https://doi.org/10.2352/issn.2694-118X.2020.LIM-30

Color image evaluation of congenital red-green color deficient and normal color vision observers

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Abstract

How and to what extent the increase of $C_{ab}*$ affects on various subjective evaluations for congenital red-green color deficiency (CVD) and normal color vision (NCV) observers was investigated using scenery, food, and graph images. Results of "Pale vs Deep" evaluation indicate similar tendency for all color vision types in all test images, indicating that CVDs recognize the saturation change of images similar to NCVs using some kind of strategy. Individual differences of the CVDs in the results of other adjective pairs such as "Unnatural vs Natural" are generally larger than those of NCVs. Some color combinations in the graph images are indiscriminable for either protan or deutan, and thus are not recommended to be used.

Introduction

Several percent of male is congenital red-green color deficiency (CVD) that they have some degree of difficulty in color discrimination of green, yellow, orange, and red colors. Decrease of color discriminability differs among observers. Range of color match in anomaloscope which is often used in the color vision test, varies from slightly wider than the normal color vision (NCV) to entire ratio of 545nm and 670 nm mixture [1]. In recent years, based the concept of universal-color-design that aims barrier-free color environment for all people with any type of color-vision, various techniques of color enhancement or recoloring have been developed to increase visibility or preference of color-image for CVDs [2-7].

Chen et al. [5] performed an experiment to evaluate the preference of color-enhanced images for 18 CVDs (9 protan and 9 deutan), and their results showed that color-enhancement is effective especially for the images with red or reddish colors. However, they did not carry out the evaluation experiment using various evaluation words.

In one of early studies on perceived quality of color images using NCVs, Fedorovskaya et al. varied average chroma of test images and had observers evaluate perceived quality, colorfulness, and naturalness [8]. Results indicated that images slightly color-enhanced from the original ones showed the highest score for perceived quality and naturalness, while colorfulness monotonously increased with average chroma. Our recent study showed that pixel-based increase of metric $C_{ab}*$ from achromatic to properly chromatic raise the rating scores for various different words of subjective evaluation, such as "Pale vs Deep", "Natural vs Unnatural", or "Dislike vs Like" etc., generally in the same manner [9]. However, few studies have been done on the effect of $C_{ab}*$ increase for various subjective evaluations for CVDs and the comparison between different types of color vision.

Therefore, in this study, we aim to investigate how and to what extent the increase of $C_{ab}*$ affects on various subjective evaluations for CVDs and NCVs using scenery, food, and graph images.

Experiment

Figure 1 shows examples of the test images. We used 5 scenery images, 3 food images, and 3 graph images. In Figure 1, *momiji* and *sakura* are scenery, *burger* is food, and *CUD*, *paper*, and *purple* are graph images. For each of them, images of 5 different C_{ab}^* converted from the original image (100%) with keeping the average $L*$ constant, were prepared. Conversion ratios employed were 50, 75, 110, 130, and 150% for calculation using the sRGB transfer function. However the average percentages measured using 2D colorimeter (Konica Minolta CA-2500) do not reach those values especially in saturated ones. Results shown in Figures 4 to 6 are plotted against the percentage based on 2D colorimetry.

Table1 indicates the adjective pairs used for 3 image groups. Seven-point scale (-3 to 3) was employed in the subjective evaluation. Instruction to the observer was that, in the case of "Pale vs Deep" for example, minus 3, 0, and plus 3 correspond to pale, neutral, and deep.

In the experiment, 6 test images with different C_{ab}^* conversion ratio were presented simultaneously, with an adjective pair at the bottom of the display as shown in Figure 2. Labels of "U" to "Z" in the figure indicate the location within the display, and images of different C_{ab}^* conversion ratio were randomly placed in these locations in each presentation. Observer was asked to evaluate each test stimuli for a given adjective pair by oral response. Uniform gray image was presented for 3 sec between test image presentation. One session includes 44 trials (5 scenery images x 4 word pairs + 3 food images x 5 word pairs + 3 graph images x 3 word pairs), and 3 sessions were repeated for each observer.

Twelve protan (protanope and protanomalous), 12 deutan (deuteranope and deuteranomalous) and, 12 NCV observers participated the experiment. Color vision of observers was examined using anomaloscope, panel D-15, and Ishihara charts. Classification of the type indicated above is mainly based on the results of anomaloscope.

Figure 1 Examples of test image

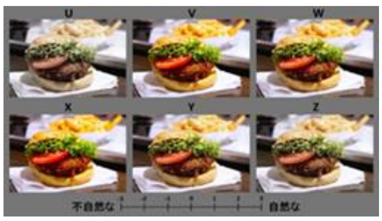

Figure 2 Presentation of test images and adjective pair

Table 1 Adjective pairs for 3 image groups

Evaluation words	Scenary	Food	Graph
Pale vs Deep	○	○	○
Like vs Dislike	○	○	
Ugly vs Beautiful	○	○	
Unnatural vs Natural	○	○	
Undelicious vs Delicious		○	
Total impression as a graphic slide			○
Discriminability of color			○

Results

Results of "Pale vs Deep" and "Unnatural vs Natural" for the scenery image of *momiji* for protan, deutan, and NCVs are indicated in Figure 3 and 4, respectively. Horizontal axis indicates the ratio of C_{ab}* based on 2D-colorimetry, with the original image of 100%. Vertical axis indicates average rating score. Three figures from the top show individual curves for protan, deutan, and NCVs, respectively, and the bottom figure shows the average curves for 3 color vision types. As shown in the figures, rating score of "Pale vs Deep" monotonously increases with the % of C_{ab}* in a very similar manner among different color vision types. Results of 3 way ANOVA (color vision type x image x % of C_{ab}*) indicated that the effect of color vision type is strongly non-significant ($p=0.406 > 0.05$).

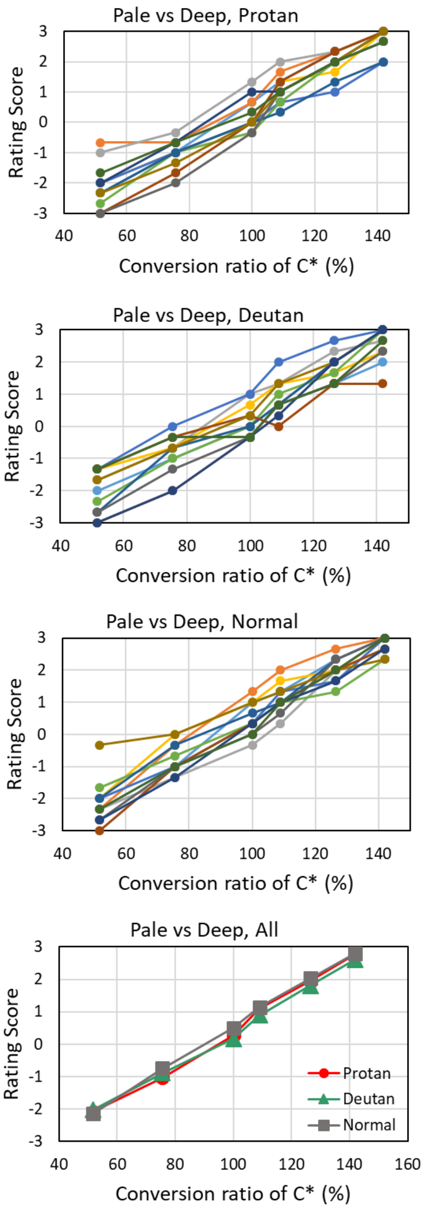

Figure 3 Results of "Pale vs Deep" for Momiji (Scenery)

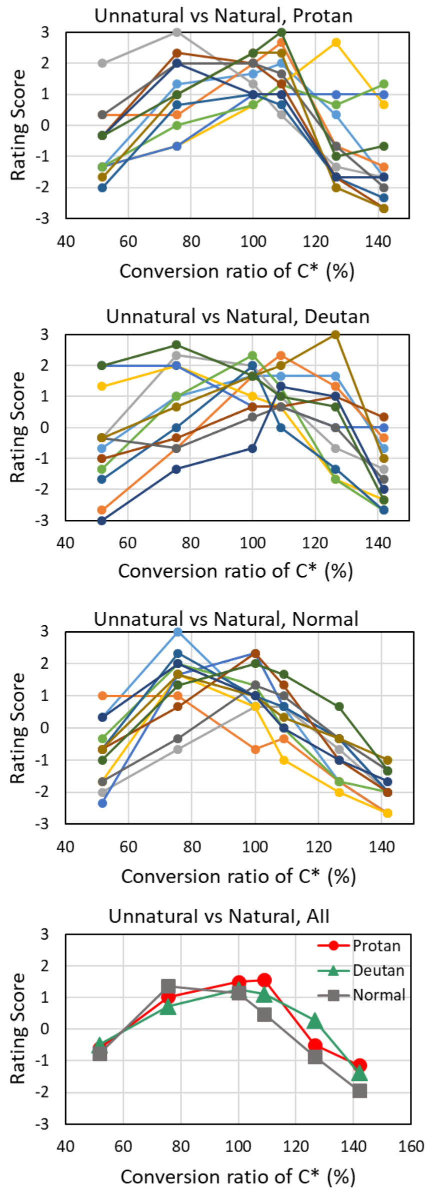

Figure 4 Results of "Unnatural vs Natural" for Momiji (Scenery)

Contrary to that, results of "Unnatural vs Natural" in Figure 4 show large individual difference for CVDs. Peak of the rating score ranges from 75% to 130%. On the other hand, most of NCVs show the peak at 75% or 100%. In the bottom figure of average results, the peak is at 110% and 100% for protan and deutan, respectively. Results of the NCVs show the peak at 75%, slightly desaturated from the original. However, the results of 3 way ANOVA shows effect of color vision types is non-significant (p = 0.495) probably due to large individual differences. In the results of Fedorovskaya et al. for NCVs [9], original image showed the highest score in naturalness evaluation. Similar results are found in 5 test images among 8 (food and scenery). Judgement of naturalness seems to depend on content of image.

Large individual differences of CVDs might reflect their variability of perceived saturation [10] and complexity of their color representation in their brain. CVDs seem to have different system for visual color perception and color names [11]. Results indicated that some degree of color enhancement would be appreciated for majority of the CVDs for perceived naturalness.

Results of "Pale vs Deep" and color discriminability for the graph image of *paper* for protan, deutan, and NCVs are indicated in Figure 5 and 6, respectively. In the latter judgement, "Hard to discriminate colors" and "Easy to discriminate colors" were appeared in the bottom of display. Horizontal and vertical axes are the same as those in Figures 3 and 4. As mentioned above, results of "Pale vs Deep" monotonously increase with the % of C_{ab}* in a very similar manner among different color vision types. It is interesting that individual difference is the smallest for protan here, and the largest for deutan. Results of color discriminability judgement show different property among different color vision types as shown in Figure 6. Protan and NCVs show similar tendency of monotonous increase with the % of C_{ab}*, while deutan shows large variability. Some curves increase with the % of C_{ab}*, other curves decrease, and two curves are nearly parallel to the horizontal axis implying that color discriminability does not change with the % of C_{ab}* for those observers. P-value obtained in 3-way ANOVA is 0.068 >0.05 for this evaluation word, but interactions are all significant.

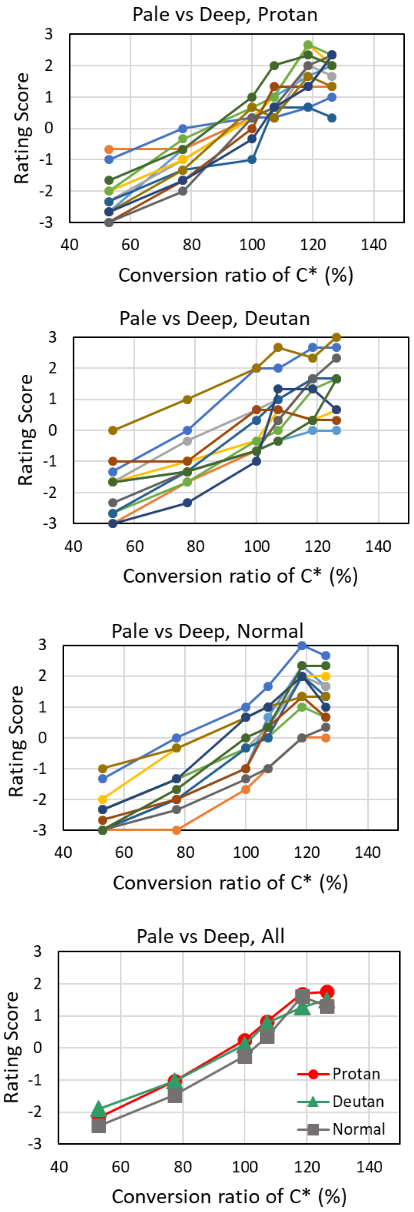

Figure 5 Results of "Pale vs Deep" for paper (Graph)

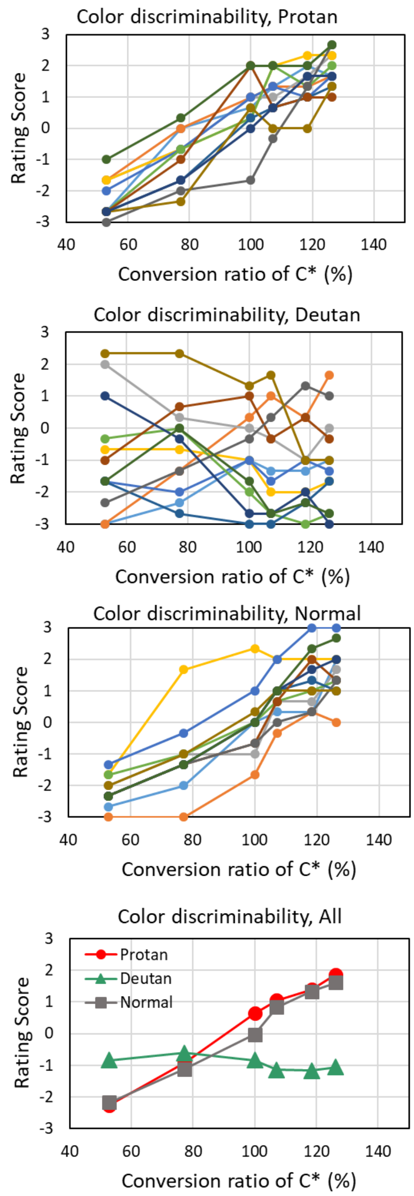

Figure 6 Results of color discriminability for paper (Graph)

Two-way ANOVA limited to the image of *paper* (color vision type x % of C_{ab}*) shows strongly significant effect of color vision type (p=4.4E-11). Contrary to the results of *paper,* in the results of *purple*, other color combination of graph image, deutan and NCVs show monotonous increase, while a tendency of decrease with large individual difference was observed for protan. These color combinations look apparently cool, but are not recommended to be used in public presentations.

To compare observers' variability in Figures 3 to 6 quantitatively, standard deviation (SD) was calculated at each percentage of C_{ab}*, and then average of the SD was derived for each result as shown in Table 2. SDs for "Pale vs Deep" do not show systematic difference among color vision types ranging from 0.43 to 0.88 for the results shown here. This tendency remains the same for all other test images. On the other hand, SDs for "Unnatural vs Natural" in *momiji* for CVDs, and for color discriminability in *paper* for deutan, are distinctively larger than that of NCVs. It is worth noting that for some CVDs easiness or hardness of color discriminability is about the same level for the images of different % of C_{ab}*, although they can recognize the paleness or deepness of colors in those images in very similar manner to NCVs.

Table 2 Average SD of the Figures 3 to 6

		P	D	N
momiji (Scenery)	Pale vs Deep	0.47	0.53	0.43
	Unnatural vs Natural	1.04	1.11	0.79
paper (Graph)	Pale vs Deep	0.58	0.88	0.79
	Color discriminability	0.69	1.42	0.79

Conclusion

How and to what extent the increase of C_{ab}* affects on various subjective evaluations for congenital red-green color deficiency (CVD) and normal color vision (NCV) observers was investigated using scenery, food, and graph images. Rating score of "Pale vs Deep" increases with the increase of C_{ab}* percentage in nearly the same manner for all color vision types in all test images, indicating that CVDs recognize the saturation change of images similar to NCVs. Judging paleness/deepness of color of displayed image is not directly reflected their deficiency of color vision. Individual differences of the CVDs in the results of other adjective pairs such as "Unnatural vs Natural" are generally larger than those of NCVs. Also, individual differences in color discriminability judgement of the CVDs for some color combinations in the graph images became extremely large. For some observers, the change of C_{ab}* does not affect at all. Those color combinations are not recommended to be used.

Color customization of display is being spread for PC and/or mobile phones. Results of this study suggest that a wide range of variability should be prepared for color enhancement or dehancement for CVDs.

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Author Biography

Miyoshi Ayama received her BS in applied physics (1978) and her PhD in Engineering from Tokyo Institute of Technology (1983). After working as a pos-doc in York University, Canada, and other places, she got a post as an Associate Professor in Utsunomiya University. She became Professor in 2001 and the Dean of the department of Engineering in 2016. She was an Associate Director of CIE Division 1 during Luo's term from 2007 to 2015. Her work has focused on the issues of color vision science and KANSEI evaluation of color image.

Acknowledgment

We thank Hiroto Mikami for his contribution in carrying out the experiment.