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A Constructive Framework for Colour Vision Deficiency in Digital Photography

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Abstract
Around 8.5% of people globally are affected by color blindness. Research explores the visual difficulties that color vision deficiency (CVD) photographers face. This study evaluates the visual skills of CVD photographers, focusing on the categories of Protanopia, Tritanopia, and Deuteranopia. It employs the HSx-Based Method, Contour Adjustment, Interpretation Process, and Perception Learning. After preliminary testing, experimental testing was conducted with control questions and minimal coaching. The Chi-square Test of Homogeneity classifies CVD and compares it to normal vision. Spearman's Rho Correlation Test confirms that all CVD categories are "photosafe," providing valuable software and product development insights.

Keywords: Color blindness, color vision deficiency photographer, constructive framework, inferential test

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1.0 Introduction
Photography involves capturing light on light-sensitive material to create an image, a process utilized in science, industry, and art. It enhances the aesthetic value of original artwork, providing a pleasing visual experience. Color, as a critical aesthetic element, holds particular importance in photography. Even professional photographers may need to thoroughly appreciate the significance of color in their work. Color can draw attention and evoke emotions, so it plays a crucial role in compelling images. Unfortunately, some individuals suffer from color vision deficiency (henceforth, CVD), which affects their ability to perceive colors accurately. This condition is typically inherited but results from trauma, medication, or disease, altering how people perceive colors and tints. Contrary to widespread usage, the term "color blindness" is a misnomer, as those affected by CVD can still perceive some colors. This is a significant issue, as CVD affects a considerable portion of the global population.

1.1 Structure Colour Adjustment Method for Colour Vision Deficiency (CVD) Users
Ribeiro (2017) explored how to assist CVD users in viewing websites. Building on earlier research, Ribeiro developed a color correction method that respects perceptual learning. For example, deuteranopes perceive orange as a pale green; thus, the recoloring method should not alter this to blue. Ribeiro (2017) devised a Colour Adjustment Algorithm using HSx-Based and Contour Enhancement

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Methods. The HSx method is based on HSV (hue, saturation, value), where adjustments are made to enhance the perception of colors like green, which Deutan users struggle with. Contour Adjustment isolates text and typography from the background, improving readability. Ribeiro's claim that the Colour Adjustment Algorithm (CAA) makes websites more accessible for CVD users is well-founded.

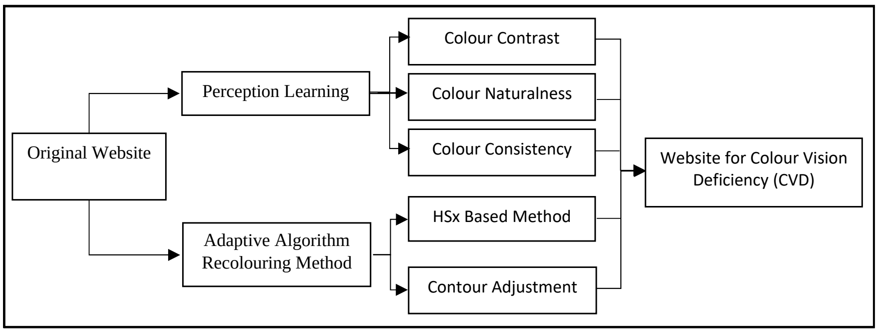

Fig. 1: Illustration Figure of Colour Adaption Algorithm (CAA) for CVD Website Users (Ribeiro, 2017)

1.2 Curator Based Interpretation

Interpretation involves critical thought because everyone has different ideas. Many photographers and academics have studied interpretation from various perspectives. The photographer, audience, and museum curator can interpret art, as McManus (2019) writes. McManus (2019) argues that interpretation must include artistic merit, social criticism, and social worth. A suitable medium can enhance an image's aesthetics. Photographers with expertise create appealing images. Photography is an art form for its theme, composition, color, lighting, and other qualities. Photographers may refine their style to make a more significant impact. Social critique is another specialization of museum curators. They critique visuals with more context and depth. Social criticism involves narratives, viewpoints, and symbolic or direct communication. This allows photographers to converse through their photographs. Art gallery curators can assess public perception and provide explanations for pictures. Additionally, gallery visitors interpret social values and competence. Beauty, marketability, desire, status, etc., are social values. Beauty, price, status, and marketability will attract attention to the image. However, they often lack the artistic and photographic skills to understand the narrative or create images. Therefore, the audience plays a vital role in conveying the most compelling image and evaluating societal values.

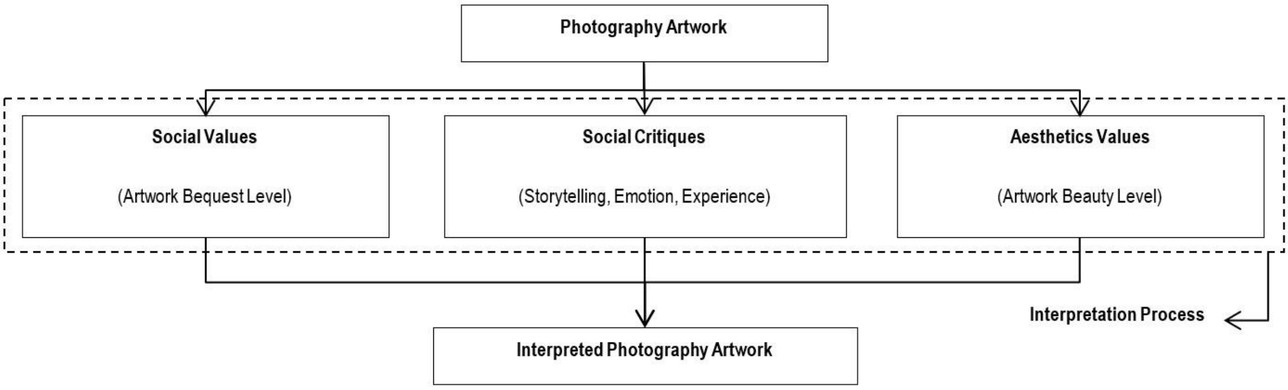

Fig. 2: Illustration Figure of Curator Based Interpretation (McManus, 2019)

2.0 Methodology

This research employs an experimental design to examine how altering the independent variable affects the dependent variable. Thomas (2021) states that experimental evidence is one of the most reliable methods for establishing causality. In this study, the treatment group viewed CVD-edited imagery, while the control group viewed images intended for normal vision. The variables were manipulated using HSx (hue, saturation, value), contour adjustment, perceptual learning, and interpretation process methods. Differences between images for average and CVD viewers were then compared to build a model for future applications.

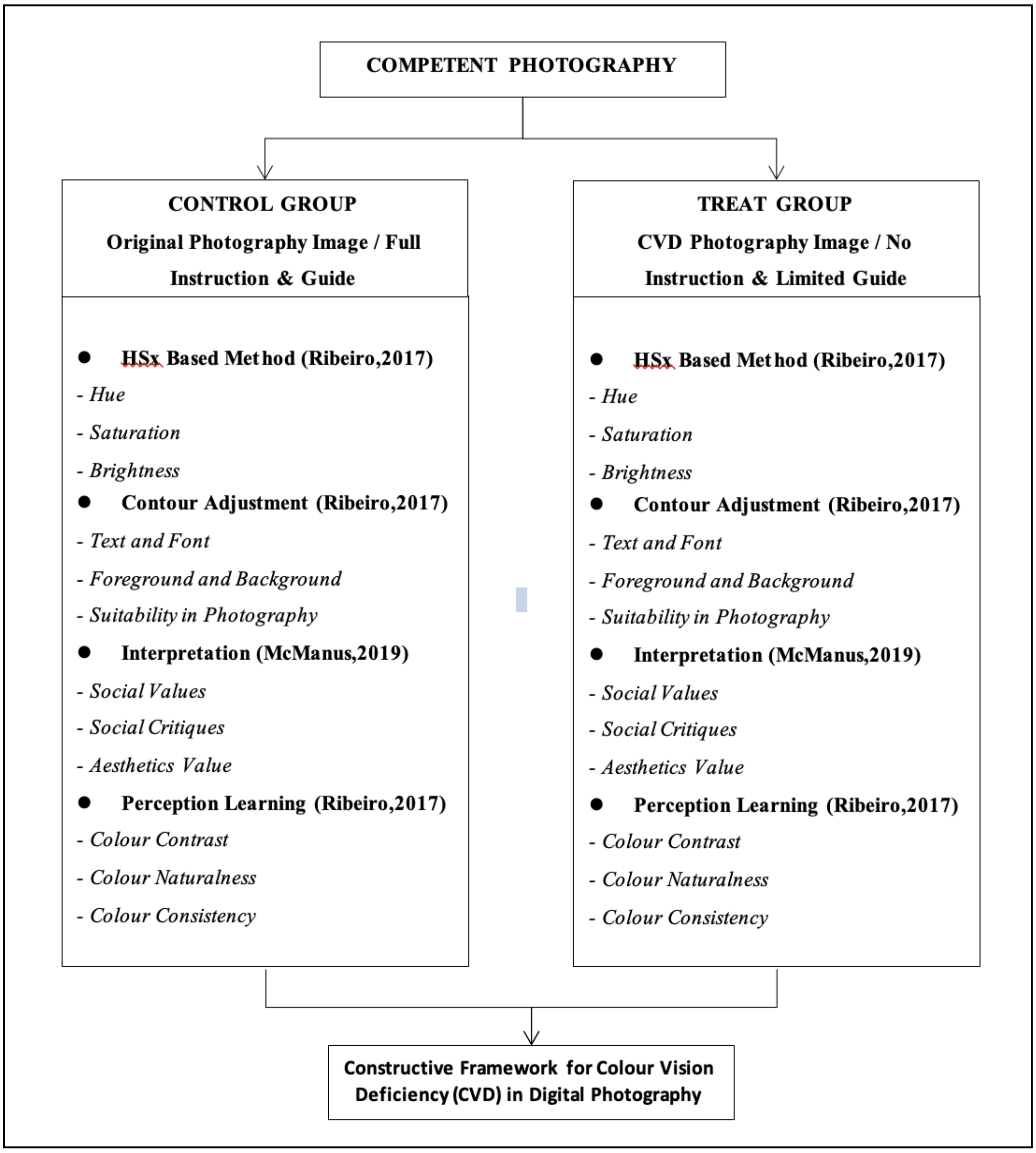

Fig. 3: Illustration Figure of Control Group vs Treatment Group

2.1 Research Population and Sampling

Samples taken from this research consisted of experienced photography students of Photography and Creative Imaging, UiTM Melaka branch. These samplings have equal technical skills and photography knowledge compared to each other. The criteria for each student are, that they have to pass a color-blind test, pass with a minimum score of 80% at the basic photography skill test and basic editing skill test. The sample size consists of 40 competent students, which are randomly divided into two groups, which are Control Group (20 students) and the Treat Group (20 students). The Randomization Method used was simple randomization using a random number generator to divide each participant into groups.

2.2 Obtaining Competent Photographers

The participants underwent a series of competency assessments, beginning with the Color-Blindness Test (Section A), in which they were required to complete a series of Ishihara Plate evaluations. The first criterion for identifying competent photographers was the absence of visual impairments. The assessment then proceeded to the Basic Photography Skills Test (Section B), comprising 30 questions focused on foundational photography knowledge, including lighting principles, photographic elements, and camera settings. Finally, participants completed the Basic Editing Skills Test (Section C), which also consisted of 30 questions covering essential editing techniques such as color correction, application of effects, and image adjustments. To qualify as a Competent Photographer, participants were required to achieve a minimum score of 80% in each section. Failure to meet this benchmark resulted in disqualification from participation in the Experimental Test.

2.3 Experimental Test Inferential Statistical Analysis

Based on the analytical testing conducted, it was determined that the measurement scale used is ordinal. The sampling method employed was purposive, and the distribution of scores within the population was non-normal, with a relatively small sample size of n=20 per group. Given these conditions, the most appropriate non-parametric comparison test, as supported by the research, is the Chi-Squared Test of Homogeneity. This test was utilized to examine differences among the various types of color vision deficiency (CVD)—namely Tritanopia, Deuteranopia, and Protanopia—across four variables: the HSx-Based Method, Contouring Adjustment, Interpretation Process, and Perception Learning.

3.0 Findings

The experimental tests revealed that the descriptive data did not meet the normality assumption for distribution. The test variables were ordinal and involved purposive sampling. Inference data was meticulously analyzed using the Statistical Package for the Social Sciences (SPSS).

3.1 Comparison of CVD Variables in the Control and Treatment Groups

Comparative tests were performed to identify differences between the types of CVD concerning the variable items. CVD, consisting of three categories—Tritanopia, Deuteranopia, and Protanopia—was assessed using the HSx Test. Based on the statistical tests' basic requirements, the most appropriate non-parametric test for comparison was determined to be the Chi-Square Test of Homogeneity. This test was utilized to analyze whether differences exist between the HSx components—hue, saturation, and brightness—of the three types of color blindness.

3.2 Differences Between CVD Types and the HSx-Based Method

As shown in Table 1 below, Tritanopia CVD revealed no significant difference in the brightness rate between regular and color vision-deficient artwork, with an asymptotic value of 0.892 ($p > 0.5$). Similarly, saturation showed no significant difference, with an asymptotic value of 0.680 ($p > 0.5$). However, Tritanopia CVD did record a considerable difference in hue, with an asymptotic value of 0.078 ($p < 0.5$). This indicates that Tritanopia presents significant differences in hue compared to normal vision, while brightness and saturation remained unaffected.

Table 1. Square Test of Homogeneity for CVD Types and the HSx-Based Method

Type of CVD	HSx1 (Brightness)	HSx2 (Saturation)	HSx3 (Hue)
Tritanopia	0.892	0.680	0.078
Deuteranopia	0.456	0.270	0.078
Protanopia	0.154	0.444	0.065

Next, Deuteranopia CVD exhibited a significant difference in brightness between regular and color vision-deficient artwork, with an asymptotic value of 0.456 ($p < 0.5$). Saturation also showed a significant difference, with an asymptotic value of 0.270 ($p < 0.5$). Finally, Deuteranopia CVD displayed a substantial difference in hue, with an asymptotic value of 0.078 ($p < 0.5$). This demonstrates that Deuteranopia leads to significant differences in brightness, saturation, and hue when compared to normal vision.

Similarly, Protanopia CVD presented a significant difference in brightness, with an asymptotic value of 0.154 ($p < 0.5$). Saturation recorded a significant difference, with an asymptotic value of 0.444 ($p < 0.5$). Furthermore, Protanopia CVD also showed a significant difference in hue, with an asymptotic value of 0.065 ($p < 0.5$). These results highlight that Protanopia leads to significant variations in brightness, saturation, and hue compared to normal vision.

Table 2. Square Test of Homogeneity for CVD Types and Contour Adjustment

Type of CVD	CAT1 (Text/Font)	CAT2 (Fore/Background)	CAT3 (Suitability in Photography)
Tritanopia	0.696	0.482	0.002
Deuteranopia	0.696	0.888	0.524
Protanopia	0.492	0.482	0.002

As detailed in Table 2 above, Tritanopia CVD showed no significant difference in text and font improvements between normal and color vision-deficient artwork, with an asymptotic value of 0.696 ($p > 0.5$). However, a significant difference was found between the foreground and background, with an asymptotic value of 0.482 ($p < 0.5$). Additionally, Tritanopia CVD recorded a significant difference in photographic appropriateness, with an asymptotic value of 0.002 ($p < 0.5$). These findings suggest that Tritanopia's contour adjustment enhances the foreground, background, and photographic appropriateness, surpassing normal vision in this regard. Consequently, the null hypothesis (H0) is rejected, and the alternative hypothesis (Ha) is accepted. However, Tritanopia's contour modifications in text and typeface did not show improvements over normal vision.

Further analysis of Deuteranopia CVD revealed no significant difference in text and font improvements between normal and color vision-deficient artwork, with an asymptotic value of 0.696 ($p > 0.5$). Likewise, the foreground and background showed no significant difference, with an asymptotic value of 0.888 ($p > 0.5$). Finally, Deuteranopia CVD exhibited no significant effect on photographic appropriateness, with an asymptotic value of 0.524 ($p > 0.5$). These results confirm that contour adjustments in Deuteranopia do not influence foreground, background, text, typeface, or photographic compatibility when compared to normal vision.

Table 3. Square Test of Homogeneity for CVD Types and Interpretation Process

Type of CVD	ITP1 (Social Values)	ITP2 (Social Critiques)	ITP3 (Aesthetics Values)
Tritanopia	0.474	0.028	0.890
Deuteranopia	0.509	0.582	0.871
Protanopia	0.249	0.030	0.890

According to Table 3, Tritanopia CVD exhibited a significant difference in social values between normal and color vision-deficient artwork, with an asymptotic value of 0.474 ($p < 0.5$). Additionally, social critiques showed a significant difference, with an asymptotic value of 0.028 ($p < 0.5$). However, Tritanopia CVD had no significant effect on artwork aesthetics, with an asymptotic value of 0.890 ($p > 0.5$). This indicates that Tritanopia artwork differs in terms of social values and critiques compared to artwork created for normal vision, thereby accepting (Ha) and rejecting (H0). Nevertheless, Tritanopia's artwork shares the same aesthetic value as that of normal vision.

The analysis continues with Deuteranopia CVD, which showed no significant difference in social values between normal and color vision-deficient artwork, with an asymptotic value of 0.509 ($p > 0.5$). Similarly, no substantial difference was noted in social critiques, with an asymptotic value of 0.582 ($p > 0.5$). Finally, Deuteranopia CVD had no significant effect on artwork aesthetics, with an asymptotic value of 0.871 ($p > 0.5$). This reveals that Deuteranopia artwork is interpreted similarly to normal vision artwork concerning social values, social critiques, and aesthetics.

Further analysis reveals a significant difference in social values between normal and color vision-deficient artwork for Protanopia CVD, with an asymptotic value of 0.249 ($p < 0.5$). Additionally, social critiques showed a significant difference, with an asymptotic value of 0.030 ($p < 0.5$). However, Protanopia CVD had no significant effect on artwork aesthetics, with an asymptotic value of 0.890 ($p > 0.5$). This suggests that Protanopia artwork differs from normal vision artwork in terms of social values and critiques, where (Ha) is accepted, and (H0) is rejected. However, Protanopia artwork exhibits the same aesthetic value as ordinary vision artwork.

Table 4. Square Test of Homogeneity for CVD Types and Perception Learning

Type of CVD	PRL1 (Colour Naturalness)	PRL2 (Colour Consistency)	PRL3 (Colour Contrast)
Tritanopia	0.361	0.690	0.329
Deuteranopia	0.088	0.189	0.531
Protanopia	0.690	0.582	0.264

According to Table 4, Tritanopia CVD exhibited a significant difference in color naturalness between normal and color vision-deficient artwork, with an asymptotic value of 0.361 ($p < 0.5$). However, no significant difference was found in color consistency, with an asymptotic value of 0.690 ($p > 0.5$). In conclusion, Tritanopia CVD displayed a significant difference in color contrast in artwork, with an asymptotic value of 0.329 ($p < 0.5$). This indicates that perception learning in Tritanopia artwork differs from normal vision artwork in terms of color naturalness and contrast, though color consistency remains the same as in normal vision.

Deuteranopia CVD showed a significant difference in color naturalness between normal and color vision-deficient artwork, with an asymptotic value of 0.088 ($p < 0.5$). A significant difference in color consistency was also observed, with an asymptotic value of 0.189 ($p < 0.5$). However, Deuteranopia CVD showed no significant difference in artwork color contrast, with an asymptotic value of 0.531 ($p > 0.5$). This suggests that perception learning in Deuteranopia artwork differs from normal vision artwork in terms of color naturalness and consistency, although color contrast remains consistent with normal vision.

The analysis continues with Protanopia CVD, which revealed no significant difference in color naturalness between normal and color vision-deficient artwork, with an asymptotic value of 0.690 ($p > 0.5$). Similarly, no significant difference was observed in color consistency, with an asymptotic value of 0.582 ($p > 0.5$). However, Protanopia CVD displayed a significant difference in color contrast in artwork, with an asymptotic value of 0.264 ($p < 0.5$). This confirms that perception learning in Protanopia artwork results in significant differences in color contrast, while color naturalness and consistency remain unchanged compared to ordinary vision artwork.

4.0 Discussion

This study applies Ribeiro's (2017) color correction algorithm as McManus (2019) tested through an interpretative process. It reviews methods that use color modification for both user and curator-based interpretation. The new constructive framework for CVD, outlined below, assists CVD photographers in achieving results akin to everyday vision photography. It is acknowledged that this issue is relatively new in research.

4.1 Normal Vision Photography as an Indicator for Colour Adjustment Method

The framework for CVD photographers focuses on an HSx-based approach, which refers to the hue, saturation, and brightness of photographic images for each type of CVD. It then applies contour adjustments to distinguish text and font, background and foreground, and to evaluate photographic suitability. After assessing societal ideals, critiques, and aesthetics for interpretation, perception learning is measured by color naturalness, consistency, and contrast.

Fig. 4: Normal Vision Photograhy

As shown in Figure 5 below, the average vision photographer is an indicator, undergoing the HSx-based method with normal saturation, hue, and brightness values. This indicator aids in observing changes and differences within the color vision deficiency framework. Following this procedure, contour adjustments are not correctly applied to images, as they primarily assist with fonts and images but fail to enhance foreground and background differentiation. Since average vision photographers can naturally perceive differences between foreground and background, contour adjustments are unnecessary and may detract from the aesthetic value. Viewers can express emotions and develop a personal connection to the artworks during the interpretation process. Aesthetic elements such as composition, subject, color, and lighting are also present in the photograph. In perception learning, the naturalness, consistency, and contrast appear normal. As the chart indicates, normal vision photographers follow the HSx-based method and act as indicators without requiring contour adjustments. They achieve excellent social critiques, social values, aesthetic values, and normal perception learning. The process chart for normal-sighted vision is shown in Figure 5.

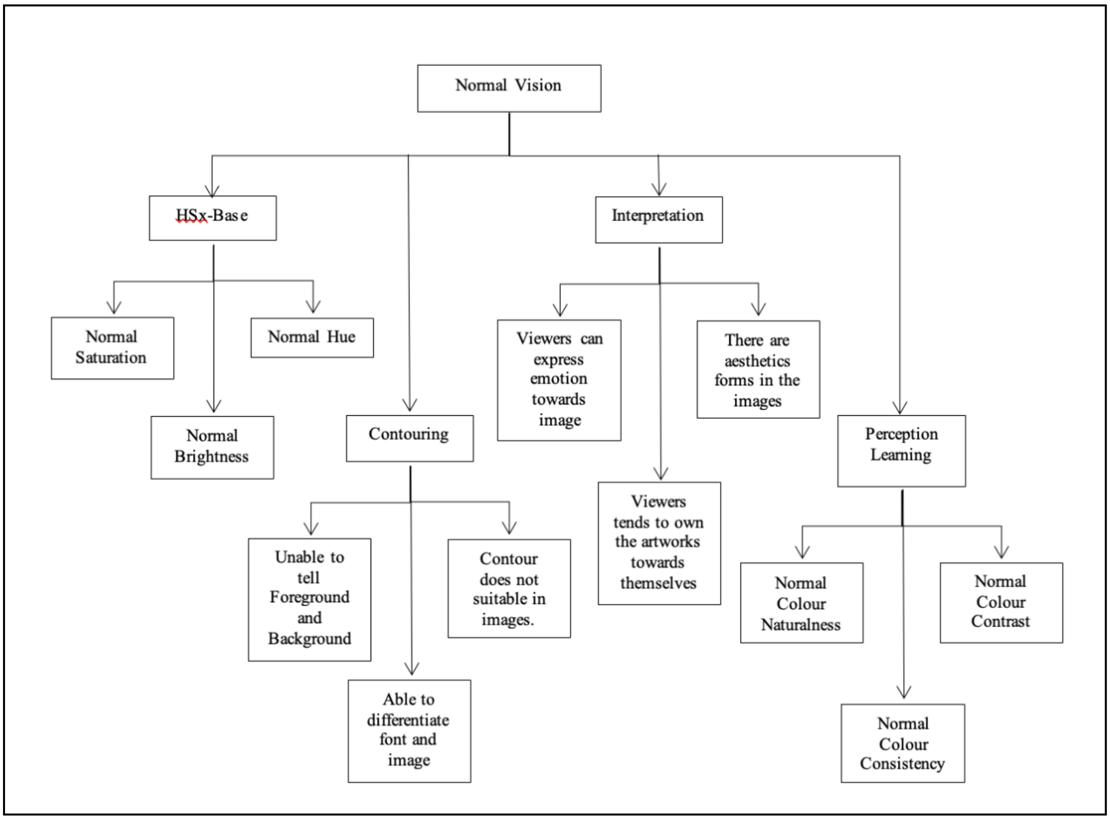

Fig. 5: Normal Vision towards HSx-Base, Contour, Interpretation, and Perception Learning

4.2 Comparison Between Types of CVD and the Colour Adjustment Algorithm

After analyzing the data, it was concluded that differences exist among the various types of CVD when compared to the normal vision framework presented in Figure 5. The observed differences concern the HSx-based method, contour adjustments, interpretation process, and perception learning. CVD is classified into three categories: Tritanopia, Deuteranopia, and Protanopia.

(a) (b)

Fig. 6. (a) Normal Vision; (b) Tritanopia towards HSx Base, Contouring Adjustment, Interpretation Process, and Perception Learning.

Referring to the statistical data, from the perspective of a Tritanopia photographer, no differences in saturation and brightness were detected compared to a normal vision photographer. However, the absence of yellow hues drastically alters the naturalness and contrast of the color vision. Despite this, the consistency remains unchanged. In terms of contour adjustments, the presence of contours helps distinguish the background from the foreground, though it is unable to differentiate fonts from images. Nevertheless, contours are suitable for use. Regarding interpretation, Tritanopia's work provides no notable social criticism or social value compared to the other CVD types. However, the aesthetic value remains intact.

Fig. 7. (a) Normal Vision; (b) Deuteranopia towards HSx Base, Contouring Adjustment, Interpretation Process, and Perception Learning.

According to the statistical data, from the perspective of a Deuteranopia photographer, there are differences in brightness and saturation compared to a typical vision photographer. The absence of green hues affects the naturalness of the color, with a marked change in consistency. However, the color contrast remains unchanged. In terms of contour adjustments, the presence of contours does not aid in distinguishing the background from the foreground, nor in differentiating fonts from images. Contours are, therefore, unsuitable for this type of CVD. Regarding interpretation, Deuteranopia does not affect social values, social critiques, or aesthetic values.

(a) (b)

Fig. 8. (a) Normal Vision; (b) Protanopia towards HSx Base, Contouring Adjustment, Interpretation Process, and Perception Learning.

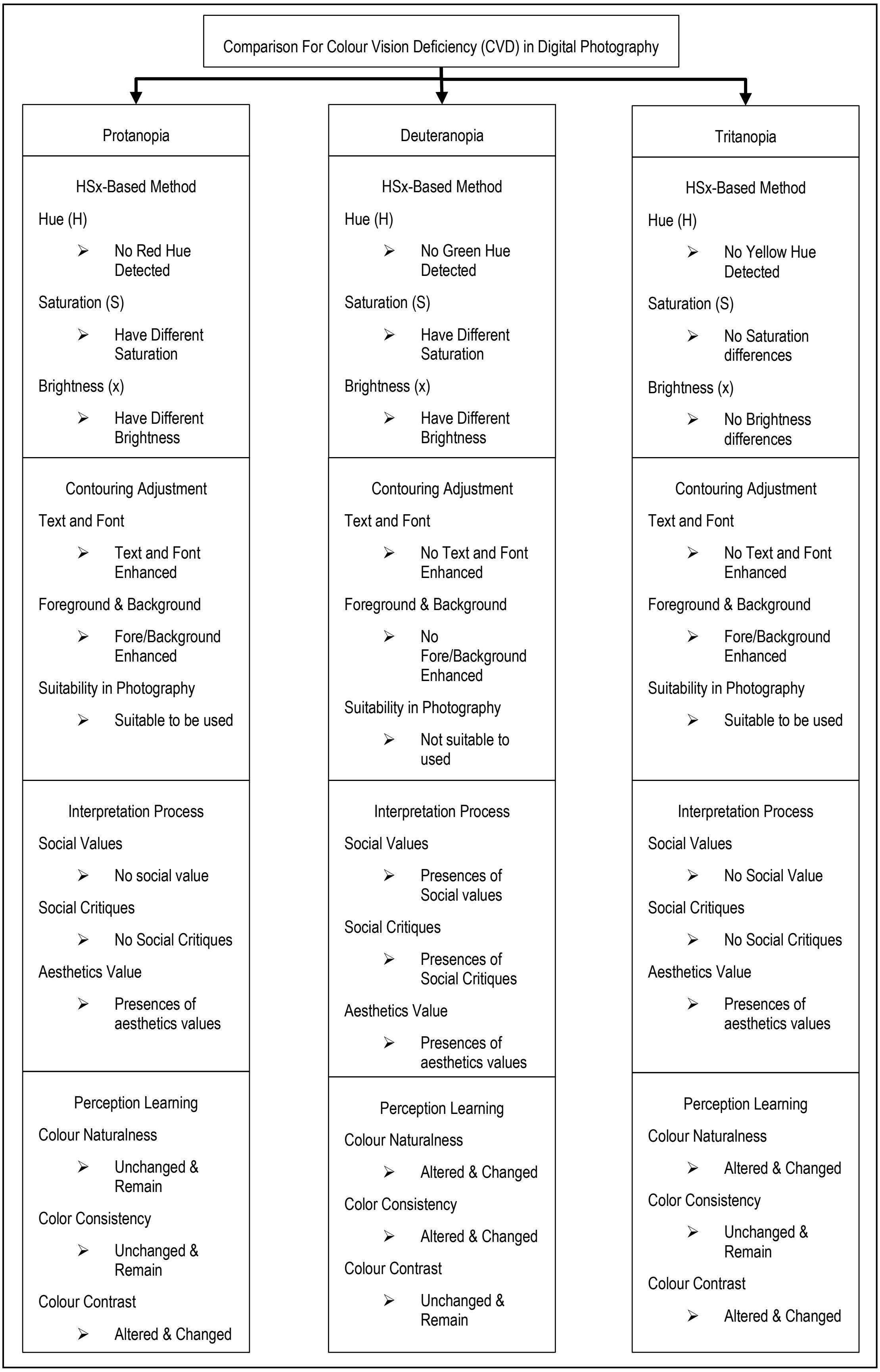

Fig. 9: Normal Vision towards HSx Base, Contour, and Interpretation in Framework

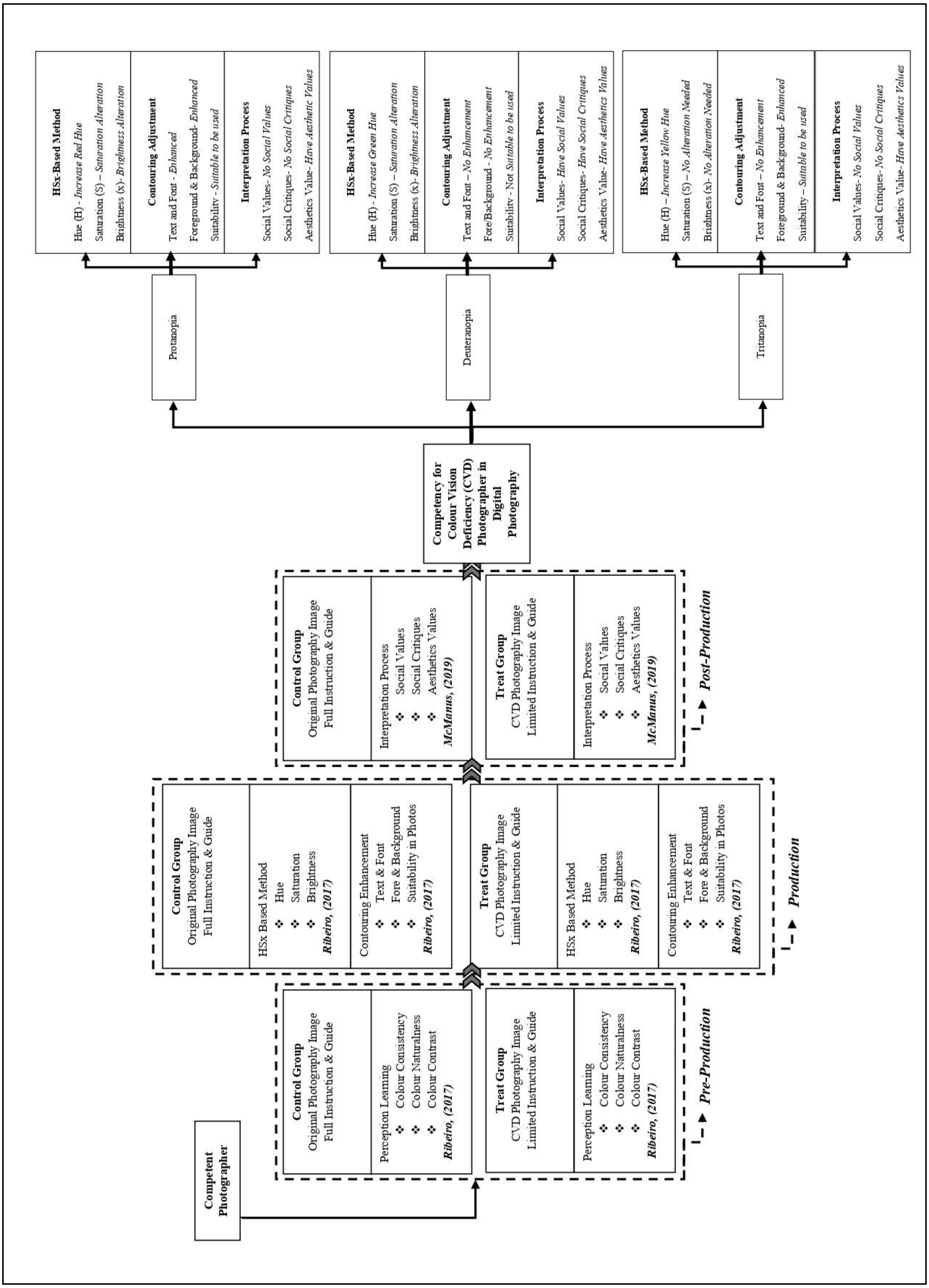

Fig. 10: Competency for Colour Vision Deficiency (CVD) Photographers in the Digital Photography Framework

The statistical data indicate that for Protanopia photographers, brightness and saturation differ from those of normal vision photographers. Furthermore, the absence of red hues results in altered color contrast. However, the color naturalness and consistency in Protanopia remain the same. Regarding contour adjustments, the presence of contours effectively distinguishes the background from the foreground and successfully differentiates fonts from images. Thus, contours are suitable for use in Protanopia CVD. Regarding interpretation, Protanopia's work, like Tritanopia's, provides no significant social criticism or social value compared to the other CVD types, although the aesthetic value remains preserved.

5.0 Conclusion

In conclusion, using this paradigm, future researchers can develop better programs and products. By adding modules, tools, and software to this architecture, CVD photographers will be able to perceive colors similarly to those with normal vision. The enhanced framework should assist CVD photographers in mastering digital photography. The framework should also emphasize color correction details, such as value ranges or percentages for each HSx element (hue, saturation, brightness). It is essential to highlight the contour range and safe contour percentages for aesthetic purposes.

5.1 Research Limitations

This study acknowledges several limitations that may affect the interpretation and generalizability of its findings. Firstly, the small sample size may restrict the statistical power and limit the accuracy and reliability of the results. Secondly, the use of self-reported data introduces potential biases, such as recall bias and social desirability bias, which may influence the validity of participants' responses. Additionally, the findings may not be generalizable to populations outside the study's specific setting or demographic, thereby limiting their broader applicability. Lastly, certain interventions or experimental conditions could not be implemented due to ethical considerations, which may have constrained the scope of the research.

5.2 Recommendations For Future Research

The current research presents a broad perspective on color vision deficiency (CVD) in photography but lacks in-depth analysis tailored to the different types of CVD—such as Protanopia, Deuteranopia, and Tritanopia. Each type affects color perception in distinct ways, which in turn impacts how photographers perceive and capture images. Without providing specific interpretations for each CVD type, the research may overlook nuanced challenges faced by individuals with differing visual impairments. Furthermore, the academic and creative discourse around photography and CVD remains limited at the international level, reducing the availability of diverse insights, frameworks, and cross-cultural perspectives. In addition, the theoretical foundations and conceptual frameworks employed are not sufficiently defined or consistently applied, which can hinder the reliability and applicability of findings. More robust methodologies—such as mixed methods research, case studies, and experimental designs—combined with clearer theoretical underpinnings would allow for a deeper, more structured exploration of the subject. Distinguishing among the CVD types through comparative analysis of their visual and perceptual characteristics can lead to more accurate and inclusive photographic frameworks. These improvements would not only elevate the quality of academic research but also support photographers with CVD in adapting their creative practices more effectively.

Acknowledgements

This paper has been made possible through the sincere contributions and encouragement of all its members.

Paper Contribution to Related Field of Study

This research contributes to the field by establishing a competency framework that allows CVD photographers to interpret colors like non-CVD photographers, benefiting the industry. This approach helps CVD photographers overcome challenges and capture high-quality images. It also facilitates the design of industry-specific CVD campaigns and solutions, promoting inclusivity and improving visual perception in photography.

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