# Immanent Dichromatic in Trichromatic Observer: Based on MDS Analyses of R-G Neutral- and Y-B Only Changed-Stimuli Observation Results

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**ABSTRACT**

*Immanent dichromatic in color normal observers is investigated by MDS (Multidimensional-Scaling). The results show that (1) color-constellations yielded when observing R-G neutral- and Y-B only changed-stimuli strongly evidence concave-shaped like dichromic, whereas (2) those gained when observing Y-B neutral- and R-G only changed-stimuli evidence oval-shape of saturation-brightness.*

## 1 BACKGROUND AND OBJECTIVES

Communications using color between people with normal vision and those with Red-Green color vision deficiency (R-G CVD), created by dichromacy or anomalous trichromacy, is becoming more important because of the widespread adoption of color desktop publishing, color displays including digital signage systems, and/or mobile devices such as smartphones and tablet computers. This means that people with CVD need to distinguish between reds and greens more frequently. Therefore, it is very important to produce effective support tools that can help people with dichromatic vision communicate with society [1].

The chromatic perception of dichromacy and/or anomalous trichromacy has not been investigated precisely. For example, Shepard et al. (1992) used color charts to claim concave-shaped constellations of colors [2] whereas Wish et al. (1974) found oval-shaped constellations by using color charts [3] and analyses based on MDS (Multidimensional-Scaling). On the other hand, the constellations of colors as identified by words chosen by people with CVD and blind people were oval-shaped, the same as trichromacy [3]. Recently, Okudera et al. showed similar results in blind people [4]-[5]. Therefore, it is important to fully elucidate the chromatic perception of dichromacy and/or anomalous trichromacy.

We have already investigated the individual differences in chromatic perception of both color-normal and color-deficient observers by employing MDS (Multidimensional-Scaling) [6]. In that investigation, we hypothesized some relationship between dichromacy and trichromacy from the viewpoints of evolution and post-natal development. The results show that (1) the constellations of colors identified from words slightly depend on color sense, however, (2) those by color charts smoothly varied from concave-shaped in dichromacy to oval-shaped with normal trichromacy. Experiments generally supported our hypothesis.

In this paper, therefore, we intensively investigate the immanent dichromatic (i.e., similar factors to color vision deficiency (CVD)) in color normal observers (CNOs) by employing the R-G neutral- and Y-B only changed-stimuli. In the next part, before explaining the experiments, we introduce the hypothesis that the distribution of color sense and the color vision development process of newborns are analogous.

## 2 HYPOTHESIS OF ANALOGY BETWEEN EVOLUTION AND POST-NATAL DEVELOPMENT

It is considered that human trichromatic vision has evolved from dichromatic vision by mutation and natural selection [7]-[8]. There are three types of cones (L-, M-, and S-cone) in the retina and two opponent color systems, i.e., red-green (R-G) and yellow-blue (Y-B), are utilized by the brain for color perception [9]-[10]. Note that S-cones, which contribute to the Y-B opponent system, are highly independent of L- or M-cones. It is considered that the functional distribution from peripheral- to central-vision traces the history of visual evolution [9]. Evidence suggests that the R-G opponent color system and the contour detection system are common in primates including humans [11]-[12].

The color perception of newborns varies rapidly and drastically between two and three months [13]-[16]. First, newborns are able to discriminate chromatic stimuli from achromatic material and perceive only red and blue, i.e., the differences between red, orange, yellow and green are imperceptible. However, at three months they acquire the R-G opponent color system. The reason why younger newborns fail at R-G discrimination is considered to be due to immature neural processing rather than the absence or failure of L- or M-cones. A significant gender difference in development has also been observed; females are faster than males. Note that, contrary to newborns, inadequate neural processing

triggered by an absence or anomaly of L- or M-cones causes color deficiency whereas the structures of neural systems are normal,.

Given the above discussion, we created the hypothesis that the distribution of color sense and the color vision development process of newborns are analogous. Therefore, it is predicted that the constellations of colors as yielded by color charts smoothly vary from concave-shaped in dichromatic, as reported in [2], to oval-shaped in trichromatic.

## 3 EXPERIMENTS

This section describes the detailed guidance for preparing figures and tables in the manuscript.

### 3.1 Methods

**(a) Experimental setup:** A 24-inch LCD sRGB color display (EIZO ColorEdge CG242W) was employed in weak natural ambient fluorescent light with high color rendering index (approx.. 300 lx, FLR40S N-EDL/M-NUJ produced by Hitachi), instead of the paper color charts used in the previous study [6]. Maximum white luminance was 211 cd/m$^2$. Viewing angle of each stimulus was 10 degrees (i.e., square stimulus with 8.8 cm sides and viewing distance of approximately 50cm). See Figure 1.

**(b) Stimuli:** Figure 2 shows the original color set with moderate saturation and their Munsell values. We created two new sets of stimuli from the original one. The first one consisted of two subsets of 10-color stimuli that varied only in a* or b* direction in CIE La*b* space made from original full color charts (See Figures 3 (c) and (d)). The second one consisted of two subsets of 14-color stimuli added four primary colors (R, Y, G, and B with high saturation, see figure 3 (b)). The first one represents special color environments that attempt to roughly simulate newborn vision (i.e., Y-B variation only) and its opposite (i.e., R-G variation only), while the second one represents certain environments that use two opponent colors with bias but appears more natural than the first one.

**(c) Subjects:** Total number of participants was twelve (ten males and two females). All were confirmed as CNOs by Ishihara test, and had normal or corrected normal sight. The participants included some of the authors.

**(d) Subjective evaluation task:** Participants were required to make paired comparisons with five grade non-similarity scale (1. Quite close, 2. Slightly close, 3. Neutral, 4. Slightly far, 5. Quite far). In a 10-color stimuli test, a set consisted of 45 randomized pairs. Two sets, with reverse left-right and sequence orders, were employed. In a 14-color stimuli test, a set consisted of 91 randomized pairs. Two sets, with reverse left-right and sequence orders, were also employed. At least one-day interval was inserted between 10-color stimuli tests and 14-color stimuli tests.

**(e) Analysis:** MDS (Multidimensional Scaling): The commonly used Non-metric MDS (isoMDS [17]) with

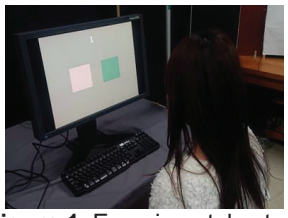


**Figure 1.** Experimental setup.

| Red (赤) | Orange (橙) | Yellow (黄) | Yellow-Green (黄緑) | Green (緑) |
|---|---|---|---|---|
| 5R 4/4 | 5YR 6.5/4 | 5Y 8/4 | 5GY 6.5/4 | 5G 4.5/4 |
| Purple-Red (赤紫) | Purple (紫) | Purple-Blue (青紫) | Blue (青) | Blue-Green (青緑) |
| 5RP 4/4 | 5P 4/3 | 5PB 4/4 | 5B 4/3 | 5BG 4/3 |

**Figure 2.** Original color set with moderate saturation and those Munsell values.


(a) Original 10-color set (out of use in the experiments)


(b) Added four primary colors with high saturation


(c) 10-color set remaining a* only hue variation


(d) 10-color set remaining b* only hue variation

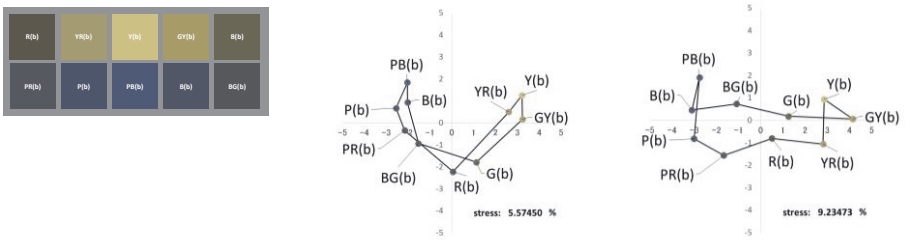
**Figure 3.** Color variations in experimental stimuli.

Euclidean distance was employed for the analysis.

### 3.2 Results and discussions

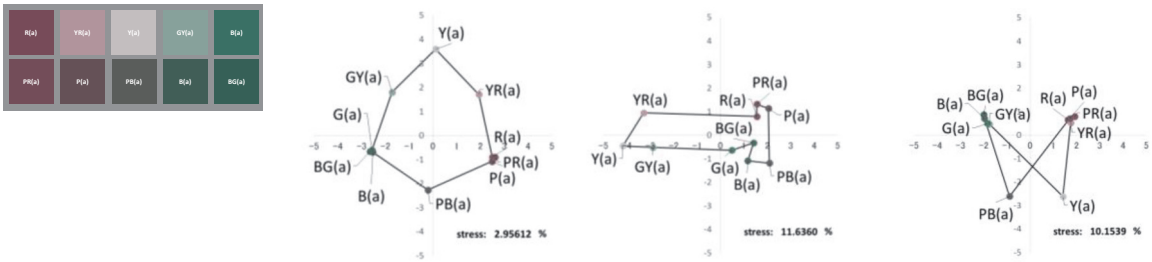
**(a) Results of 10-color stimuli tests:** Figures 4 and 5 show the results of “10-color with only b* hue variation” and “10-color with only a* hue variation” tests, respectively. It is suggested that, in the “10-color with only b* hue variation” test results, the primary axis is the Y-B component combined with brightness, whereas the secondary axis was an unknown component. As expected by our hypothesis, it was similar to the results for CDOs in previous experiments [6]. On the other hand, it was suggested that, in the “10-color with only a* hue variation” test results, the meanings of two axes were able to be interpreted in all cases. These results are reasonable.

**(b) Results of 14-color stimuli tests:** Figures 6 and 7 show the results of “14-color with only b* hue variation” and “14-color with only a* hue variation” tests,



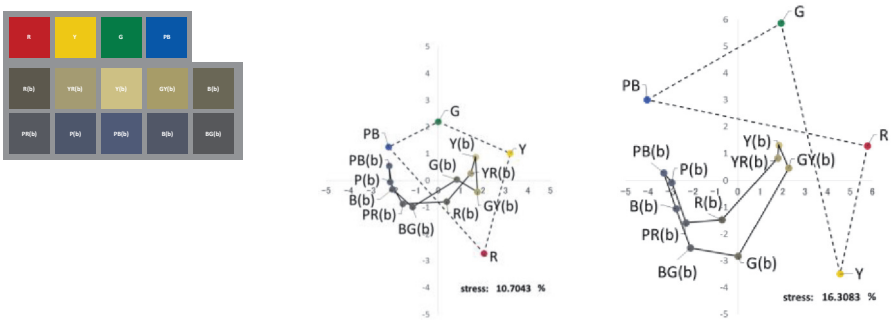

(a) Example of Group-b1 (10) (b) Example of Group-b2 (10)

**Figure 4.** Examples of "10-color with only b* hue variation" experimental results. Panels (a) and (b) show examples of concave-shaped results clearly or weakly, respectively. It was suggested that primary axis represented Y-B component combined with brightness, whereas secondary axis represented unknown component. Populations of (a) and (b) were nine and three, respectively.



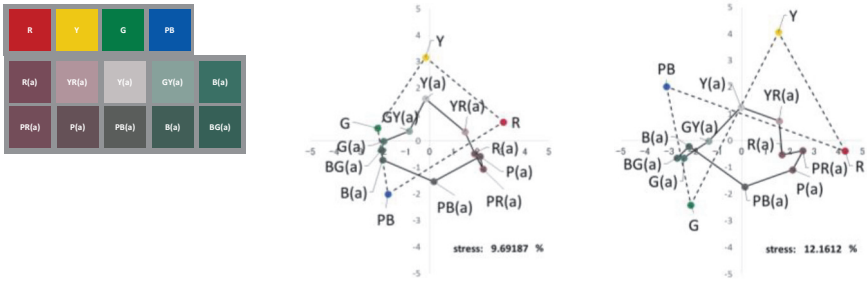

(a) Example of Group-a1 (10) (b) Example of Group-a2 (10) (c) Example of Group-a3 (10)

**Figure 5.** Examples of "10-color with only a* hue variation" experimental results. Panels (a) to (c) show three examples; it was suggested that each example of constellation consisted of combination of hue- and brightness-differences. In panels (a) and (c), primary and secondary axes denoted hue- and brightness-difference, respectively. In panel (b), primary and secondary axes denoted brightness- and hue-difference, respectively. Populations of (a), (b) and (c) were eight, two and tow, respectively.




(a) Example of Group-b1 (14) (b) Example of Group-b2 (14)

**Figure 6.** Examples of "14-color experiment with only b* hue variation" experimental results. Panels (a) and (b) show examples of normal-rotation and crossed-rotation hue circle of four primaries, respectively. Populations of (a) and (b) were six and six, respectively.




(a) Example of Group-a1 (14) (b) Example of Group-a2 (14)

**Figure 7.** Examples of "14-color experiment with only a* hue variation" experimental results. Panels (a) and (b) show examples of normal-rotation and crossed-rotation hue circle of four primaries, respectively. Populations of (a) and (b) were four and eight, respectively.

respectively. These results suggested that (1) the experiments were relatively difficult for observers because all stress values were approximately ten or higher, so (2) individual differences were quite large and it was difficult to precisely classify the results. The only thing suggested from the experiments was that the two groups in segregation of four primary colors were observed; normal-rotation and crossed-rotation hue circle of four primaries.

**(c) Discussions:** The experimental results in "10-color with only b* hue variation" test suggested that the immanent dichromatic in color normal observers (CNOs), which is formed as part of personal visual development, possibly existed. This seems not to be functioning in colorful environments like urban landscapes because there have been few reports about immanent dichromatic function in CNOs and the common sense is "R-G opponent color difference is dominant". However, in fact, CNOs are able to frequently and unconsciously encounter the situations in which a* hue variation is relatively small (e.g. rural landscapes filled with dull colors as shown in Figure 8). In these situations, the Y-B opponent color, instead of R-G opponent color, could be salient, suggesting that the immanent dichromatic in CNOs is functioning.

## 4 CONCLUSIONS

We investigated immanent dichromatic (i.e., similar factors to color vision deficiency (CVD)) in color normal observers (CNOs) by employing the R-G neutral- and Y-B only changed-stimuli. The results showed that (1) the color-constellations yielded when observing R-G neutral- and Y-B only changed- stimuli dominantly varied to concave-shape like dichromic, whereas (2) those attained when observing Y-B neutral- and R-G only changed-stimuli dominantly varied to saturation-brightness oval-shape. This finding is quite novel because it is considered by contemporary commonsense that trichromacy in color vision is individually very stable and therefore it does not reverse to create dichromacy (i.e., retain immanent dichromacy) in adults.

Color difference is usually objectively evaluated within "uniform color space" like CIE La*b* based on the idea that trichromacy is stable in individual adults. However, our findings suggest some reconsideration of previous basic ideas. In other words, we should consider the application extent of these ideas because CNOs possibly use immanent dichromatic features when their observing scenes are changed. We hope that this kind of research will be taken up in the future.


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**Figure 8.** Example of rural landscape. Yellow and blue are relatively salient except for isolated red by white surround.

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