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Correlation Analysis of Image Reproduction and Display Color Temperature Change to Prevent Sleep Disorder

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ABSTRACT This paper aims to determine the effect of the smartphone warm color temperature function that relieves display's HEVL (high-energy visible light and short wavelength series blue light), which is known to cause suppression of melatonin secretion on actual image reproduction quality. For this study, the author of this paper measured the display based on the color difference in 26 sampling colors. It was found that for correlated color temperature (CCT) of 4000 K or less, the color difference rose sharply, centering around red and green. In hardware or software, a low CCT was realized by reducing the output centered on blue and green, but in actual color quality, a problem arose in the red and green channels. As far as tone gradation is concerned, ΔE increased for CCT of 4500 K or less while the accuracy of the shadow detail was reduced. With regard to color gamut reproduction, for the coverage of sRGB color space, the color gamut became narrow for CCT of 5500 K or less, and for volume, the color gamut became narrow sharply for CCT of 4000 K. It was found that the maximum CCT changes to prevent a decline in melatonin secretion at a level of minimizing the degradation of image quality is 4000–4500 K.

INDEX TERMS High-energy visible light, smart-phone, light-emitting diode, human circadian melatonin rhythm.

I. INTRODUCTION

Apple Inc. released 'Night Shift' mode in iOS, their smartphone's operating system, in 2016. Night Shift adjusts the color temperature automatically by calculating the sunrise and sunset in the area in which the user lives. Apple stated that Night Shift relieves sleep disorder by lowering the level of HEVL (high-energy visible light) that occurs on the display. [1] Apple has invested in technology to prevent sleep disorder caused by smart device use and acquired Beddit, a venture business from Finland specializing in sleep monitoring. In Microsoft's Window 10, night mode was added in an automatic update in April 2017. The color temperature on display during night can be changed as well as by turning on/off a function.

Samsung Display obtained German TUV Rheinland Eye Comfort certification in February by lowering their smartphone's OLED blue light weight from 12% to 7%, a reduction of over 61% compared with the general LCD blue light emission. Samsung Display reported that it succeeded in maintaining a DCI-P3 color space (gamut), which is needed to reproduce a display image 100% by adjusting the blue light wavelength. As the use of smart devices increased, technology that can provide users looking at a display for a long time optimum and more comfortable use is needed. Some studies have asserted that the smartphone blue light (HEVL) suppresses the creation of melatonin and disturbs the sleep cycle, harming human health.

Though some studies reported that exposure by a display light on mobile device cause harm to various human body cycles (circadian phases) and health, smartphones have come into worldwide use. Distribution rate in advanced countries such as USA, Australia, Spain, Germany, Britain, France, Italia, Argentina, Japan, and Canada stand at 66%–93%. According to a report by the Pew Research Center, USA's pollster in February 2019, the distribution rate in the Republic of Korea stood at 95% as of February 2019, ranking the Republic of Korea first among twenty-nine countries surveyed.

Such increase in smartphone use is attributed to its wide utilization. Mobile technology brings an innovative change to personal socio-cultural and behavioral patterns, in areas

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such as industry, education, health, and social life. Industry is progressing along with a combination of mobile device and internet wireless communication. Smartphones allow voice communication, messaging, personal information management (PIM), photo/videography, navigation, audio/video recording, data transmission/acquisition, social network app access, and web search. Smartphones influence almost all areas of human lives [2].

Today, people use smartphones/mobile devices very frequently in everyday life. We access functions via the smartphone needed in everyday lives while walking. A user looks at a display on a smartphone over three hours a day on average, particularly before he/she goes to bed at night [3]. The use of a smartphone and mobile device is expected to continue to increase, although extended smartphone use (especially during night) is likely to harm human health. This is why Apple's Night Shift function or Samsung's blue light reduction technology is highly favored.

Reducing the high-energy visible light (HEVL) band on display makes the color temperature on a screen change to warm color and become dark. Reducing the blue light by adjusting the output spectrum distribution can degrade the quality of the image reproduced on the screen. [4] Furthermore, users are chromatically adapted to the ambient illumination in the daytime. Accordingly, most users are negative about artificial change in the color temperature on the display. [5].

When using a smartphone at night and the illumination intensity is low, a user visually adapts to the changed color temperature on display. Quantitative study and analysis are required to determine how and how much color reproduction quality of the image or video degrades when the color temperature is changed artificially. It is because understanding the point in time when the image quality degrades concretely facilitates the development of color temperature guidelines for an optimal solution to health problems that smartphones can create, including preventing the suppression of melatonin secretion.

Therefore, it is necessary to determine the color reproduction quality in ismage or video that users experience to reveal how much color shift occurs when using a display with functions applied, such as Night Shift, with chromatic changes shown on a display. We can observe a change by measuring the actual colors displayed on equipment with a spectrophotometer. We can analyze the CIEXYZ output distribution of colors, changes in luminance and gradation, color gamut, and color accuracy, based on the CIEDE2000 formula, reproduced on a display according to change steps in the color temperature of the device and the light intensity.

The purpose of this study is to determine color temperature values in a scientific way that can minimize the degradation of the color quality recognized via the display while using the healthcare functions regarding melatonin secretion and visual acuity when a user uses the smartphone at night.

FIGURE 1. Apple iOS 12.2's Night Shift function.

II. RELATED STUDIES

A. HEALTH DAMAGE OF EMITTING DIODE

When white is reproduced on LED (Light Emitting Diode) BLU (Back Light Unit), it is common to coat yellow phosphor on the blue LED [6]. At such a time, because the energy wavelength of the short band from the visible light spectrum is distributed more strongly than the other wavelengths, it has a great influence on the secretion of melatonin, which controls the human circadian rhythm.

According to a recent study, there is a significant correlation between the degradation of sleep quality caused by smartphone use at night before going to bed and body function disorder [7], [8]. If a person is exposed to short wavelengths at night for over two hours, suppression of melatonin is shown, and body temperature and cardiac rate increase. Studies that place in doubt the correlation between excessive nighttime use of artificial light and health have also been conducted [9], [10].

Biological reactions caused by light lead to studies on visible wavelengths. High energy light, exhibiting short wavelengths in the blue part of the spectrum, has a stronger influence on a body than red light, which has low energy. [11] A study reported that short wavelength (blue light) occurring on a smartphone LED (light-emitting diode) display has a negative influence on sleep, suppressing energy metabolism and wakefulness in the next morning [12]–[14].

According to a study conducted by Gall and Lapuente (2002) and a study by Kozakov et al. (2008), melatonin suppression factor by color temperature of illumination stands at 0.459 for 3900 K and 0.892 for 7100 K. In a study conducted by Kraneburg et al. (2016) that covered the correlation between the color temperature of illumination under working conditions and melatonin proposed using illumination with a color temperature of at least 4000 K to suppress the secretion of melatonin while working at night. It is estimated that with

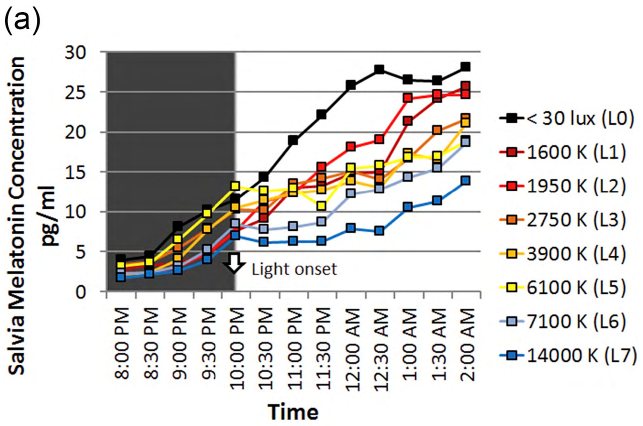

FIGURE 2. **Mean salivary melatonin concentrations of all subjects over time (8 p.m.–2 a.m.) under illumination conditions L1–L7 and the control condition (L0). The arrow at 10 p.m. indicates light onset under L1-L7 [15].**

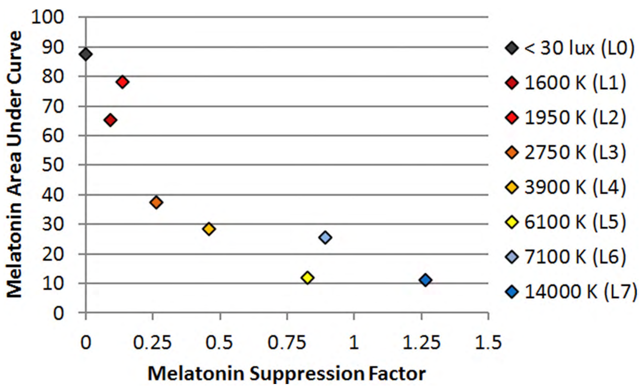

FIGURE 3. **Mean integrated area under curve (10:30 p.m.–2 a.m.) for salivary melatonin concentrations of all subjects under illumination conditions L1–L7 and the control condition (L0), with concentrations at 10 p.m. set as the zero point in relation to the melatonin suppression factor [15].**

a color temperature of 4000 K or less, melatonin secretes normally with no influence on sleep.

According to the Kraneburg study, night work suppresses the generation of melatonin and changes biorhythms, based on the color temperature of illumination. As shown in Fig. 2, when measured under various control conditions ranging from illumination conditions L1 to L7, with a color temperature of greater than 3900 K, strong suppression of melatonin is shown.

As shown in Fig. 3, in the range of L1 to L3 (1600 K–2750 K), melatonin generation was similar to that of the dim light condition (L0), but under illumination conditions L4 to L7, melatonin generation level was remarkably low [15].

Kuse *et al.* asserted that the harmfulness of the blue light occurring on a display could be demonstrated. The influence of the smartphone on an eyeball was examined and it was concluded that when blue, white, and green LED lights were directed onto the visual cells of mice, cells receiving blue light showed damage of 80%, and cells receiving white light showed damage of 70% while cells on which blue light

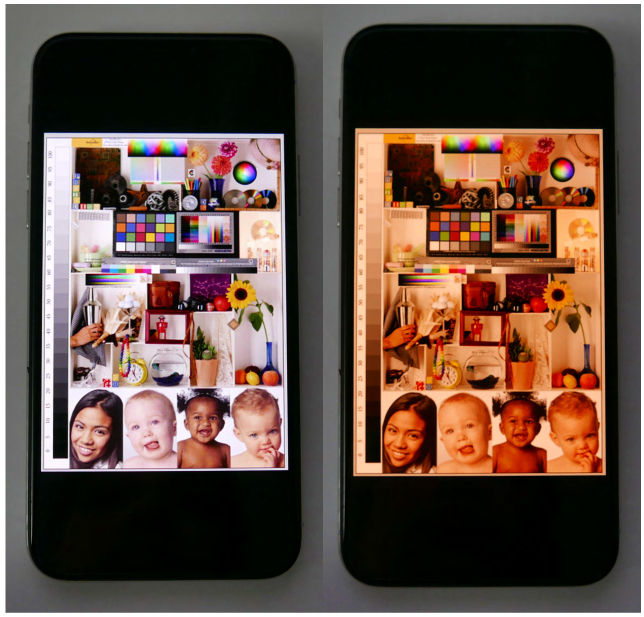

FIGURE 4. **Before (left) and after (right) color temperature change.**

was showed little change. The blue light caused a change in reactive oxygen species three times greater than that caused by white or green light, which indicates greater aging by the blue light [16].

B. COLOR IMAGE QUALITY

Studies on the improvement in the quality of image and video reproduced on a display have increased in line with the release of the mobile tablet PC and smartphone. These studies mainly addressed objective picture quality evaluation, analyzing the device performance and subjective color image perception of the user. Early topics of study included improving color reproduction performance using gamma and correlated color temperature (CCT) correction on a small-sized LCD display and the influence of gamma and gamut set on a display on reproduced colors [17], [18].

A study determined the color temperature suitable for users by analyzing the influence of the Kelvin value in indoor space in terms of color temperature change based on preference, visual fatigue degree, and work progress degree [19]. A study attempted to quantify subjective picture quality evaluation by modeling men's perception of white-point and color reproduction and presented the white-point and color coordinate preferences of eleven primary colors [20]. A study was conducted on the optimum color temperature conversion curve regarding which colors users prefer when performing MPEG-7 image color temperature changes [21]. Kim *et al.* also proposed an approach to control the visible spectrum distribution reproduced on the display through ICC color characterization [22].

Recently, there was a study on a look up table (LUT) technique to correct digital colors in an image or video by mapping one color space to another color space [23], [24].

There was also a recent study on the texture, color temperature, and contrast ratio necessary to improve stereoscopic image quality.

The above-mentioned studies approached the harmfulness of the smartphone HEVL to health in various ways and revealed significant discoveries in the field of color image and video quality reproduction on a display. However, there have not yet been any studies that have attempted to determine the degradation level of color quality in image or video, or place constraints on conditions through a quantitative approach based on CIEDE2000. Accordingly, this study aims to propose optimum color temperature setting for nighttime smartphone viewing by measuring the color reproduction level on a display according to the changes in various color temperatures and integrating the results.

III. METHODOLOGY

A. EXPERIMENTAL DEVICES

MacOS operating system version 10.14.3 LCD display device

- Including Night Shift function (color temperature conversion setting on a display at night has been enabled)
- Based on LCD display using white led backlight
- A display includes 100% volume of the sRGB color space [25], [26]

B. EXPERIMENT ENVIRONMENT

- Set initialization state of a display and an operating system
- Disable special calibration or color profile setting
- Disable additional function of active true tone according to ambient light
- Display measurement in indoor environment where ambient light is completely controlled
- Experiment is conducted in maximum brightness state which a display can be reproduced

C. EXPERIMENTAL METHOD

- Warm up measuring instruments and displays for 30 min before experiment
- Measure emissive spectrum by using i1Pro 2 Rev. E spectrophotometer manufactured by X-Rite
- Use high-resolution spectral mode provided by applicable a measuring instrument and measure with 3.3 nm spacing for more precise measurement
- Use CIE 1931 2° as standard observer
- Use version 2.0.1 of ArgyllCMS, GNU General Public License (GPL) software for measurement
- Quadrangular sampling patch is fixed at the center of a screen with a size of 20% of width and length of a display
- Black output ($d_r = d_g = d_b = 0$) for sections other than sampling patches to minimize any influence on measurement of a display
- Apply change in CCT to analyze change in color quality

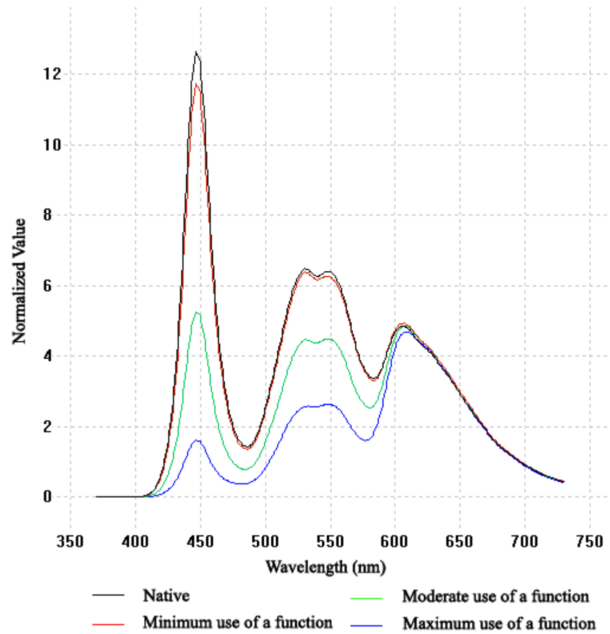

FIGURE 5. Change in spectrum distribution according to the use of the color temperature adjustment function.

D. AREAS OF MEASUREMENT

- Distribution of display spectrum
- Change in display luminance
- XYZ tristimulus values
- Color reproduction areas – volume & coverage based
- Color difference – CIEDE2000 based

IV. RESULTS AND ANALYSIS

A. EXPERIMENT 1: SPECTRUM DISTRIBUTION

Figure 5 below shows the spectrum distribution of 370–770 nm, in the visible light section of the spectrum, from a display that was used as a sample.

As shown in the actual measurement of spectrum distribution, a display brings a change to the warm color temperature by lowering the output of the blue channel at 450 nm and the green channel at 540 nm from the RGB primary color channels. A change in the red channel at 610 nm was shown to be insignificant.

The native white-point of a display used as a target display was 7324 K. The CCT was measured as a function of Night Shift function use. When the Night Shift function was minimally used, the CCT was 6673 K, moderate use corresponded to a CCT of 4501 K, and maximum use corresponded to a CCT of 2905 K. Accordingly, a user nighttime viewing of an image or video with Night Shift results in a CCT that is lower than the default value by 650–4000 K. In other words, a user sees warm screen colors, shifted to yellowish from the blueish cool screen color.

B. EXPERIMENT 2: CHANGE IN LUMINANCE

Reducing the output of some RGB channels is required to change the CCT on a display in the maximum output state for

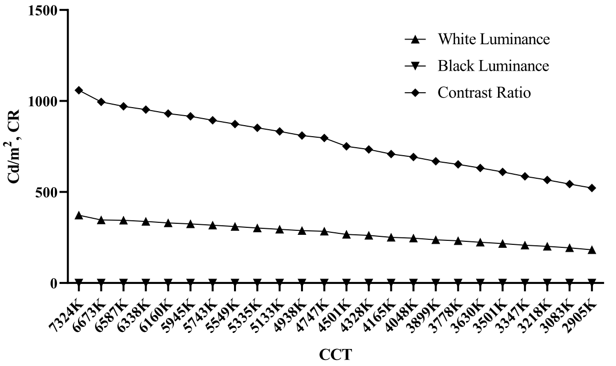

FIGURE 6. Change in luminance according to a change in the CCT of a display.

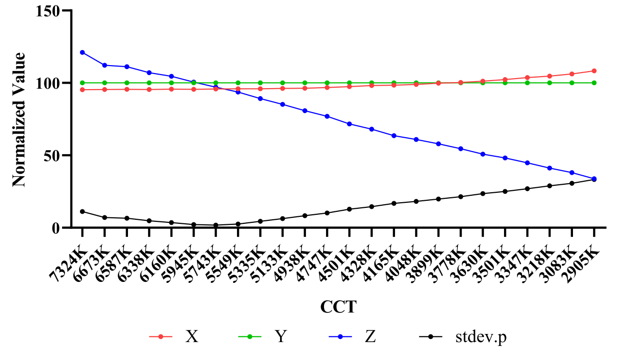

FIGURE 7. XYZ tristimulus values according to the CCT based on the relative color system.

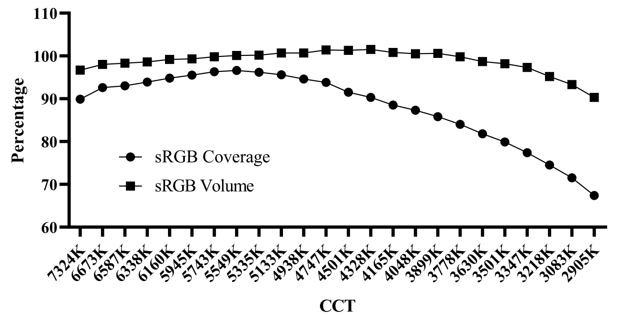

FIGURE 8. Change in the color gamut according to a change in the CCT on a display.

each RGB primary color channel. As the output of one channel is lowered, the total sum of the RGB channels is lowered; hence, a change in CCT influences the overall luminance of a display. Figure 6 shows the change in brightness of a display according to change in CCT.

LCD display which showed luminance of 372.6 cd/m^2 in a native state stood at luminance of 182.4 cd/m2 when CCT to 2905K level showing a reduction of luminance up to 51% compared with a native state.

Luminance of black was kept constant irrespective of a change in CCT because CCT was changed by adjusting RGB primary color channels in a state that brightness of backlight was fixed which was characteristics of LCD display. This caused contrast ratio to fall to 522.1:1 in 2905K CCT from 1059.1:1 in a native state dynamic range dropping by half and such changes in luminance and contrast were made in a linear way. The more activated Night Shift function is, the less contrast ratio of image or video which a user sees on a screen and the more reduced the scope of dynamic range which is needed to deliver details of shadow or highlight is.

C. EXPERIMENT 3: TRISTIMULUS VALUES

Analysis of color quality on a display using additive color system on each RGB channel was conducted. XYZ tristimulus values were calculated by using color matching function for CIE 1931 standard color observer (2°) according to CCT [27]. When calculating tristimulus values, the relative color system was normalized to a Y tristimulus value of 100.

$$X = \frac{K}{N}\int_{\lambda} S(\lambda)I(\lambda)\bar{x}(\lambda)d\lambda,$$
$$Y = \frac{K}{N}\int_{\lambda} S(\lambda)I(\lambda)\bar{y}(\lambda)d\lambda,$$
$$Z = \frac{K}{N}\int_{\lambda} S(\lambda)I(\lambda)\bar{z}(\lambda)d\lambda$$

At such a time, $N = \int_{\lambda} I(\lambda)\bar{y}(\lambda)d\lambda$ was used for the normalization. Figure 7 shows the result.

In the native state, the XYZ standard deviation was 11.16, which decreased to 5700 K as the CCT was reduced but increased again. For CCT lower than 4700 K, the deviation rose compared with the native state. Based on viewing at 6500 K, the default value for CCT of a display, XYZ tristimulus values of up to 5100 K exhibited similar levels. However, for a CCT lower than 5100 K, the difference between the XYZ tristimulus values rose sharply. The standard deviation was wider than the native state for CCT of 4700 K or less. However, tolerance can be explained differently according to target displays. If the threshold value is set to the standard deviation at 6500 K = 6.56, the default value on a display, the tolerance for XYZ tristimulus values are greater for 5100 K or less.

D. EXPERIMENT 4: COLOR REPRODUCTION

In terms of coverage targeting the sRGB color space, at 5500 K, the highest reproduction was shown and the color gamut narrowed as the CCT was reduced. In terms of volume, the color gamut was reduced sharply for CCT lower than 4000 K. Reduction in the color gamut means that the range of colors that a display can reproduce is reduced. Accordingly, as shown in Fig. 8, if you see images or videos via a display in which CCT was set to 4000 K or less, you are likely to see poor quality color because the color gamut has been reduced.

As shown in Figure 9, the color gamut in the native state exhibits a state that is similar to the sRGB color space set as a target from 10% to 90% lightness. This means that the colors targeted when reproducing HDTV video contents in ITU BT.709 format or sRGB color space based images are reproduced normally within similar colors.

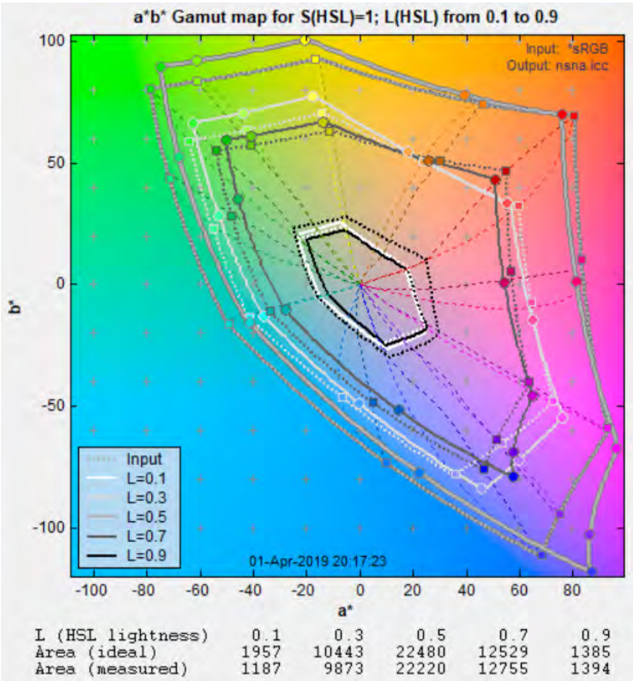

FIGURE 9. **a∗b∗ gamut map in a native state.**

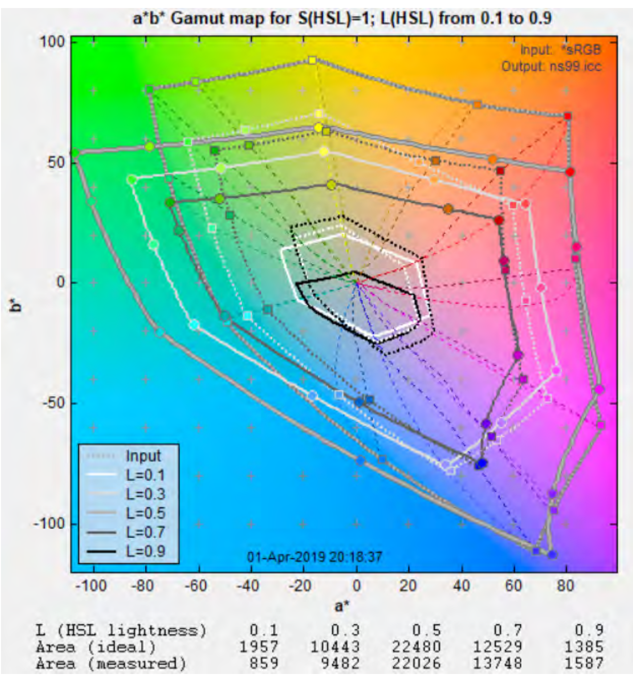

FIGURE 10. **a∗b∗ gamut map in the maximum state of Night Shift.**

When looking at the change in color gamut in the a∗b∗ gamut map based on 100% saturation from 10% to 90% lightness, for the lowest CCT, as shown in the full line in Fig. 10, in the red and green area, the color gamut shrinks bent in the negative direction of b∗. Colors of areas shrunk like this are not reproduced on a display; hence, the device cannot show correct colors.

TABLE 1. **Sampling colors for color difference measurement.**

#	Device Values			Nominal Values				
	R	G	B	L*	a*	b*	γ	
01	255	255	255	100	0.02	-0.02		
02	0	0	0	0.83	0.45	-1.38		
03	26	26	26	9.75	0.01	-0.04	1.96	
04	51	51	51	21.58	0.01	-0.01	2.1	
05	77	77	77	32.72	0.01	-0.01	2.16	
06	102	102	102	43.31	0.01	-0.01	2.2	
07	128	128	128	53.47	0.01	-0.01	2.22	
08	153	153	153	63.27	0.01	-0.01	2.24	
09	179	179	179	72.79	0.01	-0.01	2.25	
10	204	204	204	82.06	0.02	-0.01	2.26	
11	230	230	230	91.12	0.02	-0.02	2.27	
12	128	0	0	26.3	47.89	38.3		
13	255	0	0	54.37	80.64	69.12		
14	255	128	128	68.71	49.4	23.86		
15	0	128	0	46.21	-47.14	47.94		
16	0	255	0	87.83	-79.14	80.78		
17	128	255	128	90.67	-55.56	48.97		
18	0	0	128	11.88	39.65	-66.12		
19	0	0	255	29.78	67.84	-111.69		
20	128	128	255	58.26	25.89	-64.67		
21	0	128	128	47.9	-30.15	-8.93		
22	0	255	255	90.67	-50.58	-14.96		
23	128	0	128	29.78	55.56	-35.98		
24	255	0	255	60.23	93.39	-60.42		
25	128	128	0	52.04	-9.38	55.38		
26	255	255	0	97.61	-15.72	93.19		

E. EXPERIMENT 5: COLOR DIFFERENCE

To determine the color difference according to the use of the Night Shift function, sampling was conducted based on the colors in Table 1, and the color difference was calculated based on CIEDE2000 [28].

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}}$$

When extracting LAB values for the color difference calculation, with regard to white-point target, the difference that occurs because of changes in the CCT was normalized by using the measured white-point at the time of the CCT measurement [29].

As shown in Table 2, the measured value was found against the target value of a display according to each sample color from #1 to #26, and the color distance was found by using ΔL∗, ΔC∗, ΔH∗, ultimately yielding the ΔE00 value [30].

As shown in Fig. 11, the color difference was found according to the change in CCT. Sections which were influenced most by the change in CCT were #03(26,26,26) color and #04(51,51,51) color. The lower the CCT was, the more the color difference changed. Color difference increased sharply for CCT of 4500 K or less. Grayscale has the characteristic of display tone reproduction, which should be considered in a future study.

TABLE 2. Calculation of nominal values, measured values, and color distance according to each sample color.

#	Device Values			Nominal Values			Measured Values			Color distance			
	R	G	B	L*	a*	b*	L*	a*	b*	$\Delta L^*_{00/w}$	$\Delta C'_{00/w}$	$\Delta H'_{00/w}$	ΔE_{00}
01	255	255	255	100	0.02	-0.02	100	0	0	0	-0.03	0	0.03
02	0	0	0	0.83	0.45	-1.38	0.84	0.44	-1.38	0	-0.01	-0.01	0.01
03	26	26	26	9.75	0.01	-0.04	4.57	0.39	-1.36	-3.16	1.39	-0.04	3.45
04	51	51	51	21.58	0.01	-0.01	17.79	-0.15	-0.16	-2.62	0.27	-0.09	2.63
05	77	77	77	32.72	0.01	-0.01	30.41	-0.17	0.17	-1.82	0.29	0.13	1.85
06	102	102	102	43.31	0.01	-0.01	41.42	-0.26	0.08	-1.72	0.38	-0.16	1.77
07	128	128	128	53.47	0.01	-0.01	52.16	-0.23	0.02	-1.28	0.32	-0.16	1.33
08	153	153	153	63.27	0.01	-0.01	62.24	-0.09	-0.22	-0.88	0.24	-0.11	0.92
09	179	179	179	72.79	0.01	-0.01	72.27	-0.03	-0.32	-0.39	0.3	-0.1	0.5
10	204	204	204	82.06	0.02	-0.01	81.44	0.14	-0.54	-0.43	0.55	-0.08	0.7
11	230	230	230	91.12	0.02	-0.02	90.85	0.21	-0.59	-0.17	0.63	-0.07	0.65
12	128	0	0	26.3	47.89	38.3	23.82	43.98	35.28	-1.81	-1.35	0.06	2.26
13	255	0	0	54.37	80.64	69.12	52.14	76.37	71.95	-2.17	-0.22	2.35	3.21
14	255	128	128	68.71	49.4	23.86	67.06	46.17	23.66	-1.31	-0.88	0.74	1.74
15	0	128	0	46.21	-47.14	47.94	45.31	-43.56	51.62	-0.86	0.08	-2.21	2.37
16	0	255	0	87.83	-79.14	80.78	89.13	-75.46	90.28	0.82	0.74	-2.8	3.01
17	128	255	128	90.67	-55.56	48.97	91.59	-54.66	54.68	0.57	0.74	-1.88	2.1
18	0	0	128	11.88	39.65	-66.12	9.74	48.6	-68.13	-1.35	1.43	3.93	**4.01**
19	0	0	255	29.78	67.84	-111.69	26.67	87.68	-119.12	-2.36	2.37	5.84	**6.14**
20	128	128	255	58.26	25.89	-64.67	56.59	33.58	-69.12	-1.52	1.67	3.7	3.45
21	0	128	128	47.9	-30.15	-8.93	46.98	-25.4	-8.09	-0.9	-2.14	0.41	2.36
22	0	255	255	90.67	-50.58	-14.96	91.47	-43.5	-13.94	0.5	-2.2	0.64	2.35
23	128	0	128	29.78	55.56	-35.98	27.08	56.33	-39.1	-2.05	0.59	-0.99	2.35
24	255	0	255	60.23	93.39	-60.42	57.32	97.67	-67.08	-2.6	1.18	-1.04	3.05
25	128	128	0	52.04	-9.38	55.38	50.7	-11.75	58.98	-1.33	1.1	1.03	2.01
26	255	255	0	97.61	-15.72	93.19	97.98	-19.94	102.36	0.22	1.79	1.21	2.17

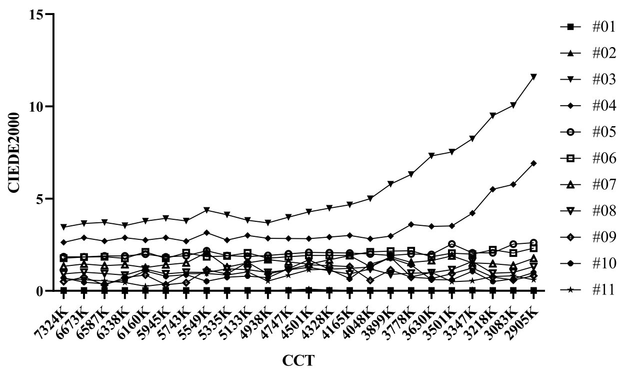

FIGURE 11. Color difference according to the grayscale brightness.

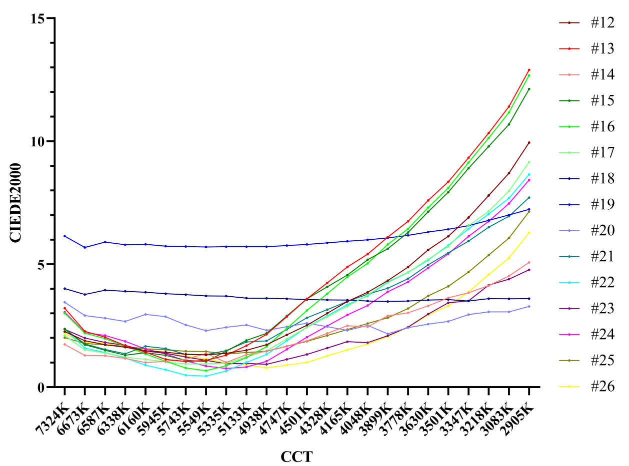

FIGURE 12. Color difference progress according to colors by the change in the CCT.

As shown in Fig. 12, colors that were influenced most by the change in CCT were #16(0,255,0), #13(255,0,0), and #15(0,128,0). It was found that a change to low CCT had a negative influence on color quality in the red and green sections. For the blue series color samples, a change in the color difference due to a change in the CCT was insignificant.

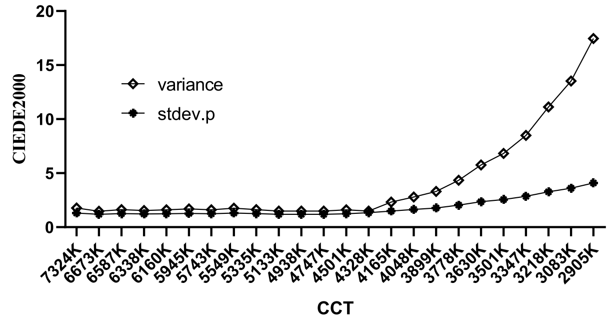

FIGURE 13. Variance and standard deviation according to CCT.

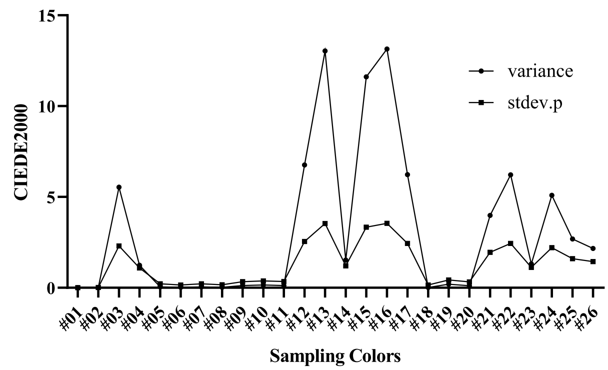

FIGURE 14. Variance and standard deviation according to the sampling colors.

TABLE 3. CCT for occurring evaluation factors and image quality degradation.

Evaluation Factors	Correlated Color Temperature (CCT)
CIE XYZ	under 5100 K
Color gamut coverage	under 4747 K
Color gamut volume	under 3630 K
CIEDE2000 sampling tone response	under 4165 K
CIEDE2000 sampling color	under 4238 K

The difference in the variance and standard deviation increased sharply for CCT of 4000 K or less. Such a result is in line with a change in CCT and color difference, according to the color samples in Fig. 13.

Examining the variance and standard deviation according to each sampling color as shown in Fig. 14, the #03, #12, #13, #15, #16, #17, #22 colors showed a sharp rise with change in CCT. Among them, the #13(255,0,0) color showed the highest change and color difference. It was found that a change to lower CCT caused the most serious difference in red.

Table 3 shows the sections in which image color quality reproduction degradation occurred.

Color gamut quality degradation is based on gamut coverage at a CCT of 6500 K and below.

Results shown in a table above are expected to be useful for healthcare display hardware and software solutions for the prevention of sleep disorder. The findings of this study are expected to make a contribution to safe guidelines, lowering the color temperature without degrading original image quality.

V. CONCLUSION

This study aimed to determine the effect of warm color temperature function, which provided to relieve HEVL (short wavelength blue light) emanating from a display, on actual image quality. HEVL has been known to causing suppression of melatonin secretion, providing a negative effect on human health. This study considered 26 sampling colors based on color difference and found that at a CCT of 4000 K or less, the color difference rose sharply, centering on red and green. As mentioned earlier, in hardware and software, low CCT was realized by lowering the output from the blue and green color channels. However, in terms of actual color quality, a negative effect was noted in the red and green channels. In terms of tone gradation, the degradation of accuracy of shadow detail increased as ΔE increased for CCT of 4500 K or less.

In terms of color gamut representation, the color gamut narrowed for a CCT of 5500 K or less based on the coverage of the sRGB color space, and the color gamut narrowed sharply for a CCT of 4000 K or less based on volume. It was found that the limit of maximum CCT change to prevent the degradation of melatonin secretion while minimizing the degradation of image quality was 4000–4500 K.

This study attempted to conduct a quantitative analysis of the color gamut representation based on CIEDE2000 and CIELAB, considering that there has been little quantitative research on actual image quality change on a display with respect to change in CCT. This study is significant in that it presented a guideline for the maintenance of color quality by objectively measuring the influence of image and video color quality. The findings of this study are expected to be useful for display manufacturers, operating system developers, application developers, and health care solution providers developing more concrete CCT control options.

Advanced research reported that luminance as well as CCT of a luminous body has a great influence on the prevention of melatonin secretion suppression. Changing the CCT on a display in the native state reduces the luminance. This study also found a reduction in luminance by up to 50%, which implies that CCT change helps prevent sleep disorder.

This study conducted an experiment based on sRGB color reproduction quality with an sRGB color space coverage 100% level display, the most popular product at present. This study presented a method that can lower color temperature while minimizing the degradation in image quality in an attempt to prevent sleep disorder. Further studies on different color gamuts, tone reproduction properties, reference color space, and displays other than LCD displays, such as OLED, are needed. Further studies to determine the correlation between changes in CCT on a smartphone, luminance in a luminous body, and degradation of melatonin secretion are expected.

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