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Color Perception in Correlated Color Temperature of Led Lighting

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Abstract

Color and light are inseparable entities that are the essential design factors in the field of interior architecture. When the light changes, the perceived color appearance of a surface within an interior environment also changes. The change in color perception is not only related to the type of a light source or the intensity of illumination, but also to the correlated color temperature (CCT) of a light source. The aim of this study is to understand how different CCTs of light-emitting diode (LED) lighting influence the color perception. A study is conducted to compare the perceptive color tendencies for inherent colors under two different CCTs of LED lighting, i.e. warm (2700º K) and cool (4000º K). In the study, Natural Color System (NCS) is utilized as a color notation system to reveal the possible tendencies and patterns concerning the relationship between the inherent and perceived colors. The general tendencies for the perceived colors revealed similar patterns in the nuance (i.e. blackness and chromaticness) color area for each inherent color and showed dispersion on the hue color area under the CCTs of both 2700º K and 4000º K LED lighting.

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Anahtar kelimeler:
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LED Aydınlatmanın Farklı Korelasyonlu Renk Sıcaklığındaki Renk Algısının Değerlendirilmesi

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Öz

Renk ve ışık, iç mimarlık alanında tasarımın temel unsuru olan ayrılmaz nesnelerdir. Işık değiştiğinde, algılanan iç mekânın yüzey renk görünümü de değişir. Renk algısındaki bu değişim, yalnızca bir ışık kaynağı türüne veya aydınlatma yoğunluğuna değil, aynı zamanda bir ışık kaynağının renk sıcaklığına da bağlıdır. Bu çalışmanın amacı, LED aydınlatmanın farklı renk sıcaklığındaki renk algısını nasıl etkilediğini anlamaktır. LED aydınlatmanın iki farklı sıcak (2700º K) ve soğuk (4000º K) renk sıcaklığı altında asıl renkler ile algılanan renk eğilimlerini karşılaştırmak amacıyla bir çalışma yürütülmüştür. Bu çalışmada, asıl renkler ile algılanan renkler arasındaki olası eğilimleri ve kalıpları ortaya çıkarmak için Doğal Renk Sistemi (NCS), bir renk notasyon sistemi olarak kullanılmıştır. LED aydınlatmanın her iki 2700º K ve 4000º K renk sıcaklığı altında algılanan renkler için genel eğilimlerde, her bir asıl renk için nüans (rengin değeri ve doygunluğu) renk alanında benzer desenleri ortaya çıkarmış ve renk türü renk alanında dağılma göstermiştir.

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Introduction

Color is a property of light. Without light color does not exist, as Porter and Mikellides (1976) claimed: “color is a sensation conveyed through the medium of energy in form of light radiations within the visible spectrum and without an observer these rays do not, in themselves, constitute color.” (p. 78). For color to become visible, there needs surfaces to be present from which the various wavelengths of light are reflected. Color is considered a complex perception that is simply the interaction of a light source, an object, and an observer (Berns, 2000).

Color and light are inseparable entities; they not only create the image of the space mentally, but their interactions also make space perceivable (Klarén and FridellAnter, 2011). Within an interior environment, light and color meet people in the form of natural and artificial lighting through sources, and according to the reflective properties of the surfaces under certain lighting conditions, this light and surface interaction modulate the colors to be perceived (Poldma, 2009).When the light changes, the perceived color of a surface within an interior environment also changes (Lauer and Pentak, 1995). The change in the color perception that is mediated through the lighting conditions influence the feelings, mood, comfort, performance, motivation, productivity, health and physiological well-being of people in that interior environment (Klarén and Fridell Anter, 2011; Öztürk, Yilmazer and Ural, 2012).Therefore, the experience of colors within an interior environment is not only perceptive but also cognitive, as well (Klarén and Fridell Anter, 2011).

With the development of technology, LED (light-emitting diode) has been widely used in interior environments as artificial light sources. Although LED is a relatively new area in the lighting technologies, it has been preferred to be utilized in interior environments because of its high efficiency, low power consumption, long lifetime expectancy, high luminous efficiency, and good color rendering over the other artificial light sources (e.g. incandescent lamps, fluorescent lamps, halogen lamps, and etc.) (de Almeida et al., 2014).Studies showed that LED lighting influences the color appearance of surfaces that resulted in an increase on the visual comfort and well-being of people in interior environments (Hong et al., 2017). Color appearance as a discipline aims to describe colors in different illumination, viewing and cognition within an environment (Berns, 2000). Briefly, color appearance is defined as an “aspect of visual perception by which things are recognized by their color” (Berns, 2000, p. 27). Shevell (2003) stated that the color appearance of surfaces is related to the perceived color which is a mental and not a physical phenomenon. The source of light that illuminates the surface and the correlated color temperature (CCT) are both important for the color appearance of surfaces. This is because the CCT also describes the color appearance of a light source, which is defined as Kelvin (K). For instance, a light that has a low CCT of 3500º K, is called warm light with an orange-yellow appearance and is referred to as a warm color. On the other hand, the light

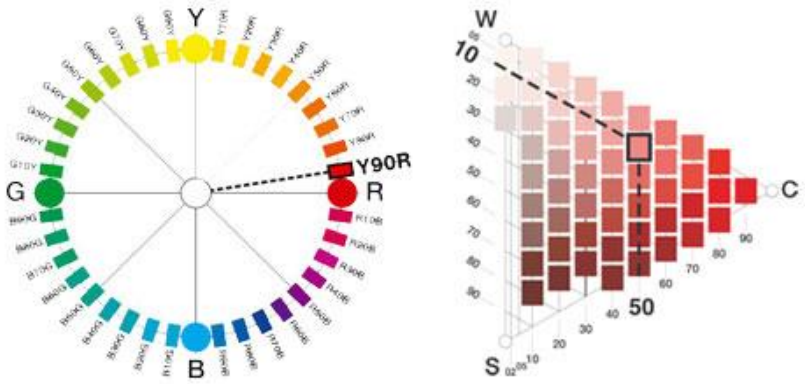
which is 4000º K and higher, is called cool light with a bluish white appearance and referred to as a cool color (Park and Farr, 2007).In her study, Hårleman (2007) indicated that the perceived color changed as the intensity of illumination and the correlated color temperature of the light changed. The CCT is considered as one of the most fundamental quantitative lighting characteristics that influences the perception and behavior of people. Hong et al. (2017) claimed that in order to get an effective color appearance of the surfaces with in interior spaces, the CCT ratings of the LED lighting should be well specified.

The fundamental question of this study is what colors do individuals see in different correlated color temperature of LED lighting? The aim is to understand and evaluate how different CCT of LED lighting influences the perception of color. A study is conducted to compare the perceptive color tendencies for inherent colors under two different CCTs of LED lighting, i.e. warm (2700º K) and cool (4000º K). The determinations of color appearances and their specifications are made with the NCS (Natural Colour System) color notation system. The tendency patterns that are found in this study would guide the designers for practical use of color in interior architecture.

Color Terminology

The NCS is a color standard that is a universal language of color communication. This study uses the NCS as a color notation system, it color terminology and the colors from the NCS glossary.

The NCS is a color ordering system that depends on six *elementary colors*. The system orders colors according to their perceptual *elementary attributes*. All colors are described in the system by their degree of visual resemblance to these elementary colors and to these elementary attributes. The elementary colors and their interrelations are represented by a three-dimensional imaginary color space in the NCS. This color space is a double cone- like model that consists of the *NCS Hue*, *NCS Blackness* (or NCS Whiteness), and *NCS Chromaticness* scales (Berns, 2000; Bergström, 2008). To understand a color notation in the color space, the double cone model is divided into two two-dimensional projections; the NCS Color Circle and the NCS Color Triangle (Hårleman, 2007) (Figure 1).



a. NCS color circle Notation of hue Y90R.

b. NCS color triangle Notation of nuance 1050.

Figure 1 Two-dimensional projections of the NCS color notation system: a. NCS color circle and b. NCS color triangle

Elementary Colors: There are six elementary colors in the NCS, four chromatic colors, Yellow (Y), Red (R), Blue (B), and Green (G), and two achromatic colors, White (W) and Black (S, swarthy). The appearance of an elementary color is described with reference to itself. For instance, R is a color that has not any resemblance to other elementary colors (Taft, 1997; Fridell Anter, 2000).

Elementary Attributes: The elementary attributes are the quantifiable characteristics of the perceptual similarities of the elementary colors. They are represented by lowercase letters that are whiteness (w), blackness (b), yellowness (y), redness (r), blueness (b), and greenness (g) (Fridell Anter, 2000).

NCS Hue: The NCS hue is briefly the relationship between two chromatic elementary attributes. It expresses the degree of the resemblance between one or two chromatic elementary colors. For instance, the numerical value for hue "Y90R" that is presented in NCS color circle in Figure 1 represents the chromatic elementary colors of Y and R. Ninety indicates the degree of the resemblance between the two colors on a 100 graded visual scale. Thus, the hue Y90R has 10% perceived resemblance to yellow and 90% perceived resemblance to red (Fridell Anter, 2000; Hårleman, 2007).

NCS Nuance: The NCS nuance is the relationship between whiteness, blackness, and chromaticness of the colors. The chromaticness of a specific color is the quantifiable attribute that expresses the visual resemblance to the pure chromatic color of the same hue. The nuance is presented in the NCS color triangle; the corners of the triangle show the relative resemblance to the elementary colors W and S and the pure chromatic color C. For instance, the first two digits and the following two digits of a given nuance "1050" in Figure 1 expresses the numerical

value of the blackness and chromaticness of the hue, respectively. The same hue can have different blackness or chromaticness. The whiteness is calculated according to the equation s + c + w = 100. The nuance 1050 thus has 10% of blackness, 50% of chromaticness, and 40% of whiteness (Berns, 2000; Fridell Anter, 2000; Bergström, 2008).

The specifications of the NCS nuance and the NCS hue together constitute the complete color notation of the NCS system. For instance, the NCS notation has the form of "1050-Y20R", the first is the nuance and second is the hue of the specific color (FridellAnter, 2000). The color space of the NCS system is illustrated by the NCS Color Atlas and Album containing 1950 standard color samples. The importance of the NCS system is that every color appearance of the *perceived* and *inherent* colors of surfaces can be placed and defined by an exact NCS notation (Hård et al., 1996; Hårleman, 2007).

Perceived Color: It is "the color that an observer perceives that an object or [a surface] has in any given light and viewing situation."(Fridell Anter, 2000, p. 31). As Hårleman (2007) stated a color percept is not a constant thing giving reference to a surface, but rather a perception that changes depending on the viewing conditions.

Inherent Color: It refers to "the color an object would have if observed in standardized observation conditions are denoted for NCS color samples in agreement with their specifications, i.e. with their color code." (Hårleman, 2007, p. 100-1). In other words, FridellAnter (2000) claimed that "to be able to describe how the perceived color varies between different situations there is however a need for a fixed point of reference among all the possible colors that the object [or the surface] can assume."(p. 23). This point of reference is called inherent color.

To identify the perceived color, Fridell Anter (2000) defined two methods: in determination method A, the observer is asked to make judgments depending on the degrees of resemblance to the elementary colors; in determination B, the observer is required to compare the colored surface with the color samples on the pages by using the NCS color atlas (Green-Armytage, 2006).

The Study

Aim and Objectives

The major aim of the study is to understand how different CCT ratings of LED lighting influence the perception of color. The study is carried out to compare the perceived color tendencies of

inherent colors under two different CCTs of LED lighting, i.e. warm (2700º K) and cool (4000º K). The objectives consist of:

- determining the differences of the given inherent colors to the perceived colors under warm LED lighting of CCT of 2700º K,
- determining the differences of the given inherent colors to the perceived colors under cool LED lighting of CCT of 4000º K,
- comparing the possible tendencies of the inherent colors with the perceived colors under the LED lighting with two different CCTs.

Participants

A total of ten participants volunteered to participate in the study. There were five male and five female participants who were the academic staff of the Faculty of Architecture, Çankaya University, Ankara, Turkey. The mean age of the whole group was 40.2, ranging from 27 to 61. All the participants were Turkish living in Ankara, Turkey.

Colors

In the study, four color samples in A9 size (52 x 32 mm) were utilized as inherent colors (see Table 1). The colors were selected from the NCS Album. The NCS album is a color design tool that contains detachable color samples showing all the NCS 1950 standard colors. The detachable color samples in the album not only help to define and match colors of different surfaces, but also most importantly, it enables the user to compare colors under different lighting conditions. In the NCS color system, colors are categorized according to their nuance attributes that are defined as blackness, whiteness, and chromaticness. Although each color in nature consists of the whole nuance attributes, a color might have a more dominant attribute (e.g blackness) among the whole nuance attributes resulting in the other two attributes being less dominant (e.g. whiteness and chromaticness) (Hård et al., 1996). In this study, the colors were selected from the nuance area where no color attribute was dominant. This indicated that the degree of blackness, whiteness and chromaticness of each color were similar. Table 1 shows the NCS notations of the four inherent colors used in the study.

Table 1 Four inherent colors with their NCS notations

Inherent Color	NCS Notation
	S 3030-Y50R
	S 3030-R50B
	S 3030-B50G
	S 3030-G50Y

The numerical value '3030' in Table 1 of each color designates the NCS nuance, and 'Y50R', 'R50B', 'B50G', and 'G50Y' specify the NCS hue of the inherent colors. The nuances of the colors indicate that each color has 30% blackness, 30% chromaticness and 40% whiteness. In the hue part of the NCS notation, '50' indicates the degree of the resemblance between the two chromatic elementary colors of Y and R, R and B, B and G, and G and Y. This means that the first color has 50% resemblance to yellow and 50% resemblance to red; the second color has 50% resemblance to red and 50% resemblance to blue; the third color has 50% resemblance to blue and 50% resemblance to green; and the fourth color has 50% resemblance to green and 50% resemblance to yellow.

Experimental Set-Up

The experiment was conducted in the Building Science and Environmental Control Laboratory of Faculty of Architecture, Çankaya University. The laboratory is approximately 20 square meters and has a façade window that faces north. To control the daylight and create a darkened experiment room, the window was blinded with the black curtain to block the natural light. The experiment was conducted with the utilization of DataColorColorMatcher® light booth, which is a property of the Building Science and Environmental Control Laboratory. The light booth was used to create a reliable viewing condition for colors to be perceived under different CCTs of LED lighting. The dimensions of the light booth are 79 x 107 x 68 cm. It has a Munsell N5 gray surround that corresponds to the uniform gray of L^* of 50. The light booth has a prismatic

diffuser at the inner top surface that includes built-in five different light sources (i.e. D65, TL 84 Fluorescent, TL 83 Fluorescent, Incandescent - 2800º K, and Ultraviolet A) for illumination. These different light sources provide a tool for visual color assessment when the color samples are viewed under different illumination. The light booth was placed on to a desk and the viewing distance between the participant and the color samples inside the light booth was about 70 cm. The illumination of the experiment room was only provided by the light booth.

Light Sources

Within the experiment, the two correlated color temperature light sources, 2700º K (warm) and 4000º K (cool), were selected in order to evaluate the possible tendencies of the inherent colors towards the perceived colors. Table 2 shows the specifications of the light sources used in the experiment.

Table 2 Specifications of the LED lamp

Brand and Model	Dimensions (in cm)	Lumen (lm)	CCT (K)	CRI (Ra)	Product
Philips Scene Switch Bulb E27	11 cm x 6 cm	806 lm	2700º K and 4000º K	≥ 80 Ra	

The light booth does not include LED light as one of the default five different light sources. However, the built-in incandescent luminaire of the light booth consists of four E27 bulbs that allow the user to change the luminaire to another light source. Thus, the intended LED lighting for the experiment was obtained by manually replacing the incandescent lighting of the light booth with the LED lighting. The utilized LED lights for the experiment were the switch bulbs with the two color settings (i.e. 2700º K and 4000º K). The color rendering index (CRI) of the LED lighting was measured 83 Ra for each CCT by using Konica Minolta CL-70F CRI Illuminance Meter. This indicates that getting a high color rendering index (CRI) from the light source (from 1 to 100 Ra) leads to obtain a better-perceived color appearance of the surfaces (Park and Farr, 2007). The illumination level was measured 1000 lux in the light booth for both CCT ratings.

Procedure

Each participant was led into the experiment room individually and was seated at a desk on which the light booth was placed with a viewing distance of 70 cm. Each participant was given a brief explanation on what was expected from the session. Due to the determination method used in the experiment; the participant was required to evaluate and match the inherent colors with the corresponding perceived colors among the samples on the pages of the NCS album. This determination procedure was done under two different CCTs of 2700º K and 4000º K LED lights, respectively. Each participant was asked to determine a color according to his/her own perception that corresponded to the presented inherent color sample in the light booth within a given interval of domain. Each inherent color had the numerical value of '50' (see Table 1) that indicated the degree of the resemblance between two chromatic elementary colors; this interval was defined by the researchers in between '30' and '70' hue areas on the NCS album. The NCS notation of the selected color that was determined by the participant was noted onto the data sheet. The duration for the procedure differed for each participant, ranging from 13 to 20 minutes; the average was 14.3 minutes.

Results and Discussion

Each participant determined a total of eight color samples and their NCS notations from the NCS album; the former four notations were obtained from the CCT rating of 2700º K, and the latter four were from the CCT rating of 4000º K. In total 80 NCS color notations were used as the data set for the study. The inherent colors were used as constant references to analyze the perceived differences under the two CCTs of LED lighting. Therefore, all corresponding perceived colors were compared to the inherent colors.

In order to evaluate the obtained data, color area (Fridell Anter, 2000) analysis was done by using the NCS circle and NCS triangle. In addition, the data was statistically analyzed by using descriptive analysis where the mean and standard deviation values were obtained to make some observations on the relationship between inherent and perceived colors under the two different CCTs of LED lighting, i.e. warm (2700º K) and cool (4000º K). The statistical analyses were done by IBM SPSS 21. To reveal the possible tendencies and patterns concerning the relationship between the inherent and perceived colors under the two different CCT ratings of the LED lighting, the nuance differences (i.e. blackness and chromaticness), and hue differences were evaluated separately to understand how various CCTs of LED lighting influences the perception of color.

For the CCT of 2700º K LED lighting, Table 3 displays the descriptive statistics of the differences in color areas between perceived and inherent colors. According to the results;

- The data set of the corresponding perceived color of the inherent color *S 3030-Y50R*, displays high dispersion in terms of the *chromaticness* (*M*: 36 *SD*: 10.75) and the *hue* (*M*: 48 *SD*: 11.35) color area. On the contrary, there is more cohesion within the distribution of the *blackness* color area.
- The data set of the corresponding perceived color of the inherent color *S 3030-B50G*, displays high dispersion in terms of the *hue* (*M*: 45 *SD*: 10.80) color area. Whereas, there are more cohesion within the distribution of the *blackness* and *chromaticness* color areas.
- The data set of the corresponding perceived color of the inherent color *S 3030-G50Y*, displays high dispersion in terms of the *chromaticness* (*M*: 30 *SD*: 8.16) and the *hue* (*M*: 60 *SD*: 8.16) color area. On the contrary, there is more cohesion within the distribution of the *blackness* color area.

Table 3 Descriptive statistics of the differences in color areas between perceived and inherent colors under the CCT of 2700º K LED lighting

Descriptive Statistics for 2700 K						
Inherent Color	Color Area	N	Min.	Max.	Mean	Std. Deviation
S 3030-Y50R	Blackness	10	20	30	23.00	4.83
	Chromaticness	10	20	60	36.00	**10.75**
	Hue	10	30	60	48.00	**11.35**
S 3030-R50B	Blackness	10	20	30	22.00	4.22
	Chromaticness	10	20	40	32.00	6.32
	Hue	10	40	50	47.00	4.83
S 3030-B50G	Blackness	10	10	30	21.00	5.68
	Chromaticness	10	20	40	29.00	5.68
	Hue	10	30	60	45.00	**10.80**
S 3030-G50Y	Blackness	10	20	30	23.00	4.83
	Chromaticness	10	20	40	30.00	**8.16**
	Hue	10	50	70	60.00	**8.16**
	Valid N (listwise)	10				

The above results indicate that the participants' selections upon their perceived colors show great distribution through the range of the *chromaticness* and *hue* color areas. Although the color *S 3030-R50B* seems to have a dispersion on the *chromaticness* (*M*: 32 *SD*: 6.32) color area, no remarkable dispersion was observed in color areas between the perceived and inherent colors.

For the CCT of 4000º K LED lighting, Table 4 displays the descriptive statistics of the differences in color areas between perceived and inherent colors. According to the results;

- The data set of the corresponding perceived color of the inherent color *S 3030-Y50R*, displays high dispersion in terms of the *chromaticness* (*M*: 35 *SD*: 8.50) color area. Whereas, there are more cohesion within the distribution of the *blackness* and *hue* color areas.
- The data set of the corresponding perceived color of the inherent color *S 3030-B50G*, displays high dispersion in terms of the *hue* (*M*: 48 *SD*: 7.89) color area. Whereas, there are more cohesion within the distribution of the *blackness* and *chromaticness* color areas.
- The data set of the corresponding perceived color of the inherent color *S 3030-G50Y*, displays high dispersion in terms of the *chromaticness* (*M*: 29 *SD*: 7.38) and the *hue* (*M*: 52 *SD*: 9.19) color area. On the contrary, there is more cohesion within the distribution of the *blackness* color area.

Table 4 Descriptive statistics of the differences in color areas between perceived and inherent colors under the CCT of 4000º K LED lighting

Descriptive Statistics for 4000 K						
Inherent Color	Color Area	N	Minimum	Maximum	Mean	Std. Deviation
S 3030-Y50R	Blackness	10	20	30	25.00	5.27
	Chromaticness	10	20	50	35.00	**8.50**
	Hue	10	40	60	48.00	6.32
S 3030-R50B	Blackness	10	20	30	23.00	4.83
	Chromaticness	10	20	40	31.00	5.68
	Hue	10	40	50	47.00	4.83
S 3030-B50G	Blackness	10	20	30	23.00	4.83
	Chromaticness	10	20	40	30.00	6.67
	Hue	10	30	60	48.00	**7.89**
S 3030-G50Y	Blackness	10	20	30	21.00	3.16
	Chromaticness	10	20	40	29.00	**7.38**
	Hue	10	40	70	52.00	**9.19**
	Valid N (listwise)	10				

The above results indicate that the participants' selections upon their perceived colors show great distribution through the range of the *chromaticness* and *hue* color areas. No remarkable dispersion was observed in color areas between the perceived and inherent colors of the color *S 3030-R50B*.

The visual representation of the perceived tendencies pertaining to selected colors is shown from Figure 2 to Figure 5. Figure 2 and Figure 3 present the color areas of the tendencies of the selected perceived colors on the NCS circle and triangle under the CCT of 2700º K LED lighting, likewise Figure 4 and Figure 5 display the color areas at the CCT of 4000º K.

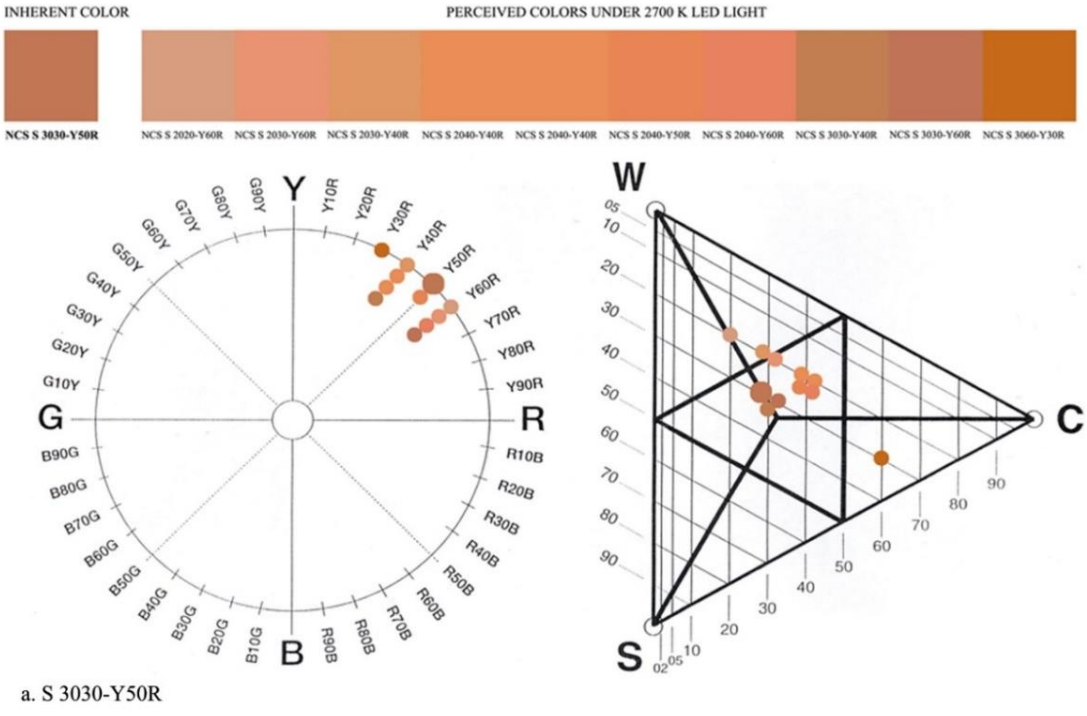
In these figures, the single colors on the left-hand side are the inherent colors and colors arranged side by side are the set of perceived colors selected by the participants. Additionally, the figures also show the color areas of the corresponding colors with their locations on the NCS circle and NCS triangle. The bigger circles on the NCS circle and NCS triangle indicate the positions of the inherent colors in the NCS system and the smaller circles demonstrate the perceived tendencies of the corresponding colors in the NCS system.

Regarding the color area analysis, the perceived tendencies of the corresponding colors and their result patterns are discussed by comparing the two different CCTs of LED lighting, i.e. warm (2700º K) and cool (4000º K). The findings are as follow;

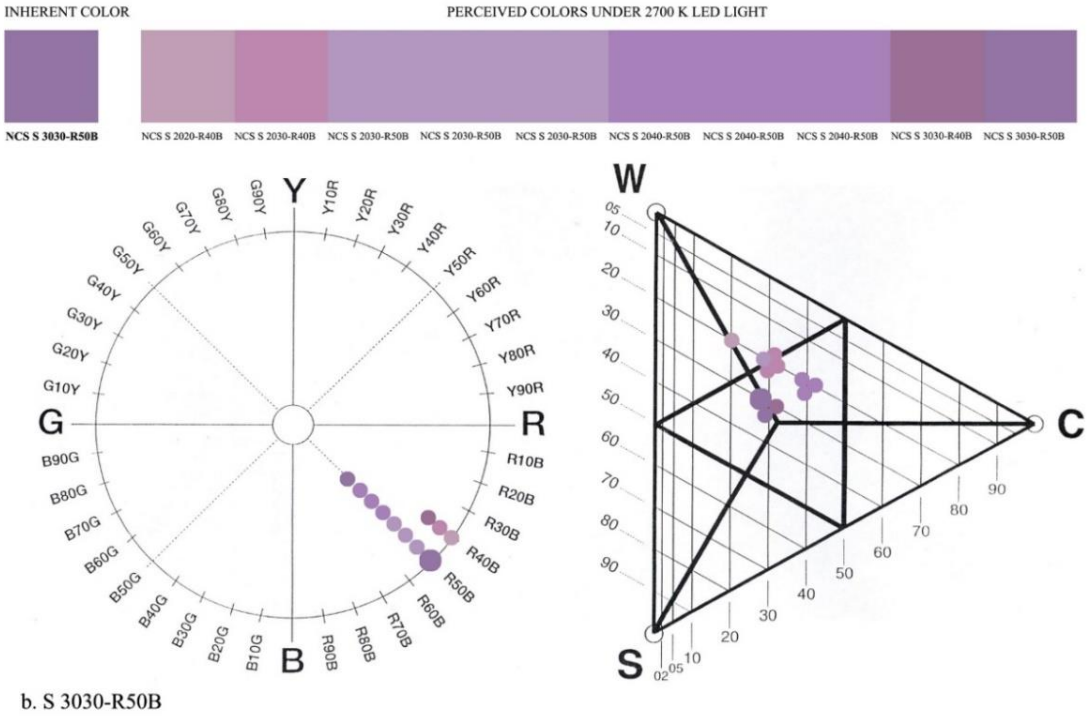
- For the inherent color *S3030-Y50R*, so-called *yellow-red* color: The distribution tendency patterns of perceived colors of *hue* color area shows more dispersion under the CCT of 2700º K LED lighting (Figure 2.a) when compared to 4000º K (Figure 4.a). Under the CCT of 4000º K LED lighting, the data set constitutes a pattern where the perceived colors of *hue* color area belong to the same hue family (i.e.Y50R) of the inherent color. The general pattern of the perceived colors have less *blackness* and more *chromaticness* under both CCT conditions of LED lighting.
- For the inherent color *S3030-R50B*, so-called *red-blue* color: The patterns of the perceived colors in terms of the *nuance* and *hue* color area under both CCT of 2700º K (Figure 2.b) and 4000º K (Figure 4.b) LED lighting are similar. This indicates that the general pattern where the perceived colors of the *hue* color area belong to the same hue family (i.e. R50B) of the inherent color. Additionally, the perceived colors have less *blackness* than the inherent color under both CCTs of LED lighting.
- For the inherent color *S3030-B50G*, so-called *blue-green* color: The distribution tendency patterns of perceived colors of *hue* color area shows more dispersion under the CCT of 2700º K LED lighting (Figure 3.a) when compared to 4000º K. Under the CCT of 4000º K LED lighting (Figure 5.a), the data set constitutes a pattern where the perceived colors of *hue* color area

belong to the same hue family (i.e.B50G) of the inherent color. In accordance, some of the participants show a tendency of perceiving colors more *chromatic* than the inherent color.

- For the inherent color *S3030-G50Y*, so-called *green-yellow* color: The distribution tendency patterns of perceived colors of *hue* color area shows great dispersion under both CCTs of 2700º K (Figure 3.b) and 4000º K (Figure 5.b) LED lighting. Although there exists a dispersion where the perceived colors divert from the inherent color, there is a greater measure of correspondence between the perceived and inherent colors at the CCT of 4000º K. The participants show a tendency of perceiving colors less *black* and more *chromatic* than the inherent color.

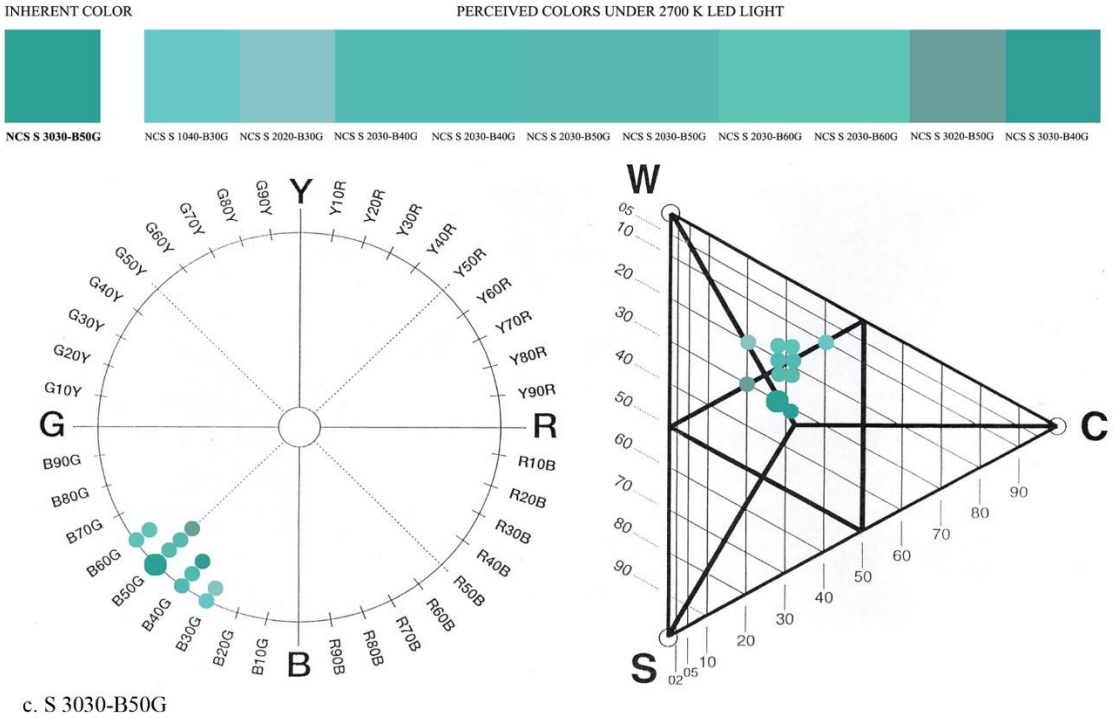


a. S 3030-Y50R

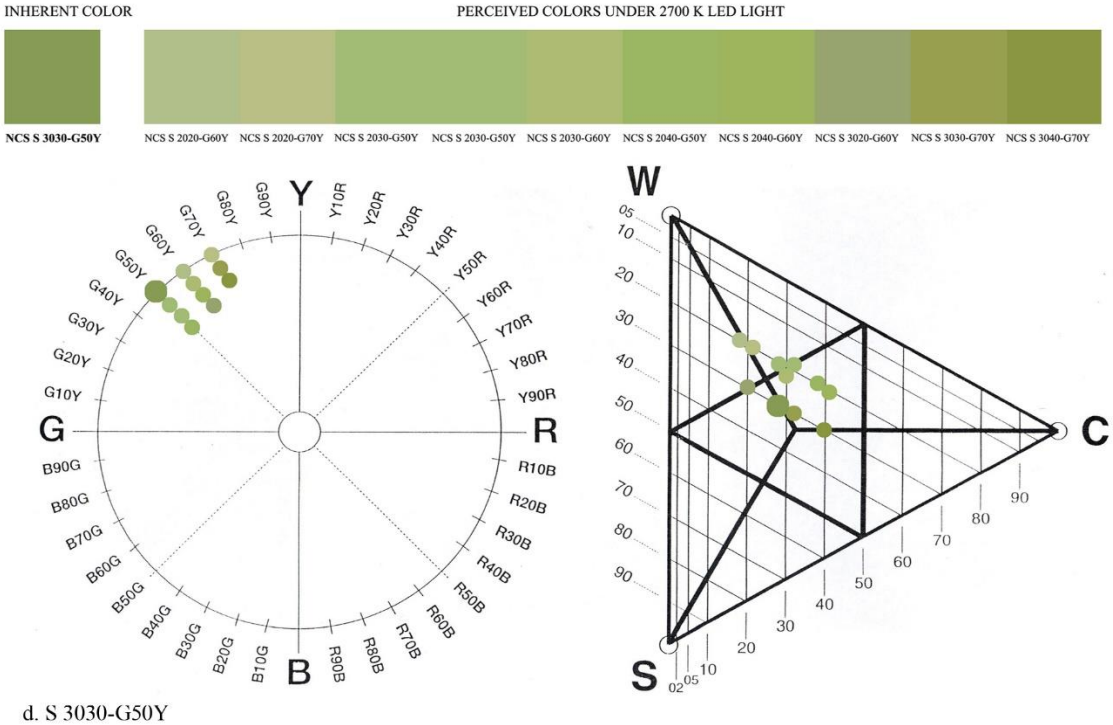


b. S 3030-R50B

Figure 2 Perceived color areas for the inherent colors; a. S 3030-Y50R and b. S 3030-R50B, at the CCT of 2700º K

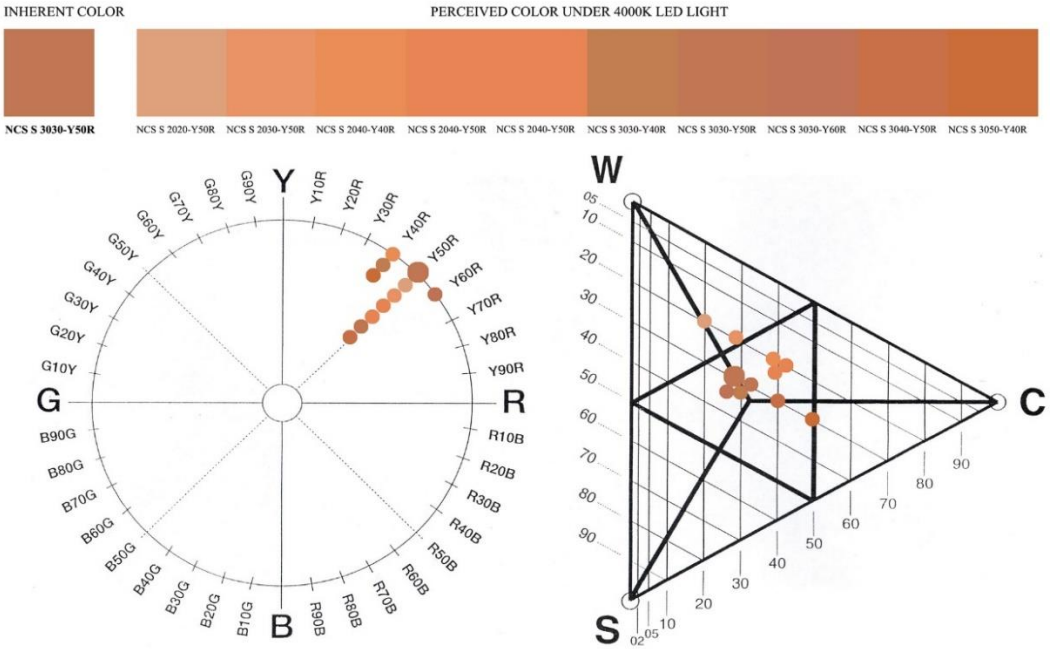


c. S 3030-B50G

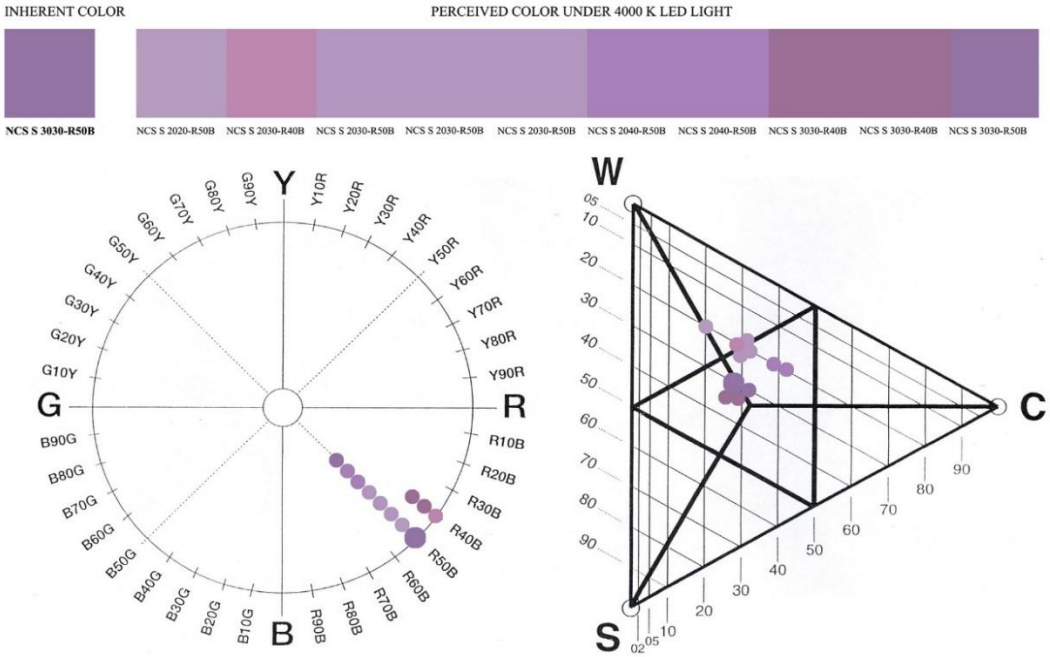


d. S 3030-G50Y

Figure 3 Perceived color areas for the inherent colors; c. S 3030-B50G and d. S 3030-G50Y, at the CCT of 2700º K

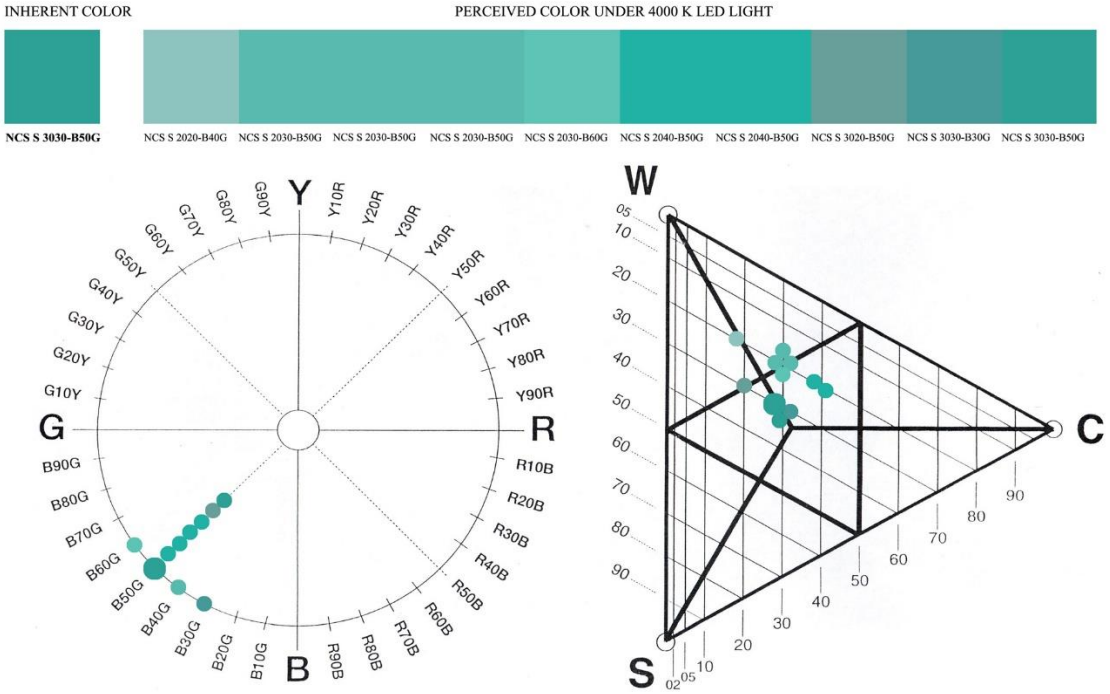


a. S 3030-Y50R

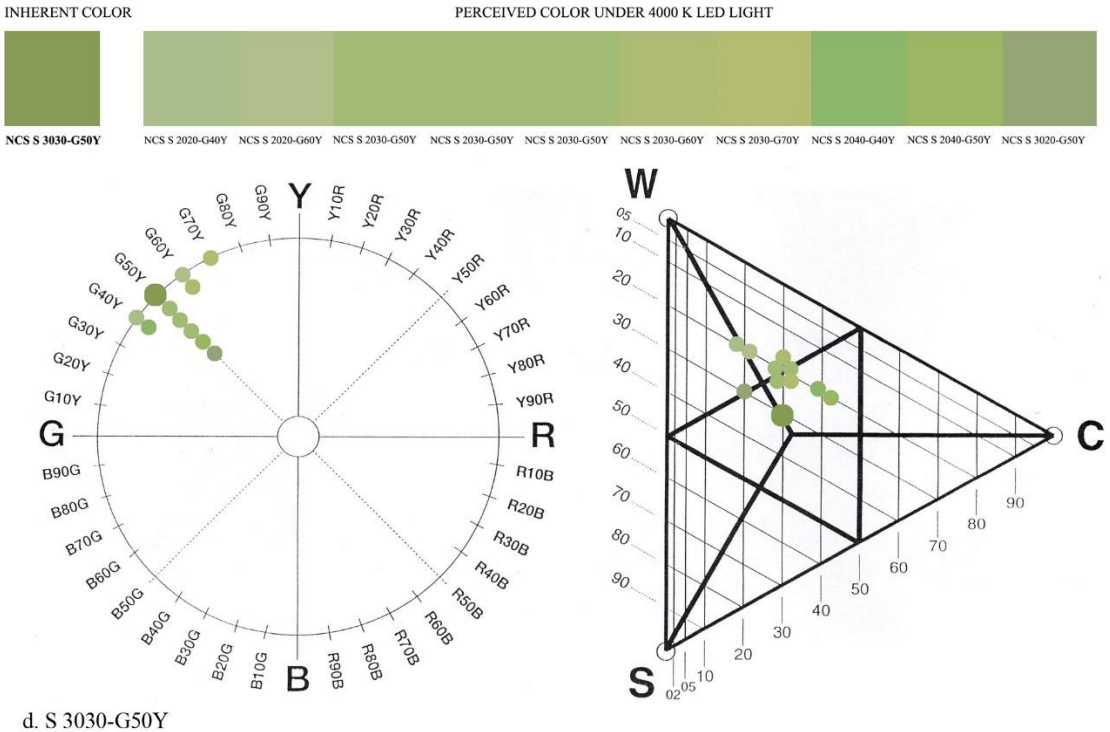


b. S 3030-R50B

Figure 4 Perceived color areas for the inherent colors; c. S 3030-Y50R and d. S 3030-R50B, at the CCT of 4000º K



c. S 3030-B50G



d. S 3030-G50Y

Figure 5 Perceived color areas for the inherent colors; c. S 3030-B50G and d. S 3030-G50Y, at the CCT of 4000º K

Conclusion

This study attempted to determine how different correlated color temperature of LED lighting influences the perception of color. An experiment was conducted to identify the perceptive color tendencies for inherent colors under the LED lighting with two different CCTs, i.e. 'warm' (2700º K) and 'cool' (4000º K). The participants determined colors according to their own perception that corresponded to the presented inherent color samples in the light booth at both CCTs of LED lighting. The NCS, a color notation system, was utilized as a color standard for the determination of perceived colors and their specifications. The inherent colors presented in this study were also selected from the NCS album. These colors were used as constant references to analyze the perceived differences under the two different CCTs of LED lighting. Therefore, all corresponding perceived colors were compared to the inherent colors. To reveal the possible tendencies and patterns concerning the relationship between the inherent and perceived colors, the *nuance* differences (i.e. blackness and chromaticness) and *hue* differences were evaluated separately.

Consequently, some definite findings were clarified through particular observable patterns. Regarding the findings of this study, the general pattern showed similar perceived tendencies of scattering on the NCS triangle for each inherent color, but showed differences of scattering on the NCS circle when LED lighting of both CCTs were compared. This indicated that, the tendencies for the perceived colors revealed similar patterns in the *nuance* (i.e. blackness and chromaticness) color area and showed dispersion on the *hue* color area under both CCTs of 2700º K and 4000º K LED lighting. The perceived color selections for *hue* color area constituted more incisive patterns and tendencies at cool LED lighting of 4000º K. However, no salient differences of perceived colors were observed for the *nuance* color area at both CCTs of LED lighting.

The distribution tendency of perceived colors with less *blackness* in comparison with the inherent colors were driven by both CCTs of warm (2700º K) and cool (4000º K) LED lighting. Under the warm LED lighting of 2700º K, the tendency of perceiving colors was more *chromatic* than the inherent color where the colors have resemblance to yellow. Additionally, the participants had more difficulties in being certain with selecting the corresponding perceived colors of S 3030-Y50R (yellow-red color) and S 3030-G50Y (green-yellow color) at the CCTs of both warm (2700º K) and cool (4000º K) lighting where both colors have resemblances to yellow, as well. The results in the perceived tendency of the inherent colors that have resemblance to blue were more distinguishable and incisive under the LED lighting of both CCTs. This result can also be seen on the color area analysis (Figure 2.b and Figure 4.b) of the color S 3030-R50B (red-blue color) where, the tendency at both CCTs of LED lighting showed similar patterns of scattering on the NCS circle and NCS triangle.

The tendency patterns that are found in this study could be a guide for the designers for practical use of color in interior architecture. Color and light are the crucial design factors in the field of interior architecture; therefore, further studies should be conducted using additional LED lighting with various CCTs under different illuminance levels with greater number of color samples and with more participants in order to attain more comprehensive outcomes.

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REFERENCES

Bergström, B. (2008). *Colour choices: A practitioner's guide to colour scheming and design*. Stockholm: ForskningsrådetFormas.

Berns, R. (3rd Ed.). (2000). Billmeyer and Saltzman's principles of color technology. New York: John Wiley & Sons, Inc.

De Almeida, A., Santos, B., Paolo, B., &Quicheron, M. (2014). Solid state lighting review– Potential and challenges in Europe. *Renewable and Sustainable Energy Reviews,34*, 30-48.

Fridell Anter, K. (2000). *What colour is the red house? Perceived colour of painted facades*. Doctoral Dissertation, Royal Institute of Technology (KTH), Stockholm, Sweden.

Hård, A., Sivik, L., &Tonnquist, G. (1996a). NCS, Natural color system – from concept to research and applications: Part I. *Color Research and Application, 21*(3), 180-205.

--- (1996b). NCS, Natural color system – from concept to research and applications: Part II. *Color Research and Application, 21*(3), 206-220.

Hårleman, M. (2007). *Daylight influence on colour design: empirical study on perceived colour and colour experience indoors*. Doctoral Dissertation, Royal Institute of Technology (KTH), Stockholm, Sweden.

Hong, S. et al. (2017). Evaluation of the visibility of colored objects under led lighting with various correlated color temperatures. *Color Research & Application, 42*(1), 78-88.

Klarén, U., &FridellAnter, K. (2011). Colour and light in space: Dynamic adaptation and spatial understanding. In *Proceedings of AIC 2011-Midterm Meeting of the International Colour Association*, Zurich, Switzerland, 485-488.

Lauer, D. A., &Pentak, S. (1995). *Design Basics*. Orlando: Harcourt Brace.

Öztürk, E., Yılmazer, S., & Ural, S. E. (2012). The effects of achromatic and chromatic color schemes on participants' task performance in and appraisals of an office environment. *Color Research & Application, 37*(5), 359-366. DOI 10.1002/col.206972012

Park, N. K., & Farr, C. A. (2007). The Effects of Lighting on Consumers' Emotions and Behavioral Intentions in a Retail Environment: A Cross-Cultural Comparison. *Journal of Interior Design, 33*(1), 17-32.

Green-Armytage, P. (2006). The Value of Knowledge for Colour Design. *Color Research and Application 31*, 253-269.

Poldma, T. (2009). Learning the Dynamic Processes of Color and Light in Interior Design. *Journal of Interior Design, 34*(2), 19-33.

Porter, T., &Mikedilles, B. (1976). *Colour for Architecture*. New York: Macmillian Publishing Co. Inc.

Shevell, S. (2nd Ed.). (2003). *The Science of Color*. Oxford: Elsevier Science.

Taft, C. (1997). *Generality Aspects of Color Naming and Color Meaning*. Doctoral Dissertation, Göteborg University, Göteborg, Sweden.

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