Exploring Color-Universal Design Considering *Kansei* Differences: Color-Vision Types and Impressions of Color Images

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Abstract. In this study, the relationship between color-vision types and impressions of color images was examined. Protan, deutan, and trichromatic color-vision participants evaluated the impressions of color images by employing the semantic differentials method, which comprised 13 adjective pairs. In the visual experiment, 20 color images were presented to 31 Japanese male participants, more specifically, 10 trichromatic, 10 protan, and 11 deutan color-vision participants. The experiment revealed that differences of color-vision resulted in different impressions for identical color images. Three factors, named activity, harmony, and potency were extracted from factor analysis. The factor scores were scattered in a three dimensional space on activity, harmony, and potency axes. Furthermore, the protan participants' factor scores did not vary widely along the harmony axis; however, the impression differences sensed in the specific color images by protan and deutan participants were hard to distinguish by using protan and deutan color-vision simulating algorithms. The knowledge of the relationship between color-vision types and color impressions may enable us to develop a concept of a universal design that considers *kansei* differences.

Keywords: Visual experiment · Semantic differentials · Factor analysis · Protan · Deutan · Trichromat

1 Introduction

The purpose of this study was to explore the feasibility of a universal design that considers *kansei* differences. *Kansei* is a Japanese word that may be defined as human characteristics or abilities related to feelings, emotions, intuition, impressions, associations, and preferences that are induced by something tangible or intangible. Furthermore, *kansei* engineering deals with research related to these characteristics or abilities [1]. Previous studies have been conducted on several types of color-vision and their characteristics as well as color-discrimination difficulties caused by color-vision deficiency [2–7]. Nevertheless, not many studies have been conducted on how the impressions of color images differ in relation to color-vision types [8–10]. The differences inherent in the types of color-vision may yield different impressions of color

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images. Analyses and investigations of the impression of color images constitute the major research topics in *kansei* engineering [11–15]. In contrast, color-vision differences have rarely been investigated in *kansei* engineering.

Human color-vision is divided into four types: Trichromatic color-vision, which is normally referred to as normal color-vision, protan color-vision, deutan color-vision, and others. Protan and deutan color-vision are the most common color-vision deficiencies and consist of dichromatic and anomalous trichromatic color-visions. Protan and deutan color-vision have almost the same characteristics of color perception; they cannot perceive reddish and greenish shades. For example, people with protan or deutan color-vision cannot discern facial flushing [16]. Because of these characteristics, it is believed that protan and deutan color-vision differs significantly from trichromatic color-vision in relation to the impressions perceived from colors.

People with protan and deutan color-vision encounter several difficulties in distinguishing and identifying colors. These difficulties in color discrimination have led to the concept of a color-universal design [17, 18]. A color-universal design considers differences between color-vision types, and provides better color discrimination and identification for everyone. However, a color-universal design does not consider impressions perceived from colors; therefore, trichromatic and protan/deutan color-vision people may perceive different impressions from an identical color design even though a color-universal design has been employed.

In order to solve this problem, our research group aimed to offer a new concept in relation to color-universal design that considers *kansei* differences depending on color-vision types. Although our endeavor required knowledge of the relationship between color-vision types and color impressions, this has, as yet, not been clarified. Consequently, this study attempted to clarify the relationship between color-vision types and impressions of color images. It is hoped that such an endeavor will result in a universal design that considers *kansei* differences.

2 Related Studies and Remaining Issues

Please Ichihara [9] found that the impressions of specific colors depended on color-vision types. Furthermore, the results of an analysis based on Osgood's semantic differentials method (SDM) revealed that people with protan and deutan color-vision perceived the colors between red and orange, orange and yellow, yellow and green, and blue and violet to be blight, gorgeous, and lively. On the contrary, they perceived colors between green and blue such as bluish-green, and violet and red, for example, purple to be dark, plain, and lonely. Ichihara [9] only examined single colors by employing color tiles of the Farnsworth-Munsell 100 Hue Color-Vision Test [19]; however, the impressions of plural color combinations or images comprises many colors that have not been investigated.

Chen et al. [8] developed a color-enhancement method to assist people with anomalous trichromatic color-vision and optimized the strength of color-enhancement according to their preferences. Chen et al. [8] examined images that comprised many colors; however, they only dealt with preference among various impressions and did not investigate the other impressions that Ichihara [9] explored.

3 Methods

A visual experiment was conducted to evaluate trichromatic, protan, and deutan participants' impressions of color images in accordance with Osgood's SDM [20]. Experimental methods employed by Ichihara [9] were also used in this study.

The participants included 31 Japanese males that were grouped according to three types of color-vision: Trichromatic color-vision (10), protan color-vision (10), and deutan color-vision (11). By employing an anomaloscope, all the protan and deutan participants were found to be dichromats without anomalous trichromacy.

Twenty color images (see Fig. 2) were selected from a copyright-free image database as visual stimuli in the experiment. The selection of these images was based on whether or not monochrome images converted from the original color images evoked specific emotions in the participants' minds. This selection criterion was employed to examine only impressions of colors contained in the image without impressions of other factors such as objects contained in the image.

The protan and deutan dichromatic simulations are illustrated in Figs. 3 and 4, respectively. These simulated images were created from the 20 color images using Adobe® Photoshop® CC [21]. Although the simulated images were not used in this visual experiment, they were useful to estimate and understand protan and deutan participants' visual performance for the 20 color images.

The 20 color images were presented in a random order to the participants by employing a liquid crystal display color monitor installed in an experimental room, which was illuminated with daylight-white (6700 K) fluorescent light.

Every participant utilized SDM to evaluate the 20 color images. The SDM is a type of a rating scale between two polar adjectives. In this experiment, the SDM consisted of 13 adjective pairs: (1) Bright—Dark, (2) Warm—Cold, (3) Hard—Soft, (4) Heavy—Light, (5) Strong—Weak, (6) Lively—Tranquil, (7) Flashy—Modest, (8) Dense—Sparse, (9) Stable—Unstable, (10) Beautiful—Ugly, (11) Elegant—Inelegant, (12) Concordant—Discordant, and (13) Dynamic—Static. The rating scale between these polar adjectives is divided into seven equal-length segments to produce a uniform-interval scale; this is referred to as the seven points scale (see Fig. 1). After the acquisition of the rating-data, factor analysis [22] was performed so as to analyze the rating scale values of the SDM.

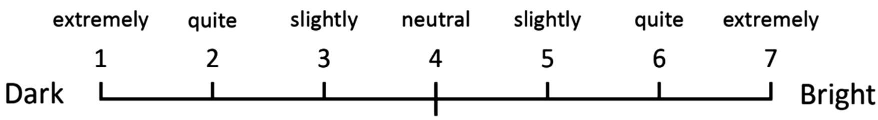

Fig. 1. SDM uses a seven points scale between two polar adjectives.

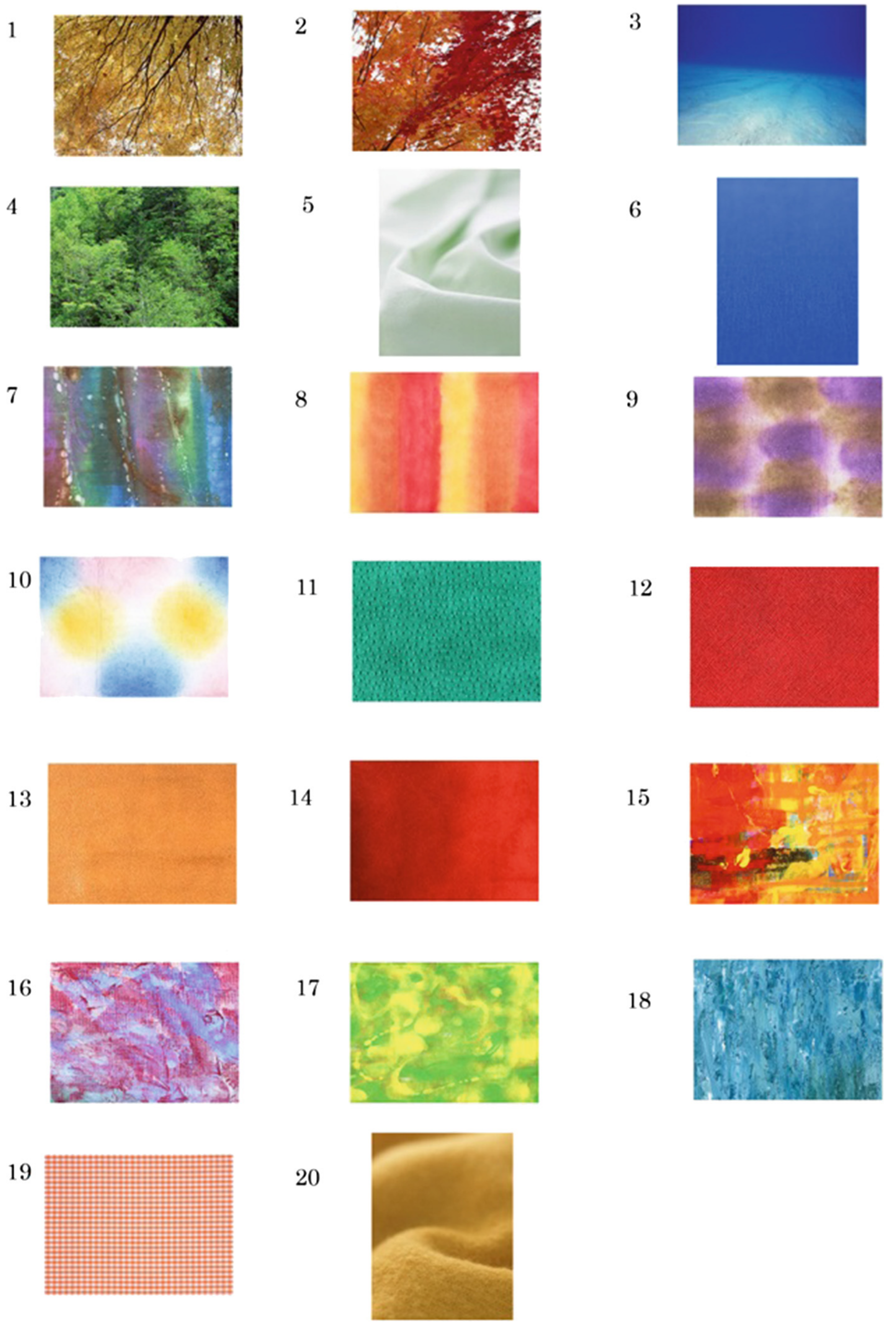

Fig. 2. Twenty color images used in a visual experiment.

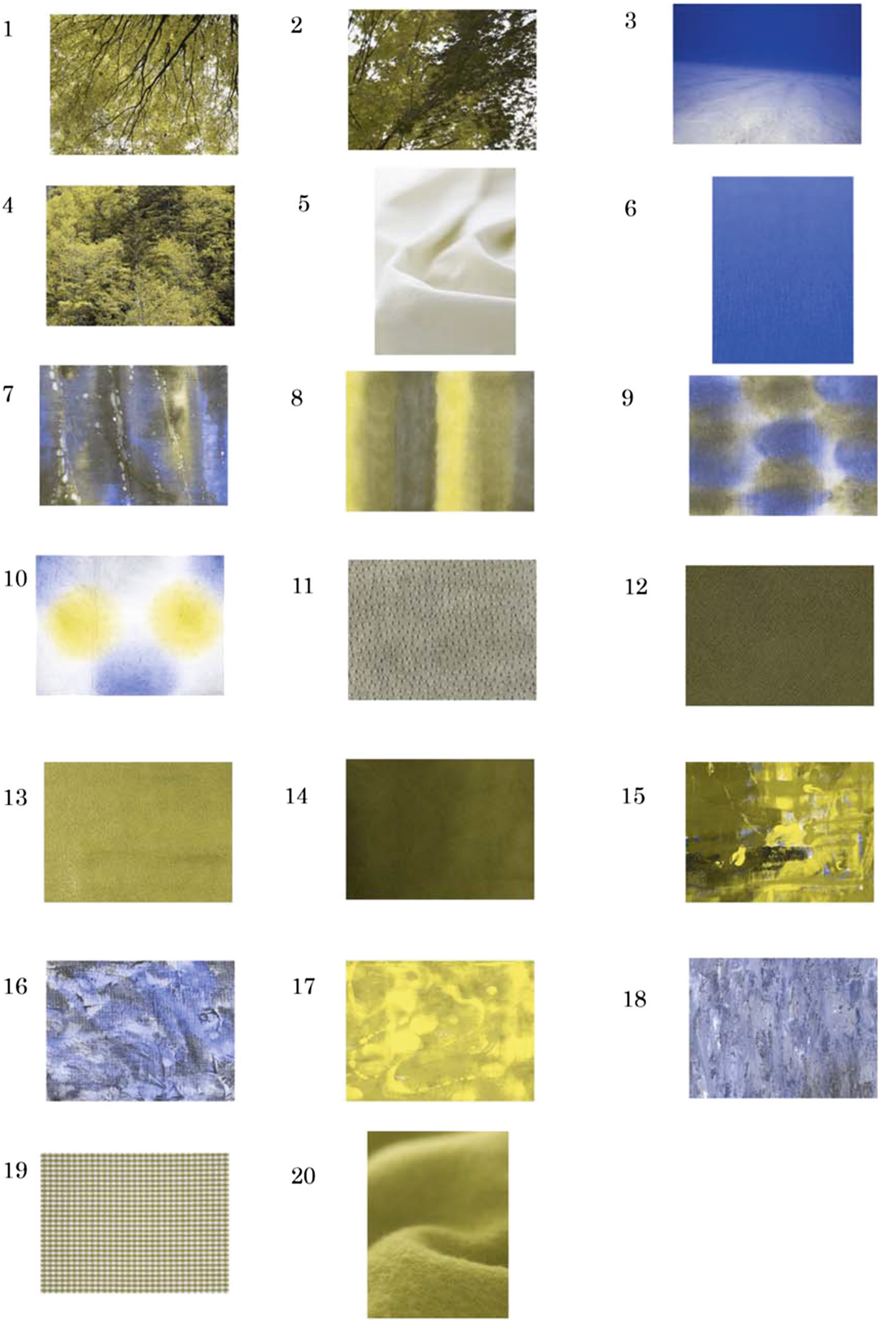

Fig. 3. Protan dichromatic simulations of the 20 color images.

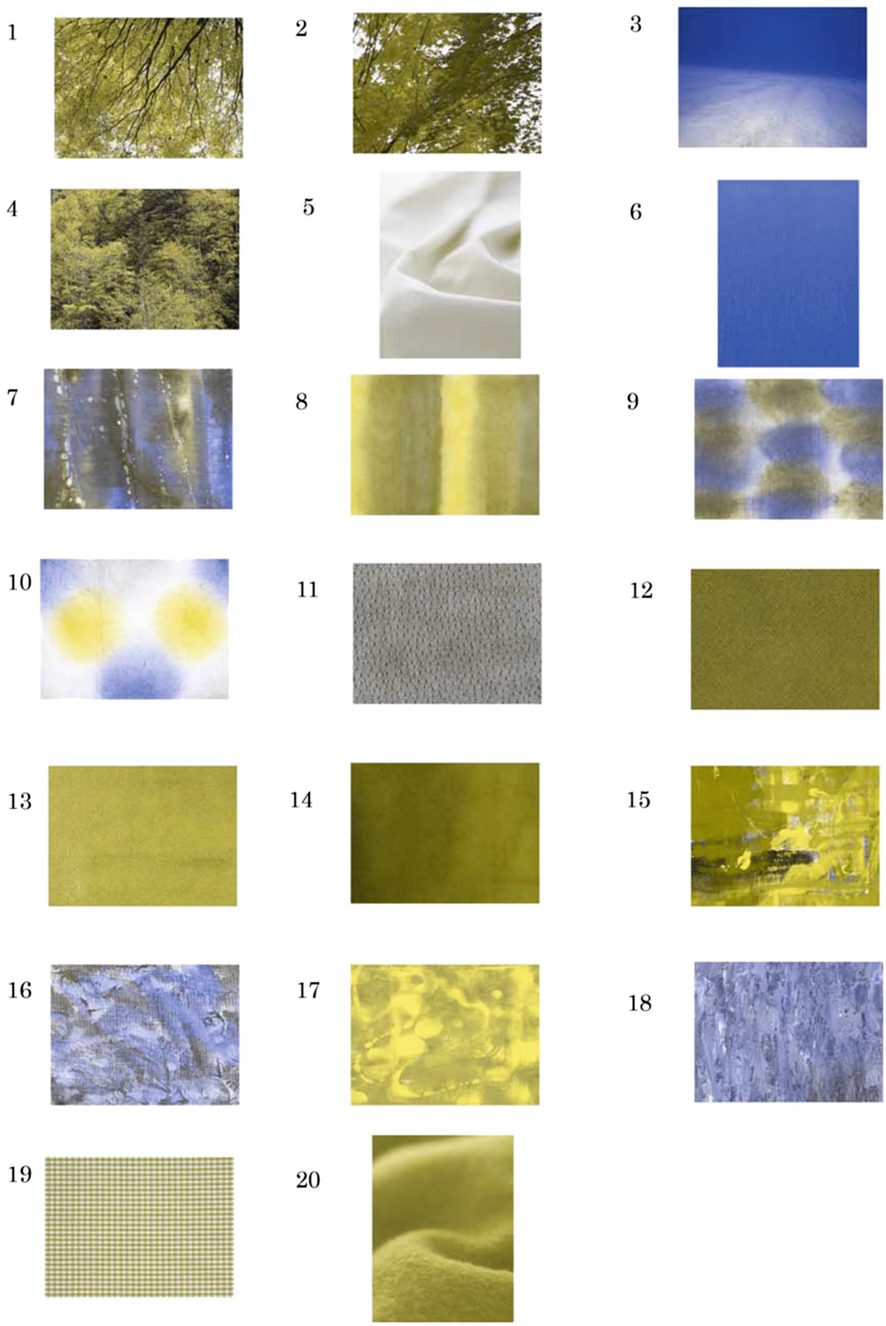

Fig. 4. Deutan dichromatic simulations of the 20 color images.

4 Results and Discussion

A polygonal line graph of the average rating values of the protan, deutan, and trichromatic participants for the 13 adjective pairs is depicted in Fig. 5. Because of the participants' lack of responses, there is no data on the graph for numbers 5, 9, 13, and 20. The blue, red, and gray lines illustrate the average rating values of the protan, deutan, and trichromatic participants, respectively. Based on the overall observations, the protan and deutan participants' impressions were much more similar to trichromatic participants' impressions than we expected firstly. However, significant differences were found in several adjective pairs including Strong—Weak, Lively—Tranquil, Flashy—Modest, Dense—Sparse, Stable—Unstable, Concordant—Discordant, and Dynamic—Static. It was also unexpected that the protan and deutan participants sensed different impressions for specific color images that were difficult to distinguish by the protan and deutan simulation algorithms.

In Table 1, the results of factor analysis, in particular, iterated principal factor analysis and promax rotation for all the rating data for the 13 adjective pairs are presented. The results revealed three factors (factors 1, 2, and 3) were extracted, and we named them activity factor, harmony factor, and potency factor, respectively. Because harmony factor may correspond to Osgood's evaluation factor, our factor analysis revealed that three typical factors were extracted as suggested by Osgood [20].

Table 1. Factor analysis Results of all the rating data for the 13 adjective pairs.

	Factor 1 (Activity)	Factor 2 (Harmony)	Factor 3 (Potency)
Lively	**0.8726**	−0.0293	0.0475
Flashy	**0.7714**	−0.0240	0.2357
Warm	**0.7172**	−0.0150	−0.1490
Bright	**0.5878**	0.1523	−0.2597
Dynamic	**0.4543**	0.0259	−0.0877
Elegant	−0.1049	**0.9078**	−0.1056
Concordant	0.0043	**0.8486**	−0.0399
Beautiful	0.1042	**0.7587**	0.1005
Stable	0.0132	**0.5710**	0.1631
Strong	0.1165	0.0658	**0.7691**
Heavy	−0.2690	0.0121	**0.7118**
Dense	0.3217	−0.0109	**0.5519**
Hard	−0.2030	−0.0917	**0.5492**

The activity factor in Table 1 shows that the factor loading values of lively, flashy, warm, bright, and dynamic were larger than those of the other adjectives. In contrast, the harmony factor in Table 1 reveals that the factor loading values of elegant, concordant, beautiful, and stable were larger than those of the other adjectives, and the potency factor in Table 1 indicates the factor loading values of strong, heavy, dense, and hard were larger than those of the other adjectives.

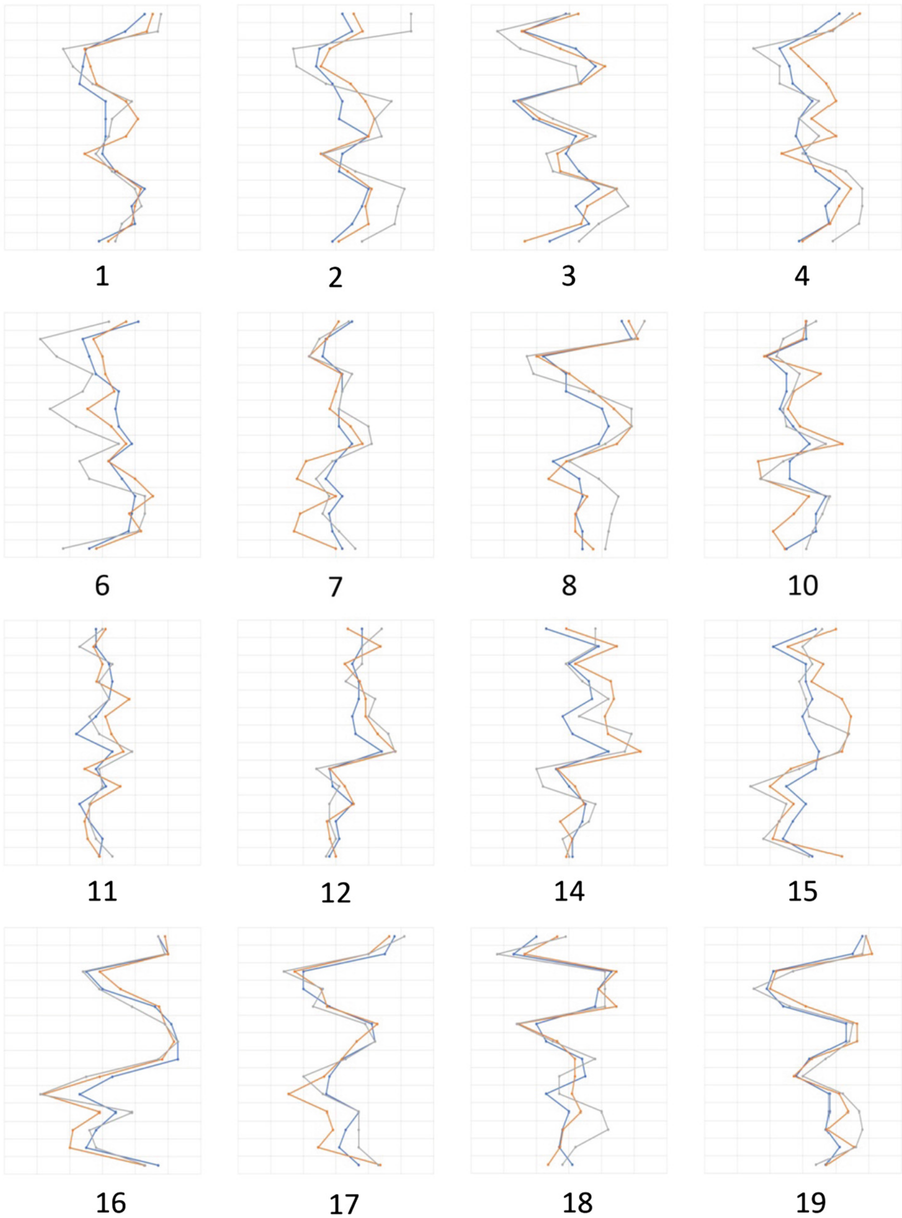

Fig. 5. Polygonal line graphs of the average rating values by the protan (blue lines), deutan (red lines), and trichromatic (gray lines) participants for the 13 adjective pairs. (Color figure online)

The plotted factor scores of the 20 images of the protan, deutan, and trichromatic participants are presented in Figs. 6 and 7. The factor scores in this study are scattered in a three dimensional space with an activity factor axis, a harmony factor axis, and a potency factor axis. In the two dimensional diagrams in Fig. 6, the activity factor is represented on the vertical axes and harmony factor on the horizontal axes. In the two dimensional diagrams in Fig. 7, the activity factor is represented on the vertical axes and the potency factor on the horizontal axes. We observed specific tendency in Fig. 6: The protan participants' factor score was not distributed widely along the harmony (horizontal) axis. This fact suggests that differences of color-vision influence the strength of sense of harmony or the sense of harmony itself that every individual perceived. The fact that differences of color-vision resulted in various evaluations of the 20 images is depicted in Figs. 6 and 7. This fact suggests that diversity in color-vision and *kansei* must be considered to develop a new concept of color-universal design that impart the intended impression to others accurately by using colors.

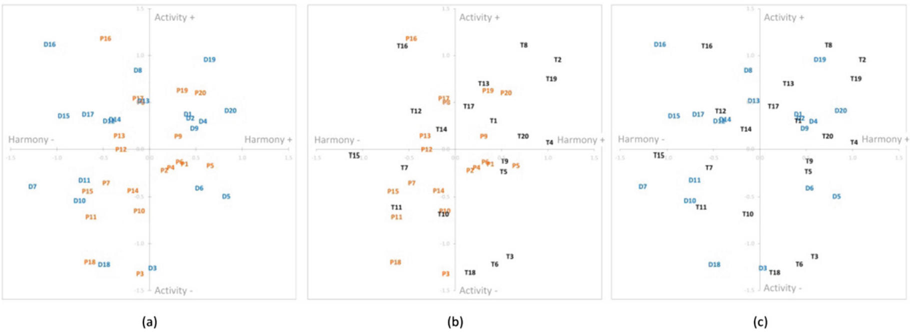

Fig. 6. The plotted factor scores (red: protan, blue: deutan, and black: trichromat) of the 20 images. The activity factor is represented on the vertical axes and harmony factor on the horizontal axes in the two dimensional diagrams. (Color figure online)

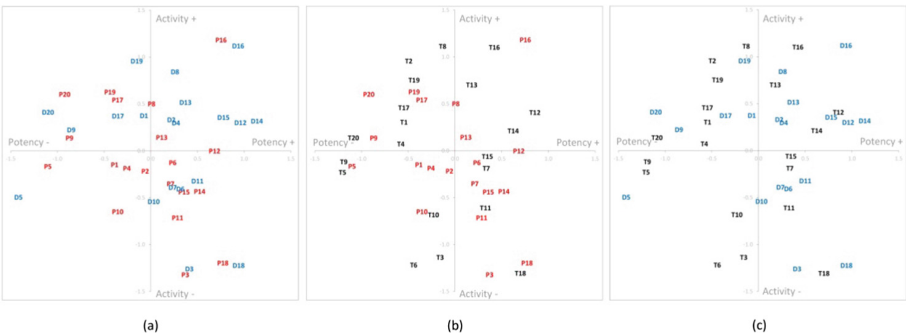

Fig. 7. The plotted factor scores (red: protan, blue: deutan, and black: trichromat) of the 20 images. The activity factor is represented on the vertical axes and potency factor on the horizontal axes in the two dimensional diagrams. (Color figure online)

5 Conclusions

The relationship between color-vision types and color impressions were examined in this study. The results revealed that differences in color-vision resulted in different impressions for identical color images.

In this study, we extracted activity, harmony, and potency factor; these factors corresponded to Osgood's three factors, activity, evaluation, and potency. They were also observed in Ichihara [9] when 100 single colors were used. This fact suggests that the relationship between color-vision types and color impressions does not depend on the number of colors so much. Furthermore, Ichihara [9] found that the values of activity axis were clearly associated with color hue (kinds of colors). In contrast, the present study did not find a significant relationship between color-vision types and color impressions with the exception of the specific tendency that the harmony scores of the protan participants did not vary widely.

Our experimental results suggest that protan and deutan simulation algorithms [21] are not always sufficient when one wants to investigate and classify their impressions for color images (see Figs. 2 and 3). The reason for this insufficiency is that protan and deutan simulation algorithms reduce the color-gamut of original images. Such simulation images cannot reproduce true dynamic ranges that protan and deutan participants see. Based on these experimental results, we could not identify colors that can give common impressions to any type of color-vision. It is recommended that the relationship between color-vision types and impressions of colors be investigated further. Furthermore, in the near future, it is hoped a universal design considering *Kansei* differences will be established if this type of research is continued.

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