though, the effect has been explained as a brain information processing in the original paper of Hunt, based on MCS model, the conclusion is that there exist contribution of the retinal stage of adjusting the sensitivity of the color matching functions to the effect.

## References

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## Biographies

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