Comparative Analysis of the Color Perception Loss for Elderly People

Mohd Fikree Hassan*, Takumi Kugimiya†, Yoshiki Tanaka‡, Kiyoshi Tanaka†, Raveendran Paramesran*
* Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Malaysia
E-mail: mfikree.hassan@gmail.com, ravee@um.edu.my
† Faculty of Engineering, Shinshu University, Japan
E-mail: 14tm213a@shinshu-u.ac.jp, ktanaka@shinshu-u.ac.jp
‡ Chukyo Medical Co., Inc, Japan
E-mail: ytanaka@chukyomedical.co.jp

***Abstract*—In recent years, based on the report provided by the Department of Statistic, there are about 2.5 million people who are over 60 years old in Malaysia. The number of people in this elderly group is estimated to increase in the next few years. Thus, technologists have focused on the elderly group by providing various support systems to assist them in their daily activities. An area of concern for this group is on the human vision aspect where it is shown in medical reports that elderly people suffer from certain degrees of color perception loss. In this paper, a comparative analysis is performed between two fundamental researches that measure the color perception loss of the elderly people. The first fundamental research is done by Okajima et. al. which employed two-factor model that relates the effect of aging to the optical density of human lens in their computation of color perception loss for elderly. Meanwhile, apart from using the two-factor model, Tanaka et. al. took into consideration the retinal illuminance model that relates the pupil size with aging. They introduced a computational model that utilizes the rate of retinal illuminance in relation to aging and the effective components of the yellowing filter. The results observed from both researches show that elderly people suffer a certain degrees of losses in their color perception.**

I. Introduction

The number of people in the elderly group in Malaysia is expected to increase in the next few years. Looking at this scenario, there are several areas of concern that need to be addressed in order to eliminate barriers in terms of physical capabilities for the elderly people such as human vision. As we age, our vision tends to deteriorate especially the ability to differentiate colors. This ability also known as color perception is the ability to distinguish the set of signals that are produced when the incoming light reacts with the three cone cells in our eyes. Each cone cell is more sensitive to either short (S), medium (M) and long (L) wavelength light and each wavelength light exhibits bluish, greenish and reddish sensitivity respectively [1, 2].

As our lens thickness continues to grow throughout our life, yellowing occurs and reduces the transmission of blue light into our eyes [3]. Moreover, the yellowing of the lens changes the spectral characteristic of the light arriving at the retina [4]. In addition to yellowing, the size of human pupil reduces linearly with age [5]. Smaller pupil size causes less amount of light arriving at the retina. Due to these effects, the elderly group may experienced color perception loss up to a certain degrees.

To describe the yellowing effect to the human lens-density spectrum, several models were introduced. Pokorny et. al [6] proposed a two-factor model that utilized age-independent and age-dependent components in their computation. Meanwhile, Weale in [7] proposed a lens aging model that exponentially related to human age and linearly related to the lens density at birth. A linear model to relate the lens density with age was suggested by Savage et. al in [8]. Comparing the results from these three models with the actual reflectance data from human observers, the two-factor model produces results that have smaller residuals [4].

Based on the two-factor model, Okajima et. al. conducted computerized simulations to investigate the effect of yellowing to elderly color perception [9]. Using Munsell color chips, it was found that the color seen by the elderly people shifted from the original color. However, these simulations only consider the yellowing effect. Meanwhile, Tanaka et. al. proposed a model to estimate the color perception of the elderly people by using the two-factor model and taking into consideration the human pupil size [10]. As compared to [9], Tanaka's method uses *RGB* color space to show the changes in the color perception of the elderly people.

Our main objective in this paper is to perform a comparative analysis between these two methods. The reason these two methods are chosen is because they implemented the same mathematical framework where the original color space; Munsell colors for [9] and *RGB* colors for [10] are converted to *XYZ* color space. Moreover, conversion between Munsell colors and *RGB* colors can be obtained from [11, 12, 13]. Several simulation experiments are performed in order to observe the differences between the two methods in terms of the color perception, chromaticity change and color difference of the images seen by the elderly.

This paper is organized as follows. Section II describes the methods for computing color perception loss. The experimental results are presented in Section III while Section IV looks into areas of improvement for future research works. Lastly, Section V concludes the paper.

II. Methods for Color Perception Loss

In this section, we first show the mathematical model used by both Okajima [9] and Tanaka [10]. In addition, [10] considers the retinal illuminance model into determining the color perception loss. Finally, the computational models of both methods are elaborated.

A. Two-factor Model

In this model, Pokorny et. al. [6] described the optical density of humans lens as a function of wavelength, λ and age, A and expressed it using the age-dependent TL_1 and age-independent components, TL_2 as below:

$$L(\lambda, A) = \begin{cases} [1.00 + 0.02(A-32)]TL_1 + TL_2 & \text{for } 20 \le A \le 60 \\ [1.56 + 0.0667(A-60)]TL_1 + TL_2 & \text{for } A > 60 \end{cases} \quad (1)$$

where TL_1 is the portion changed by aging after age 20 and TL_2 is the portion independent of age.

In order to simulate the lens transmittance of an elderly people of age A as seen by a young people of age 32 years old, the spectral transmission factor of human lens can be derived from Eq. (1) as below:

$$F(\lambda, A, 32) = \frac{10^{-L(\lambda,A)}}{10^{-L(\lambda,32)}} \quad (2)$$

B. Retinal Illuminance Model

As proposed by Winn in [5], the pupil size decreases linearly with age at all illuminance levels. Thus, the pupil size can be expressed in terms of age, A as below:

$$l(A) = -0.011A + 1.557 \quad (3)$$

Furthermore, from Eq. (3), the rate of retinal illuminance of an elderly people of age A as compared to a young people of age 32 years old can be expressed as

$$S(A, 32) = \frac{l(A)}{l(32)} \quad (4)$$

C. Okajima's Method [9]

Okajima et. al. used Munsell color chips to observe the age-related changes of the human color perception. In their research, they computed the light reflected from the chips onto the retina. This can be expressed using the tristimulus values (X, Y, Z) for elderly people of age, A computed using the expressions below:

$$X(A) = k \sum_{\lambda=400}^{650} E(\lambda)\bar{x}(\lambda)\rho(\lambda)F(\lambda, A, 32) \quad (5)$$

$$Y(A) = k \sum_{\lambda=400}^{650} E(\lambda)\bar{y}(\lambda)\rho(\lambda)F(\lambda, A, 32) \quad (6)$$

$$Z(A) = k \sum_{\lambda=400}^{650} E(\lambda)\bar{z}(\lambda)\rho(\lambda)F(\lambda, A, 32) \quad (7)$$

where $E(\lambda)$ is the spectral energy distribution, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ are the standard CIE color matching function, $\rho(\lambda)$ is the spectral reflectance of the Munsell color chips. The wavelength has 10nm interval and k is the maximum luminous efficacy (683 lumen/W).

D. Tanaka's Method [10]

The main difference between Tanaka's method and Okajima's method is that Tanaka et. al. used images in *RGB* color space to produce the elderly color perception. The *RGB* values are converted into *XYZ* color space using the translation matrix, α as below:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} X_r + X_g + X_b \\ Y_r + Y_g + Y_b \\ Z_r + Z_g + Z_b \end{bmatrix} \quad (8)$$

where each X_m, Y_m, Z_m $(m = r, g, b)$ are called separated components.

In this method, instead of spectral reflectance, they used the luminescence emission spectrum for red f_r, green f_g and blue f_b filter for the LCD display. Thus, the tristimulus values (X, Y, Z) for elderly people of age, A are computed as below.

$$X_m(A) = k \sum_{\lambda=400}^{650} E(\lambda)\bar{x}(\lambda)f_m(\lambda)F(\lambda, A, 32) \quad (9)$$

$$Y_m(A) = k \sum_{\lambda=400}^{650} E(\lambda)\bar{y}(\lambda)f_m(\lambda)F(\lambda, A, 32) \quad (10)$$

$$Z_m(A) = k \sum_{\lambda=400}^{650} E(\lambda)\bar{z}(\lambda)f_m(\lambda)F(\lambda, A, 32) \quad (11)$$

where $(m = r, g, b)$, k is the scaling factor and the wavelength interval of 10nm.

An important parameter in this method is the ratio between the stimulus for elderly age A with the stimulus for young observer age 32 years old called effective components $K_r^{(n)}$, $K_g^{(n)}$, $K_b^{(n)}$ $(n = X, Y, Z)$.

Using the separated components, the transmission factor of human lens by elderly people based on young observer can be computed using the equations below:

$$K^{(n)} = \frac{K_r^{(n)} n_r + K_g^{(n)} n_g + K_b^{(n)} n_b}{n_r + n_g + n_b} \quad (12)$$

where $(n = X, Y, Z)$.

Finally, the color perception of elderly age A can be computed as below:

$$X(A) = K^{(X)} SX \quad (13)$$

$$Y(A) = K^{(Y)} SY \quad (14)$$

$$Z(A) = K^{(Z)} SZ \quad (15)$$

where S is the rate of retinal illuminance from Eq. (4) and X, Y, Z are the tristimulus values computed in Eq. (8).

III. Experimental Study and Results

In this section, both Okajima's and Tanaka's methods are simulated mainly using Macbeth ColorChecker chart. Four color patches are chosen for these experiments: Bluish Green, Moderate Red, Yellow and Cyan, as shown in Fig. 1. The Munsell to *RGB* conversion for the color patches are obtained from [11,12]. In addition, the chromaticity change of the four color patches is observed in the second subsection. Finally, the color differences between the original images and the images perceived by the elderly in these two methods are computed and compared in the last subsection.

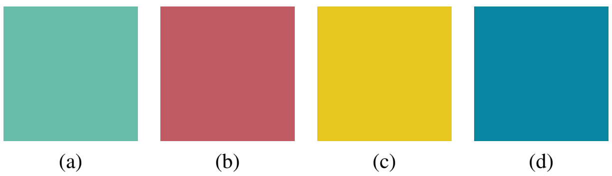


Fig. 1. Macbeth ColorChecker color patches: (a) Bluish Green, (b) Moderate Red, (c) Yellow, (d) Cyan.

A. Color Perception Observed by Elderly

In this experiment, the Munsell notation of the color patches are implemented in Okajima's method and the *RGB* values of the color patches are implemented in Tanaka's method. The scaling factor, k used in both methods are defined as

$$k = \frac{100}{\sum_{\lambda} E(\lambda)\bar{y}(\lambda)} \tag{16}$$

Each color patches are simulated for elderly people of age 70 and 80 years old. The results are shown in Table I and II respectively.

It can be observed from the results, as age increases, the colors seen by elderly people become darker due to the yellowing of the human lens. However, since Okajima's method is not considering the effect of retinal illuminance, their results are darker than the results from Tanaka's method. It can be seen that the Bluish Green color patch in Table II appears like a green color patch for elderly people of age 80 years old. This is due to the amount of short wavelength light (bluish sensitivity) arriving onto the human lens is lesser than the medium and long wavelength lights [10].

To further analyze the different between the images seen by the elderly people and young observer, we use three synthesized images constructed using colors from Munsell color chips. The *RGB* values of the Munsell color chips are obtained from [13]. The results are shown in Table III. It can be seen from the results, all the bluish color blocks lost their blue sensation when simulated for elderly people of age 80 years old. Moreover, purple and yellow look like brown and orange respectively. In addition, some of the colors from the results look almost the same. These results show that elderly people experience color perception loss and may face difficulty in differentiating colors in their daily activities.

TABLE I
Color Perception of Elderly People of Age 70 Years Old

Original image	Okajima's method [9]	Tanaka's method [10]

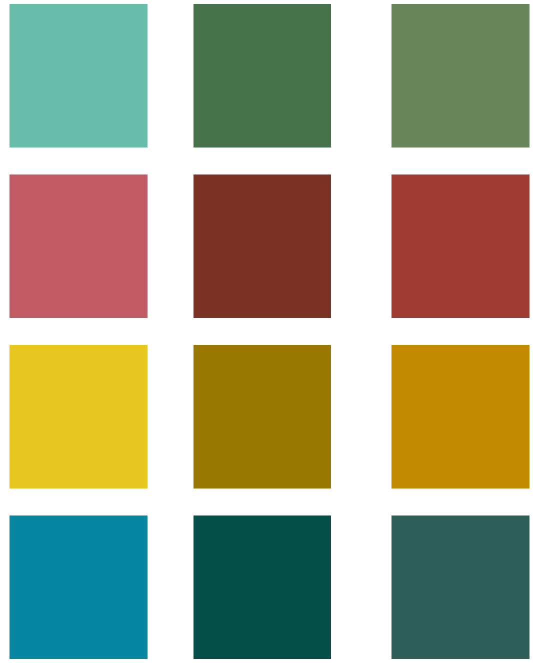


TABLE II
Color Perception of Elderly People of Age 80 Years Old

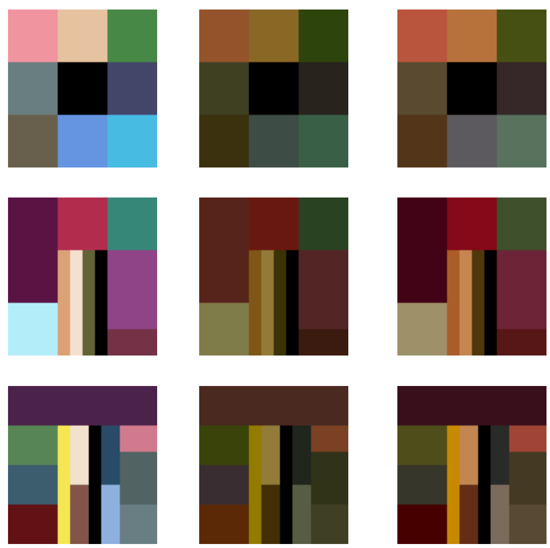
Original image	Okajima's method [9]	Tanaka's method [10]

B. Chromaticity Change of Macbeth ColorChecker Patches

In this experiment, the chromaticity change of the color patches is observed. From the tristimulus X, Y, Z values, the

TABLE III
COLOR PERCEPTION OF ELDERLY PEOPLE OF AGE 80 YEARS OLD

Original image	Okajima's method [9]	Tanaka's method [10]



xy-chromaticity values of the the color patches for several ages are computed. The chromaticity graphs for the color patches are plotted in Fig. 2 to 5 respectively.

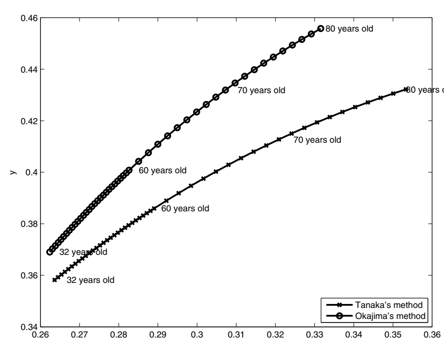


Fig. 2. Age-related change of the xy-chromaticity values of Bluish Green.

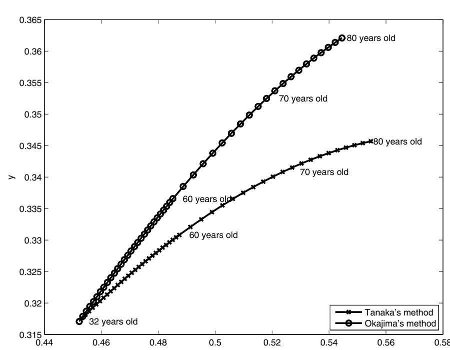


Fig. 3. Age-related change of the xy-chromaticity values of Moderate Red.

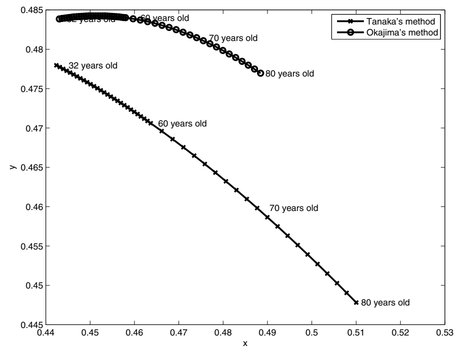


Fig. 4. Age-related change of the xy-chromaticity values of Yellow.

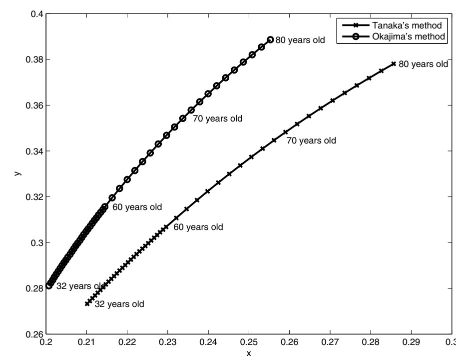


Fig. 5. Age-related change of the xy-chromaticity values of Cyan.

Except for Fig. 4 that represents the chromaticity graph of the yellow color patch, it can be observed that the chromaticity of the other three color patches shifted towards the yellow region of the CIE chromaticity diagram. For the yellow color patch, the chromaticity shifted towards darker yellow region. This shifting is due to the yellowing effect on the human lens. Moreover, the age-related shifts not only affect the saturation of the colors but also the hue [9].

In addition, the rate of retinal illuminance implemented in Tanaka's method is not effecting the chromaticity of the color patches. It should also be noted that the initial chromaticity points of each color (labelled as 32 years old) for both methods may not be the same due to the different reflectance parameters used. However, the difference between the initial chromaticity points is small (≈ 0.01) and both initial points are still within the same chromaticity region.

C. Color Difference, ΔE_{00}

In this experiment, the distance between the two colors; original color and color seen by elderly is observed using CIEDE2000 color difference standard, ΔE_{00}. The color difference, ΔE_{00} of the four color patches for elderly people of age 80 years old is computed and cross-checked with [14]. The results are plotted in a bar graph shown in Fig. 6 and it shows that Okajima's method produces images that have slightly higher color difference as compare to Tanaka's method.

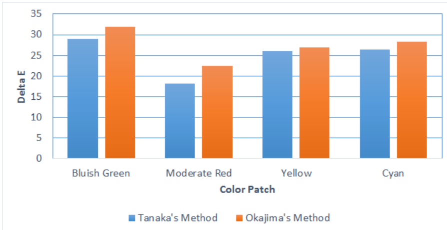


Fig. 6. ΔE_{00} between the original color and color seen by elderly people of age 80 years old.

Furthermore, we extend this experiment using two Munsell colors with Hue of 7.5PB and 2.5R. For both colors, we maintain the Value to 3 and 4 respectively and varies the Chroma values. These color chips are shown in Fig. 7 and 8 respectively. In addition, we also fix the Chroma of the two Munsell colors to 6 and 8 respectively and vary the Value as shown in Fig. 9 and 10 respectively.

(a) C2 (b) C4 (c) C6 (d) C8 (e) C10

Fig. 7. Munsell Color Chips of Hue 7.5PB, Value 3.

(a) C4 (b) C6 (c) C8 (d) C10 (e) C12

Fig. 8. Munsell Color Chips of Hue 2.5R, Value 4.

(a) V4 (b) V5 (c) V6 (d) V7

Fig. 9. Munsell Color Chips of Hue 7.5PB, Chroma 6.

(a) V4 (b) V5 (c) V6 (d) V7

Fig. 10. Munsell Color Chips of Hue 2.5R, Chroma 8.

We simulated all the colors using both methods for elderly people of age 80 years old and computed the CIEDE2000 color difference, ΔE_{00}. The results are plotted and shown in Fig. 11 to 14.

It can be observed here that the results from Okajima's method are significantly higher than the results produced by Tanaka's method for all cases. The gap between ΔE_{00} for Okajima's and ΔE_{00} for Tanaka's is bigger here as compared to previous result in Fig. 6. This may be due to the two different sources that we used to obtained the Munsell to *RGB* color conversion. Nevertheless, all the results show that

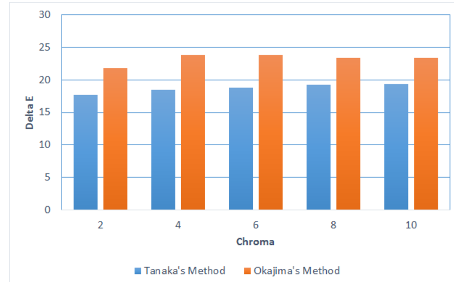


Fig. 11. ΔE_{00} between the original color and color seen by elderly people of age 80 years old for Hue 7.5PB, Value 3.

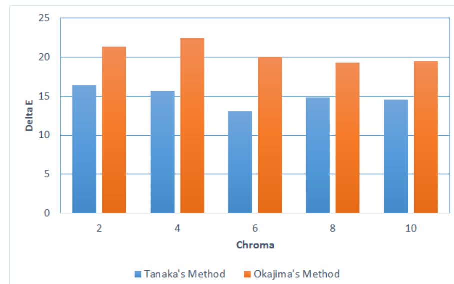


Fig. 12. ΔE_{00} between the original color and color seen by elderly people of age 80 years old for Hue 2.5R, Value 4.

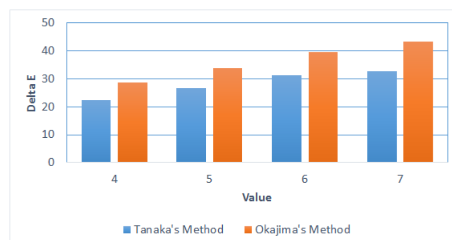


Fig. 13. ΔE_{00} between the original color and color seen by elderly people of age 80 years old for Hue 7.5PB, Chroma 6.

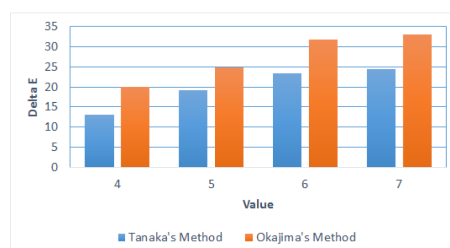


Fig. 14. ΔE_{00} between the original color and color seen by elderly people of age 80 years old for Hue 2.5R, Chroma 8.

Okajima's method produces higher ΔE_{00} as compared to Tanaka's method. This may be due to the effect of retinal illuminance used in Tanaka's method.

IV. Future Works

From all the experiments, the results obtained show that the images seen by the elderly people become yellowish due to the yellowing pigmentation that happen on the human crystalline lens. However, research on the yellowish pigmentation process of the human crystalline lens can still be extended. Furthermore, although Tanaka's method considers the effect of retinal illuminance model, it did not consider the effects of different luminance levels to elderly color perception. The effect of chromatic adaptation to elderly color perception can also be studied. Another interesting area that can be explored is the formulation of the quality assessment and evaluation method to mathematically determine the degrees of color perception loss experienced by the elderly people.

Thus, these areas can be explored in future research works in order to enhance existing methods and accurately mimic the elderly color perception. Improvement of the existing methods will leads to obtaining the ground truth of the color experienced by the elderly people. In a survey performed by Ishihara et. al [15] shows that elderly people have several difficulties in their daily activities. Some of them have difficulty finding goods in stores because of the confusion that occurs when looking at the displays. Some even bump into a glass door since they cannot recognize it soon enough. They also have difficulty to go down the stairs since they cannot estimate the depth of the stairs. By obtaining the ground truth, elderly color compensation methods can be proposed to help the elderly people in their daily activities.

V. Conclusions

This paper presents a comparative analysis to observe the color perception loss of the elderly people using two methods; Okajima's and Tanaka's methods. Okajima's approach utilizes Munsell color space while Tanaka's approach uses *RGB* color space. Based on their experiments, both methods produce almost the same results for color perception observed by the elderly. However, Okajima's method produces darker color images compared to Tanaka's method. This is due to the fact that Okajima's method only consider the yellowing effect to the human lens. Both methods show that the age-related chromaticity change happened to the color patches. The chromaticity of the color patches shifted towards the yellow region of the CIE chromaticity diagram for both methods. Moreover, the color difference computed from Okajima's method is higher than the one computed from Tanaka's method. The differences are summarized in Table IV.

In our opinion, Tanaka's method is more suitable to be used as a reference experimental method to observe the color perception of elderly people since it uses *RGB* color space where the *RGB* values of the digital images can easily be obtained in digital devices. Finally, we have proposed several areas of interest for future works in order to enhance current methods.

TABLE IV
Summary of Differences between Okajima's and Tanaka's Methods

	Okajima's method [9]	Tanaka's method [10]
Color space used	Munsell color	*RGB* color
Two-factor model	Yes	Yes
Retinal illuminance model	No	Yes
Elderly color perception	Darker than [10]	Brighter than [9]
Chromaticity change	Towards yellow region	Towards yellow region
Color difference	Higher than [10]	Lower than [9]

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