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Changes in Illumination Preferences for Textiles with Varying Physical Color Attributes

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Abstract: This study analyzed people's preferences for different illuminants regarding textiles with a wide range of colors in terms of lightness, chroma, and hue. To analyze these changes in illumination preferences according to the physical color attributes of textiles, the Commission Internationale de l'Eclairage L^*_{10}, a^*_{10}, b^*_{10}, $C^*_{ab,10}$, and $h_{ab,10}$ values were measured for 27 types of textile fabrics. Preferences for D65 (6504 K), CWF (4230 K), and an A and CWF mixed illuminant (approximately 3500 K), each with different correlated color temperatures (CCTs), were evaluated for the 27 fabric types. The results showed that regardless of the physical color attributes of the fabric, people preferred D65 (a bluish-white illuminant with a high CCT) the most, followed by CWF (which has a medium CCT) and A+CWF (a reddish illuminant with a low CCT). People's preferences for D65 and CWF showed significant differences depending on the hue of the fabric. Both illuminants showed high preferences among neutral fabrics compared with chromatic fabrics. Among chromatic fabrics, the preferences for D65 and CWF were generally high when the fabric was a cool color, such as blue, rather than a warm color, such as yellow. The lower the chroma $C^*_{ab,10}$ of the fabrics, the higher the preferences for D65 and CWF were.

Keywords: Color appearance, Physical color attributes, Illumination, Correlated color temperature, Preferences

Introduction

Color, a visual attribute that includes lightness, chroma, and hue, is a critical factor that affects the purchases of consumers in various industries. Colors influence the overall image of a company as they are used in corporate identity (CI), or the visualization of the overall image of a company's purpose, activities, and ideology, as well as the products and stores of the company. The clothing industry is not an exception. For example, the black and white CI of Chanel evokes a modern, polished, and emotional image, while the colorful products of Benetton evoke a peaceful image of clothes that can be worn by anyone. In particular, the colors of textiles used in clothing have a primary impact on consumers at the point of purchase and are a crucial design element, having a direct impact on the decision to buy [1]. However, colors often confuse producers and consumers as they are perceived completely differently depending on the product size, shape, background, illumination under which it is observed, and physical color attributes (e.g., CIE (Commission Internationale de l'Elcairage) L^*_{10}, a^*_{10}, and b^*_{10} values). The subjective colors perceived by people—in contrast to physical color attributes as objective values—is called color appearance [2].

Illuminants are an important environmental factor that influences the perception of clothing products [2,3]. They are a critical element of visual merchandising (VMD)—a system that presents, arranges, and displays merchandise around the store—providing information such as the design, color, and materials of clothing products, and stimulating the consumers' desire to buy by forming a positive atmosphere of the clothing store in general [4]. Currently, the standard illuminants used in the clothing industry differ by country, such as cool white fluorescent (CWF) in the US and TL84 in Europe [5]. Hence, as shown in Figure 1, even the same textile products with identical physical color attributes are perceived as having different colors depending on the country and store in which they are displayed. As a result, preferences for the same products can vary accordingly. Thus, it is necessary to design the illuminants of clothing stores based on the preferences of target consumers. This can be done by displaying the clothing products with appropriate illuminants which feature the representative colors of the brand or seasonal trend colors.

While the importance of illuminants in the colors and color appearances of products is widely recognized in the clothing industry, not many studies on this topic have been conducted in academia. Chae suggested and verified the accuracy of a color appearance prediction method for textiles that change based on the illuminant, using 24 textile samples of various hues (red, red-yellow, yellow, yellow-green, green, green-blue, blue, and blue-red) and two illuminants with correlated color temperatures (CCTs) of 2700 K and 6500 K [5]. Choi *et al*. conducted an experiment that asked subjects to rank five fabrics (red, yellow, green, blue, and blue-red) according to their similarity to colors observed under natural light while under illuminants with the CCTs of 2800 K, 6500 K, and 4200 K [6]. It was found that the higher the CCT of the illuminant, the more similar the colors of fabrics were perceived to be when compared with colors observed under natural light, except for the color red. Jeong and Lee took photographs of the color appearances of chromatic fabrics (red, yellow, green, blue, and blue-red) and neutral fabrics (white and black), and

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Figure 1. Color changes of textiles under different illumination conditions.

measured the colors on the printed photographs [7]. The results showed that brighter fabrics were more affected by the illuminant, and glossy fabrics were found to be brighter under a bright illuminant than matte fabrics.

These studies analyzed the effects of illuminants on the colors and color appearances of textiles in various and systematic ways. However, most of them did not compare the magnitude of the illuminant effect for each textile color using concrete values. Furthermore, no study has been conducted on illumination preferences according to the physical color attributes of textiles for actual subjects. Since colors are both a physical attribute and an emotional attribute (i.e., one that is felt by people), it is crucial for color research to examine the relationship between the two by measuring physical color attributes and conducting subjective color experiments in parallel.

Therefore, the present study attempted to analyze the changes in people's illumination preferences according to the lightness, chroma, and hue of textiles based on the measurements of physical color attributes. The specific objectives of the study are as follows: 1) examine the CCTs of illuminants that are generally preferred by people for various colors of textiles; 2) analyze the differences in illuminant preferences by the hue group of textiles (red, red-yellow, yellow, yellow-green, green, green-blue, blue, blue-red, and neutral group); and 3) analyze the concrete correlations between illuminant preferences and the lightness, chroma, and hue values as the physical color attributes of textiles.

Experimental

Samples

This study used polyester knitted fabrics in 24 chromatic colors and 3 neutral colors provided as samples by Pantone. The chromatic color samples consisted of eight hues in three levels of lightness (i.e., light (L), medium (M), and dark (D)): red (R), red-yellow (RY), yellow (Y), yellow-green (YG), green (G), green-blue (GB), blue (B), and blue-red (BR). Furthermore, the neutral color samples consisted of white (W), gray (GY), and black (BK) samples in three levels of lightness. All the samples were 100 % polyester warp knitted fabrics without surface texture, and had a uniform size of 2×2 inches and a uniform thickness of 0.51 mm. Surface texture has been reported in many color literature as an important factor that influences the

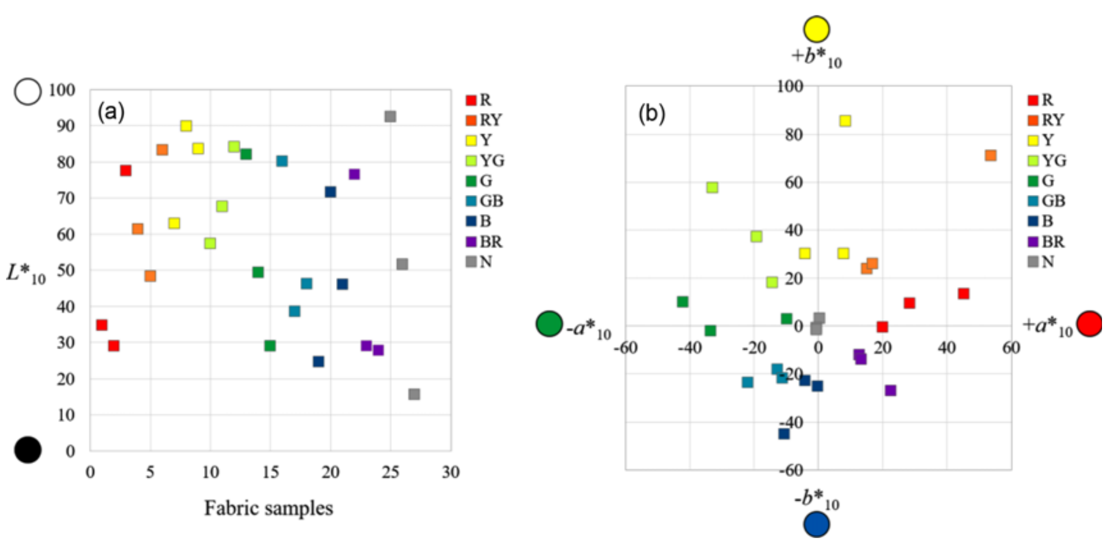


Figure 2. Distribution of 27 fabric samples in the CIELAB color space; (a) L^*_{10} and (b) $a^*_{10}b^*_{10}$ spaces.

measurements of physical color attributes and people's subjective color perception [1-3,8-11]. Therefore, this study utilized samples with a smooth surface (i.e., without surface texture) to analyze changes in illumination preferences according to the physical color attributes of textiles, excluding the effects of other factors.

Measurement of Physical Color Attributes

The spectral reflectance (R%) values of 27 samples were measured in 10 nm intervals in the visible spectrum region of 360-740 nm using a spectrophotometer (KONICA MINOLTA CM-2600d, Japan). For this measurement, a large caliber (MAV: 8 mm) and specular component included (SCI) mode—a measurement method that includes both regular and diffuse reflections to obtain objective color information—were used. The measured spectral reflectance was converted to lightness L^*_{10}, redness-greenness a^*_{10}, yellowness-blueness b^*_{10}, chroma $C^*_{ab,10}$, and hue $h_{ab,10}$ values based on the CIE standard illuminant D65 and 10^{o} standard observer, pursuant to the procedure suggested by the American Society for Testing and Materials (ASTM) [12]. Figure 2, which contains the distribution of 27 samples in the CIELAB color space based on the measurements of physical color attributes, shows that the samples of this study are evenly distributed in lightness (Figure 2(a)) and hue (Figure 2(b)).

Assessment of Illumination Preferences

Subjects

Twenty-two students of the Chungbuk National University in South Korea in their 20s and 30s participated in the present experiment on the assessment of illumination preferences. Before starting the main test, the Ishihara pseudoisochromatic plates test was conducted to assess the color sense of the subjects. The results showed that all subjects had normal color discrimination ability. Thus, the data of all subjects were used when analyzing the experimental results. Prior to commencing the study, all subjects were provided with information on the object and nature of the research, and provided their informed consent.

Illuminants

A light booth that provides the CIE standard illuminants A, CWF, and D65 (SpectraLight 204 Light Booth, Han Won Soway Co., Korea) was used for this experiment. The booth had a size of 65×45×61 cm (length×width×height), and all internal walls were gray of medium lightness (L^*_{10}= approximately 50). Before starting the test, a pre-test was conducted for three standard light sources on five subjects. The results showed that illuminant A was consistently unfavored by all subjects regardless of the sample color because of its excessively red CCT, or the color of the light source expressed in absolute temperature. The higher the CCT, the bluer it is; the lower the CCT, the more reddish it is. The CCT of the illuminant A was 2856 K. Based on these results, it was not used alone in the main test. The illuminants that were used in the main test were D65 (CCT = 6504 K) and CWF (CCT=4230 K) as commonly used standard light sources, and the A and CWF mixed illuminant (A+CWF illuminant; CCT=approximately 3500 K).

Test Procedure

Each subject rated their preferences for the three illuminants (A+CWF, CWF, D65) with regard to 27 samples using a 5-point Likert scale. The test was conducted in a dark room where all light was blocked except for the booth light. The illuminants inside the booth were presented in the same order for every sample: CWF with a medium CCT, D65 with a high CCT, and A+CWF with a low CCT. In this presentation order, the illuminant of a medium CCT was

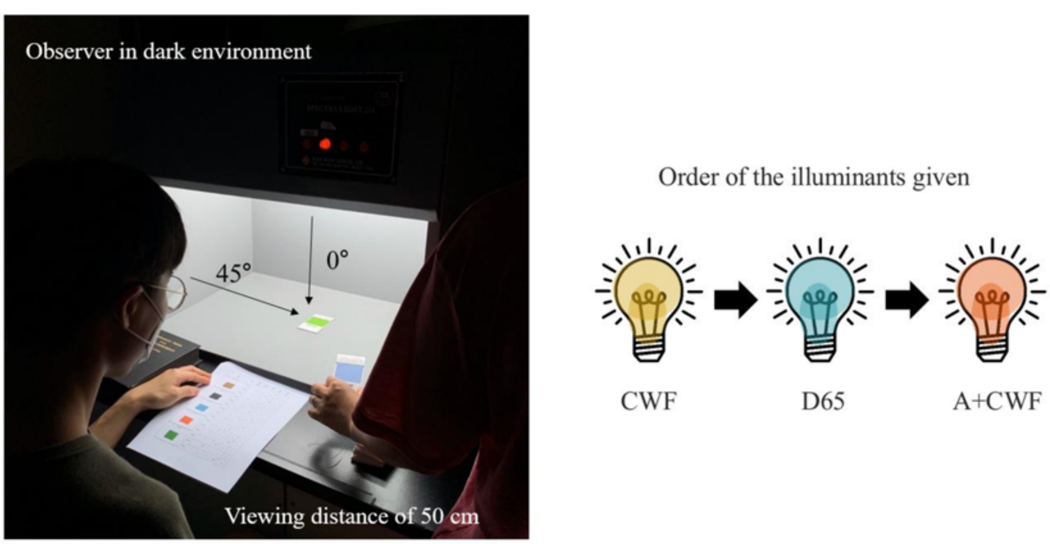


Figure 3. Method of illumination preference assessments in which 27 samples were presented in random order.

presented first, considering the chromatic adaptation [2] of the human visual system. Each sample was presented at the center of the floor of the light booth in random order by the tester. The illumination and viewing geometry was 0 °/ 45 °—which is one of the standard conditions specified by the CIE [13]—and the observation distance was 50 cm. Figure 3 summarizes the test method.

To assess the repeatability of subjects and verify the reliability of test data, all subjects performed the test twice under the same conditions with a time interval of one week. The coefficient of variation (*CV*) was calculated using equation (1) based on the two test data sets. *CV* is the relative error between two data sets as a percentage. In equation (1), *N* denotes the number of data pairs, which is 27 in this study, and X_i and Y_i denote the first and second preference assessment values of each subject for the pair *i*. Since the *CV* is an error value, a lower *CV* means higher repeatability of the subject; when the assessment values of two sets match perfectly, the *CV* has a value of zero [14]. The *CV* in this study is 8.32 on average, indicating higher reliability of data than other studies that conducted subjective color tests [10,15,16]. The equation for *CV* is as follows:

$$CV = \frac{\sqrt{\frac{1}{N}\Sigma(X_i - Y_i)^2}}{\bar{X}_i} \times 100 \quad (1)$$

Data Analysis

The CCTs of the illuminants for textiles that were commonly preferred by the subjects were analyzed by numerically comparing preferences for the three illuminants with different CCTs, i.e., A+CWF, CWF, and D65 illuminated to 27 samples. Next, a one-way analysis of variance (ANOVA) and Scheffé's post-hoc test were performed to statistically analyze any significant differences in illumination preferences for the hue groups of samples (i.e., red, red-yellow, yellow, yellow-green, green, green-blue, blue, blue-red, neutral color groups). In addition, the color appearance values of the samples under illuminants that showed significant differences in preferences were calculated and compared. Lastly, Pearson's correlation analysis and a simple regression analysis were performed to analyze the specific correlations between illumination preferences and the lightness, chroma, and hue values as the physical color attributes of textiles.

Results and Discussion

General Preferences for Correlated Color Temperatures of Illuminants for Textiles

To verify the CCTs of illuminants that are commonly preferred by people for textiles of various colors, the average preferences for A+CWF (approximately 3500 K), CWF

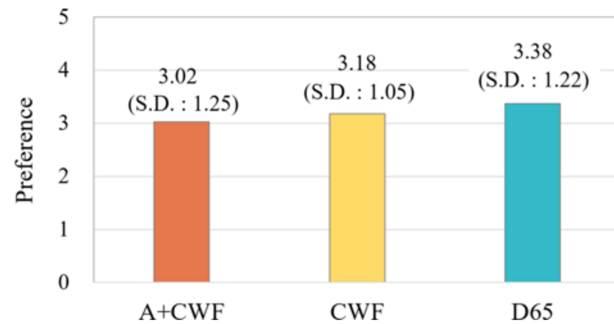


Figure 4. Numerical comparison of the preference for A+CWF (approx. 3500 K), CWF (4230 K), and D65 (6504 K) illuminants in sample observations.

(4230 K), and D65 (6504 K) illuminants for 27 textile samples were numerically compared. Figure 4 shows the average preference values (1-5) and standard deviation (S.D.) of subjects for the three illuminants. As shown in the figure, there were slight differences in preferences among the three illuminants. Regardless of the sample colors, the D65 illuminant showed the highest preference at 3.38 (S.D.: 1.22), followed by CWF (average: 3.18; S.D.: 1.05) and A+CWF (average: 3.02; S.D.: 1.25). This suggests that when observing textiles, people prefer bluish-white illuminants with a high CCT over reddish illuminants with a low CCT. In particular, D65 is a standard illuminant, as defined by the CIE, that reproduces outdoor daylight at midday. Therefore, the color observed and measured under D65 is known as the true color (original, objective, and physical color attributes) of an object. As such, it is widely used for color communication (i.e., all communications related to color between businesses) in various industries, including the clothing industry [3,5]. This shows that illuminants close to the CCT of daylight and those which do not greatly change the original color of textiles are preferred over illuminants with artificial CCTs.

Before starting the main test, a pre-test was performed with illuminant A (2856 K), which had the lowest CCT, in addition to illuminants A+CWF, CWF, and D65. The results showed that the preference for illuminant A was very low, or less than 2 on average. Hence, the illuminant A was excluded from the main test. The results of the pre-test also support the results of the main test.

Differences in Illumination Preferences among the Hue Groups of Textiles

To analyze the differences in illumination preferences among the hue groups of textiles, the samples were classified into nine groups based on their physically measured hue values, that is, $h_{ab,10}$ (and a^*_{10}, b^*_{10}), red (R: 0< $h_{ab,10}$<45), red-yellow (RY: 45<$h_{ab,10}$<90), yellow (Y: 90< $h_{ab,10}$<135), yellow-green (YG: 135< $h_{ab,10}$<180), green (G: 180< $h_{ab,10}$<225), green-blue (GB: 225< $h_{ab,10}$<270), blue (B:

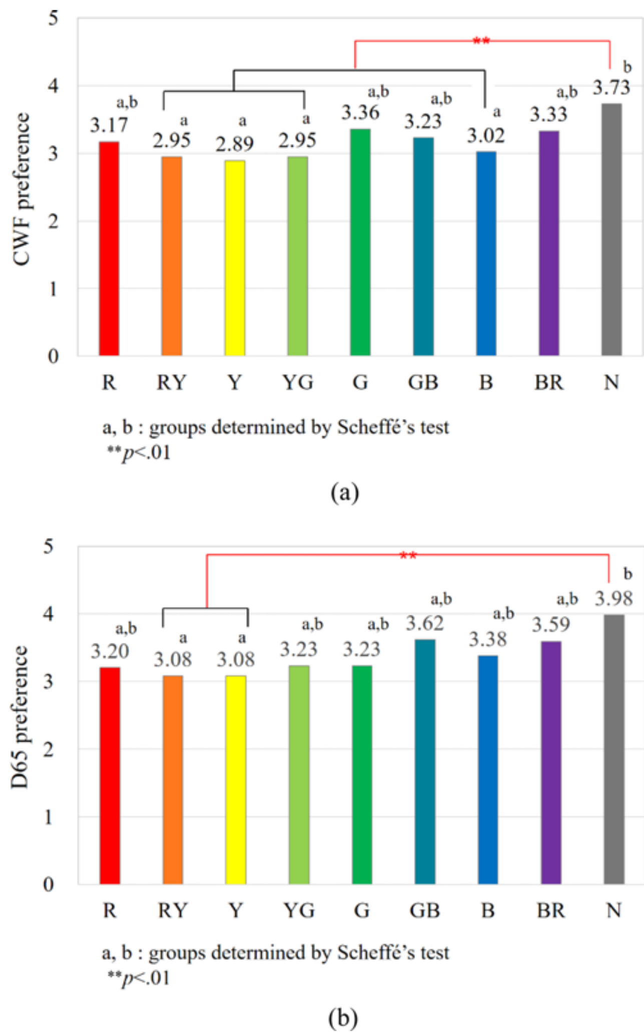


Figure 5. Different preferences for (a) CWF (4230 K) and (b) D65 (6504 K) illuminants according to the hue group of samples.

$270<h_{ab,10}<315$), blue-red (BR: $315<h_{ab,10}<360$), and neutral color (N: $-5<a^*_{10}$, $b^*_{10}<5$). Afterward, a one-way ANOVA and Scheffé's post-hoc test were performed to determine the preference assessment values of A+CWF, CWF, and D65 of the subjects for each hue group of samples. The results showed statistically significant differences in the preferences of subjects for each hue group for the single illuminants CWF and D65 (as CIE standard light sources) among the three illuminants ($p<0.01$). In contrast, there were no significant differences in preferences for the A+CWF as a mixed illuminant ($p>0.05$). The differences in preferences between CWF and D65 illuminants for each hue group of samples are shown in Figure 5.

As can be seen in Figure 5(a), the post-hoc test results regarding preferences for the CWF illuminant of each hue group showed that the preference for the CWF illuminant of the neutral color sample group was higher than the red-yellow, yellow, yellow-green, and blue hue sample groups (average preference for the CWF illuminant of the red-yellow, yellow, yellow-green, blue hue color groups: 2.95; average preference for the CWF illuminant of the neutral color sample group: 3.73). As shown in Figure 5(b), there was a significant difference in the preference for the D65 illuminant between the red-yellow and yellow hue sample groups and the neutral color sample group. The preference for the D65 illuminant of the neutral color sample group was likewise high, similar to the preference for the CWF illuminant (average preference for D65 illuminant of the red-yellow and yellow hue sample groups: 3.08; average preference for D65 illuminant of the neutral color sample group: 3.98). This suggests that neutral-colored textiles can obtain positive effects from illuminants in perceiving color or color appearance compared to chromatic-colored textiles in general, regardless of the CCT of the illuminant. Furthermore, using CWF and D65 illuminants is generally not recommended for chromatic-colored textiles in red-yellow and yellow hues.

To verify the significant color preference trend of textiles under the effect of illuminants, the color appearance values of 27 samples under the two illuminants that showed significant differences in preferences were calculated and compared. In general, the color appearance values of colored objects can be determined based on the spectral data (spectral reflectance data at 1 nm intervals in the visible region) of the object and illuminant and the color matching functions [13] of the CIE standard observer (CIE 2° standard

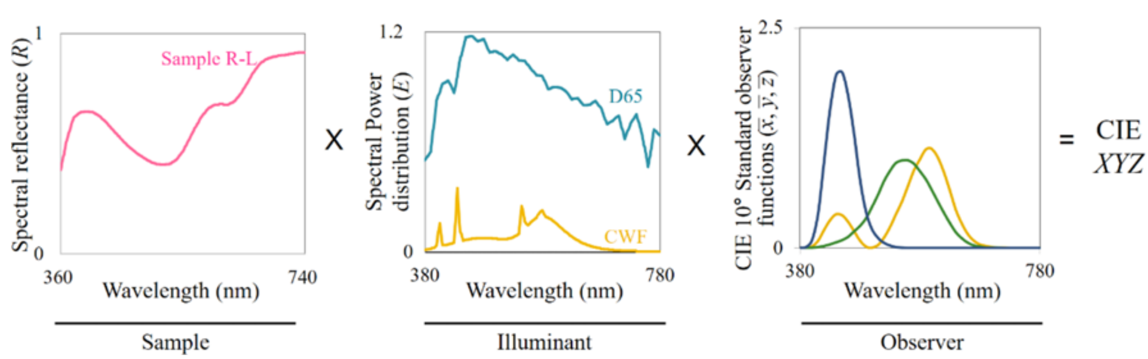
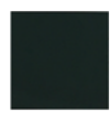
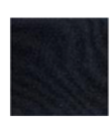


Figure 6. Calculation of the *XYZ* tristimulus values of fabric samples (example of Sample R-L).

Table 1. Colorimetric values of 27 fabric samples under CWF and D65 illuminants

Light sample				Medium sample				Dark sample			
Image	Colorimetric value			Image	Colorimetric value			Image	Colorimetric value		
		CWF	D65			CWF	D65			CWF	D65
R-L[a]	L^*_{10}	79.10	77.62	R-M	L^*_{10}	35.35	34.83	R-D	L^*_{10}	29.91	29.05
	a^*_{10}	14.01	19.94		a^*_{10}	33.07	45.23		a^*_{10}	20.29	28.48
	b^*_{10}	0.78	-0.61		b^*_{10}	13.18	13.5		b^*_{10}	10.54	9.54
	$C^*_{ab,10}$	14.03	19.95		$C^*_{ab,10}$	35.60	47.2		$C^*_{ab,10}$	22.87	30.04
	$h_{ab,10}$	3.20	358.24		$h_{ab,10}$	21.73	16.62		$h_{ab,10}$	27.44	18.53
RY-L	L^*_{10}	85.44	83.25	RY-M	L^*_{10}	66.35	61.32	RY-D	L^*_{10}	49.55	48.3
	a^*_{10}	11.97	16.85		a^*_{10}	37.87	53.63		a^*_{10}	11.08	15.18
	b^*_{10}	29.87	25.88		b^*_{10}	78.73	70.93		b^*_{10}	27.28	23.76
	$C^*_{ab,10}$	32.18	30.88		$C^*_{ab,10}$	87.36	88.92		$C^*_{ab,10}$	29.44	28.19
	$h_{ab,10}$	68.16	56.93		$h_{ab,10}$	64.31	52.91		$h_{ab,10}$	67.91	57.42
Y-L	L^*_{10}	90.84	89.88	Y-M	L^*_{10}	87.62	83.58	Y-D	L^*_{10}	64.98	62.98
	a^*_{10}	-3.08	-4.17		a^*_{10}	3.57	8.44		a^*_{10}	4.01	7.95
	b^*_{10}	33.23	30.14		b^*_{10}	94.74	85.39		b^*_{10}	34.11	30.1
	$C^*_{ab,10}$	33.37	30.42		$C^*_{ab,10}$	94.81	85.8		$C^*_{ab,10}$	34.34	31.13
	$h_{ab,10}$	95.30	97.87		$h_{ab,10}$	87.84	84.36		$h_{ab,10}$	83.30	75.2
YG-L	L^*_{10}	84.78	84.25	YG-M	L^*_{10}	67.49	67.65	YG-D	L^*_{10}	56.76	57.41
	a^*_{10}	-13.35	-19.17		a^*_{10}	-23.08	-32.88		a^*_{10}	-10.99	-14.31
	b^*_{10}	40.18	37.26		b^*_{10}	60.38	57.6		b^*_{10}	18.49	18.07
	$C^*_{ab,10}$	42.34	41.9		$C^*_{ab,10}$	64.64	66.33		$C^*_{ab,10}$	21.51	23.05
	$h_{ab,10}$	108.38	117.23		$h_{ab,10}$	110.92	119.72		$h_{ab,10}$	120.74	128.38
G-L	L^*_{10}	78.50	82.09	G-M	L^*_{10}	46.26	49.34	G-D	L^*_{10}	27.94	28.99
	a^*_{10}	-23.09	-33.43		a^*_{10}	-29.37	-42.01		a^*_{10}	-7.91	-9.69
	b^*_{10}	-7.00	-2.15		b^*_{10}	7.23	10.02		b^*_{10}	1.78	3.01
	$C^*_{ab,10}$	24.13	33.5		$C^*_{ab,10}$	30.24	43.19		$C^*_{ab,10}$	8.10	10.15
	$h_{ab,10}$	196.85	183.67		$h_{ab,10}$	166.18	166.58		$h_{ab,10}$	167.29	162.77
GB-L	L^*_{10}	77.63	80.08	GB-M	L^*_{10}	42.38	46.33	GB-D	L^*_{10}	35.37	38.62
	a^*_{10}	-9.42	-12.71		a^*_{10}	-15.85	-21.87		a^*_{10}	-8.07	-11.22
	b^*_{10}	-22.16	-18.08		b^*_{10}	-29.81	-23.61		b^*_{10}	-26.57	-21.64
	$C^*_{ab,10}$	24.08	22.1		$C^*_{ab,10}$	33.76	32.18		$C^*_{ab,10}$	27.77	24.38
	$h_{ab,10}$	246.97	234.89		$h_{ab,10}$	242.00	227.2		$h_{ab,10}$	253.11	242.59
B-L	L^*_{10}	69.57	71.71	B-M	L^*_{10}	40.28	46.15	B-D	L^*_{10}	21.91	24.75
	a^*_{10}	-3.10	-4.16		a^*_{10}	-6.90	-10.52		a^*_{10}	0.20	-0.15
	b^*_{10}	-26.89	-22.79		b^*_{10}	-55.46	-45.11		b^*_{10}	-31.00	-25.26
	$C^*_{ab,10}$	27.07	23.16		$C^*_{ab,10}$	55.89	46.32		$C^*_{ab,10}$	31.00	25.26
	$h_{ab,10}$	263.43	259.66		$h_{ab,10}$	262.90	256.87		$h_{ab,10}$	270.36	269.65
BR-L	L^*_{10}	75.60	76.5	BR-M	L^*_{10}	27.42	28.99	BR-D	L^*_{10}	27.34	27.86
	a^*_{10}	9.40	12.73		a^*_{10}	17.27	22.63		a^*_{10}	8.51	13.32
	b^*_{10}	-13.91	-12.02		b^*_{10}	-30.97	-26.91		b^*_{10}	-16.02	-13.93
	$C^*_{ab,10}$	16.79	17.51		$C^*_{ab,10}$	35.46	35.16		$C^*_{ab,10}$	18.13	19.28
	$h_{ab,10}$	304.05	316.66		$h_{ab,10}$	299.14	310.06		$h_{ab,10}$	297.97	313.73
W-L	L^*_{10}	92.58	92.57	GY-M	L^*_{10}	51.19	51.58	BK-D	L^*_{10}	15.11	15.57
	a^*_{10}	0.26	0.33		a^*_{10}	-1.43	-0.58		a^*_{10}	-0.58	-0.6
	b^*_{10}	3.52	3.19		b^*_{10}	-1.49	-0.79		b^*_{10}	-2.21	-1.6
	$C^*_{ab,10}$	3.53	3.20		$C^*_{ab,10}$	2.06	0.98		$C^*_{ab,10}$	2.28	1.71
	$h_{ab,10}$	85.72	84.17		$h_{ab,10}$	226.10	233.76		$h_{ab,10}$	255.25	249.36

a: Name of the sample indicates color group (R: red; RY: red-yellow; Y: yellow; YG: yellow-green; G: green; GB: green-blue; B: blue; BR: blue-red) and lightness (L: light; M: medium; D: dark). Note: Some colorimetric data under D65 were derived from the previous part of this research series on the effect of illuminants on textile colors [5].

observer or 10° standard observer) [3]. Figure 6 summarizes how the CIE *XYZ* tristimulus values of samples were calculated from the spectral data of the samples, CWF and D65 illuminants, and the CIE 10° standard observer. Here, the CIE standard data [17] were used for the spectral data of the illuminants, and data interpolation and extrapolation were performed to match the intervals with the spectral data regions of the sample and illuminant. Thereafter, the CIE L^*_{10}, a^*_{10}, b^*_{10}, $C^*_{ab,10}$, and $h_{ab,10}$ values were calculated from the XYZ values using equations (2)-(10) where X, Y, Z and X_n, Y_n, Z_n are the tristimulus values of the sample and reference white, $E(\lambda)$ is the spectral power distribution of the illuminant at the wavelength λ, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ are the color matching functions, and k is a normalizing constant [2,3]. Table 1 shows the color appearance values of 27 samples under the CWF and D65 illuminants.

$$L^*_{10} = 116(Y/Y_n)^{1/3} - 16 \tag{2}$$

$$a^*_{10} = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \tag{3}$$

$$b^*_{10} = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}] \tag{4}$$

$$C^*_{ab,10} = \sqrt{(a^{*2}_{10} + b^{*2}_{10})} \tag{5}$$

$$h_{ab,10} = \tan^{-1}(b^*_{10}/a^*_{10}) \tag{6}$$

where

$$X_n = k\int_\lambda E(\lambda)\bar{x}(\lambda) \tag{7}$$

$$Y_n = k\int_\lambda E(\lambda)\bar{y}(\lambda) \tag{8}$$

$$Z_n = k\int_\lambda E(\lambda)\bar{z}(\lambda) \tag{9}$$

where

$$k = 100/\int_\lambda E(\lambda)\bar{y}(\lambda) \tag{10}$$

The average color differences of the 27 samples under the two illuminants CWF and D65 were 1.92 $|\Delta L^*_{10}|$ (S.D.: 1.57) for lightness difference, 3.79 $|\Delta C^*_{ab,10}|$ (S.D.: 3.75) for chroma difference, 7.85 $|\Delta h_{ab,10}|$ (S.D.: 4.27) for hue difference, and 4.17 $\Delta E_{CMC(2:1)}$ (S.D.: 1.80; 7.03 $\Delta E^*_{ab,10}$) for total color difference. These values were much larger than the chroma difference (suprathreshold chroma color-difference tolerances: approximately 1.3-3.2 $|\Delta C^*_{ab,10}|$), hue difference (suprathreshold hue color-difference tolerances: approximately 0.8-3.5 $|\Delta h_{ab,10}|$), and total color difference (suprathreshold total color-difference tolerances: 1.3 $\Delta E^*_{ab,10}$ or higher) that can be detected by people as previously reported by related color studies, excluding the lightness difference [18-21]. Meanwhile, the preferences for the illuminants CWF and D65 used on neutral color samples (W-L, GY-M, BK-D) were significantly higher than those of the red-yellow and yellow samples (RY-L, RY-M, RY-D, Y-L, Y-M, Y-D). Under the two illuminants, the average color differences of neutral color samples (0.29 $|\Delta L^*_{10}|$, 0.66 $|\Delta C^*_{ab,10}|$, 5.03 $|\Delta h_{ab,10}|$, 0.98 $\Delta E_{CMC(2:1)}$) were much smaller than the color differences of red-yellow and yellow samples (2.58 $|\Delta L^*_{10}|$, 3.21 $|\Delta C^*_{ab,10}|$, 7.88 $|\Delta h_{ab,10}|$, 4.56 $\Delta E_{CMC(2:1)}$). Furthermore, although the difference was small, the difference in average preference of the two illuminants on the neutral color samples (D65 3.98 - CWF 3.73=0.25; see Figure 5) was larger than the difference in average preference of the two illuminants on the red-yellow and yellow samples (0.16; see Figure 5). These results show that the difference in preference of illuminants for textiles does not always have a linear relationship with the color differences of textiles observed under illumination. In other words, the color perceived and assessed subjectively by people is distinct from the objective physical color attributes of an object.

Relationship between the Physical Color Attributes of Textiles and Illumination Preferences

A Pearson correlation analysis was performed to analyze the relationship between the concrete values of physical color attributes and illumination preferences of textiles. For the analysis, the lightness L^*_{10}, chroma $C^*_{ab,10}$, and hue $h_{ab,10}$ values of 27 samples—which were measured with a spectrophotometer—were used as independent variables, and the preferences for the three illuminants (A+CWF, CWF, D65) rated on a scale of 1-5 were used as dependent variables. Table 2 contains the results of the correlation analysis. Among the three illuminants, the preferences for single illuminants CWF and D65 were significantly affected by the physical chroma and hue of the observed samples (p<0.01). In contrast, the preferences for the mixed illuminant A+CWF were not significantly affected by the physical color attributes of the samples (p>0.05).

Table 2. Pearson's correlation coefficients between the variables studied

Independent variables[a]	Dependent variables[b]		
	A+CWF preference	CWF preference	D65 preference
L^*_{10}	-0.03	-0.04	-0.06
$C^*_{ab,10}$	0.04	-0.15**	-0.12**
$h_{ab,10}$	-0.05	0.11**	0.11**

**p<0.01. [a]Physical color attributes (spectrophotometrically measured color values), that is, lightness L^*_{10}, chroma $C^*_{ab,10}$, and hue $h_{ab,10}$ values of 27 fabric samples. [b]Preferences for A+CWF (approx. 3500 K), CWF (4230 K), and D65 (6504 K) illuminants rated from 1 to 5.

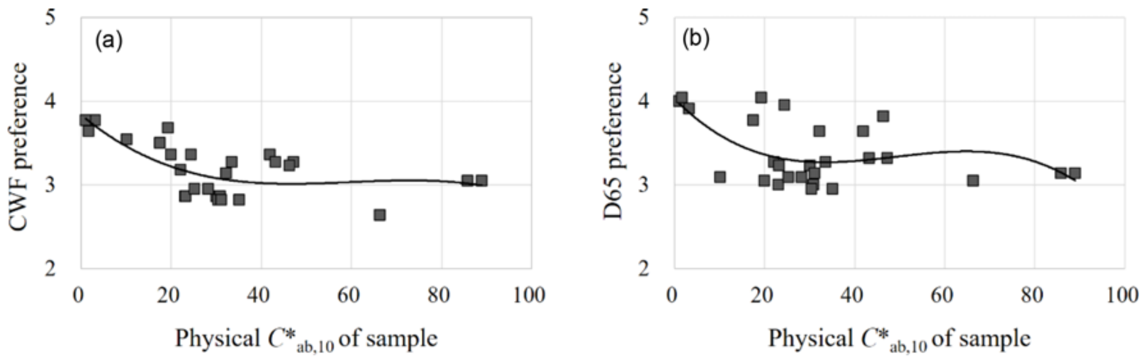


Figure 7. Changes in preference for (a) CWF (4230 K) and (b) D65 (6504 K) illuminants according to the $C^*_{ab,10}$ of samples.

A simple regression analysis was likewise performed to analyze the trend of how the preferences for CWF and D65 illuminants change according to significant variables, i.e., the physical chroma and hue of samples. To obtain the trend line of the two illumination preferences, the first-, second-, and third-order functions were attempted for all data, and the third-order function with the highest explanatory power was determined as the final trend line. Figure 7 shows the preference change trend of the CWF and D65 illuminants according to the physical chroma $C^*_{ab,10}$ of the sample. Figure 8 shows the preference change trend of the two illuminants according to the physical hue $h_{ab,10}$ of the sample.

As can be seen in Figure 7, the preferences for CWF and D65 illuminants were generally higher when the chroma of the sample was lower, that is, when the color was less vivid. The preference for the two illuminants was the highest particularly when the chroma of the sample was near 0, or when it was close to a neutral color. With respect to illumination preferences according to the hue of the sample, Figure 8(a) indicates that the preference for the CWF illuminant was generally lower when the $h_{ab,10}$ of the sample was 0-90, which is close to red-yellow. Based on the hue of the sample, the preference for the illuminant D65 was generally lowest when the $h_{ab,10}$ of the sample was between 0 (or 360: red) and 90 (yellow); it was generally high when the $h_{ab,10}$ was between 225 (green-blue) and 315 (blue-red), as shown in Figure 8(b).

To summarize, the lower the chroma of both samples of CWF and D65 standard illuminants and the closer their hue to the cool color (including neutral color), the more they were preferred by the subjects. The results of this study are expected to provide useful guidelines to textile designers and store managers in terms of planning the preferred colors of clothing products among consumers and creating an environment for selling clothing products that can promote consumer purchases within the clothing industry. In this study, however, the samples in the chroma range of 50-80 $C^*_{ab,10}$ were insufficient. Clearer study results could be presented if more chroma samples and subjects were utilized in future studies.

Conclusion

This study analyzed the illumination preferences of people with regard to textiles that have a wide range of colors. To this end, tests were conducted to assess illumination preferences using 27 knitted fabric samples of chromatic and

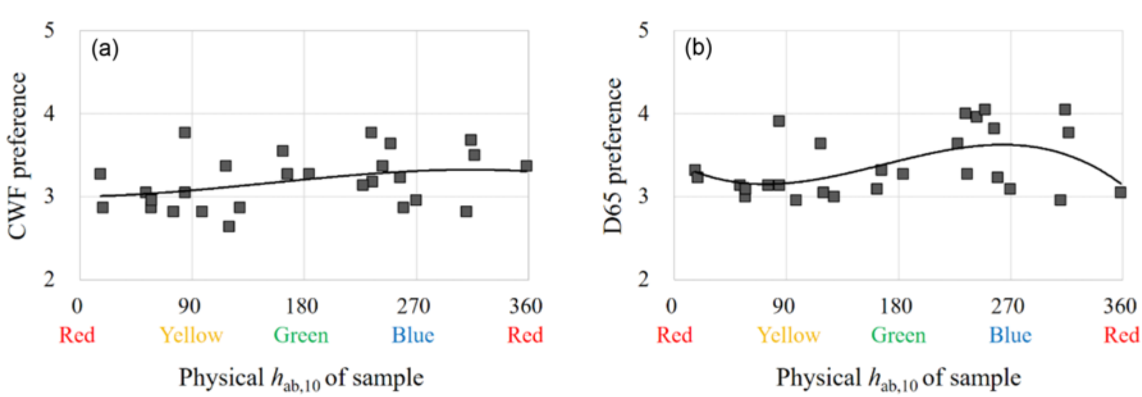


Figure 8. Changes in preference for (a) CWF (4230 K) and (b) D65 (6504 K) illuminants according to the $h_{ab,10}$ of samples.

neutral colors, as well as the D65 (6504 K) and CWF (4230 K) standard illuminants and the A and CWF mixed illuminant (A+CWF illuminant; approx. 3500 K), with each illuminant having different CCTs. The results showed that people preferred D65 (the bluish-white illuminant with a high CCT) the most—regardless of the sample color—followed by the CWF illuminant with a medium CCT and the red A+CWF illuminant with a low CCT. In particular, people's preferences for the D65 illuminant and CWF illuminant—the standard illuminant in US stores—showed significant differences based on the hue and chroma of the sample. For both illuminants, the preference for neutral-colored samples was higher than for chromatic-colored samples. Furthermore, the lower the chroma of the sample, the higher the preference for the two illuminants was in general.

The findings of this study are expected to be useful in forming a sales environment for clothing products that is preferred by consumers and promoting consumer purchases. For example, it is recommended to use a main or point illuminant with a cool hue rather than a warm hue for a brand that uses neutral colors or cool colors with a low chroma in the corresponding season. As previously discussed, however, this study used relatively fewer samples in a certain chroma section (i.e., 50-80 $C^*_{ab,10}$). More distinct results on illumination preferences could be presented if a follow-up study were to be conducted with more samples and subjects. Furthermore, this study used flat knitted fabrics with a smooth surface as its samples. Since the surface texture of textiles is another important design element among clothing products that influences color appearance (that is, the color perceived by people), follow-up research is required on the effects of illuminants using samples of various textures that affect the color appearance.

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