PRELIMINARY STUDY ON SPECTRAL CHARACTERISTICS FOR IDENTIFICATION OF SKIN COLOR UNDER CIRCULATORY DYSFUNCTION USING ARTIFICIAL SKIN SAMPLES

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Abstract

To assist development of appropriate light sources to diagnose circulatory dysfunction conditions effectively based on the color appearance of patient's skin under emergency situation in disaster sites, a set of urethane skin model samples have been developed, which simulate visual characteristics of real human skins under different circulatory dysfunction conditions (shocked, healthy, and congested) for young female/male and elderly female/male. Their characteristics have been evaluated by calculations of samples' color differences under various light spectra compared to those of real skins. Visual evaluation experiments have been conducted using these samples to evaluate distinction between different circulatory dysfunction conditions under the optimized light-emitting diode (LED) light spectra used in our previous study. The developed urethane samples were found better in closeness of colors to real skin than previously-used paper color charts, but it needs further improvements in matching spectral reflectance characteristics. The experimental method directly comparing perceived color differences of the samples under the LED lights and reference lights (broadband spectra) was found useful for such evaluation.

Keywords: skin color, spectral distribution, circulatory dysfunction, emergency medical care

1 Introduction

In a disaster situation, in confined spaces after earthquake, typhoon, or tsunami disasters, victims can become a crush syndrome and need an immediate treatment at the rescue site. Under such a situation, it is necessary to judge correctly whether the victims rescued from debris have fallen into circulatory dysfunction and to apply appropriate medical treatment, in order to increase the survival rate. Unfortunately, it is difficult to judge their physical conditions by visual observation at the disaster site often due to poor performance of their lighting equipment. Also in a non-disaster medical environment such as in hospitals, where conventional lighting (such as by fluorescent and incandescent lamps) is being replaced by LED lighting, development of LED light sources enabling the medical staff to judge patients' conditions more accurately with enhanced color rendition performance than conventional light sources is desired.

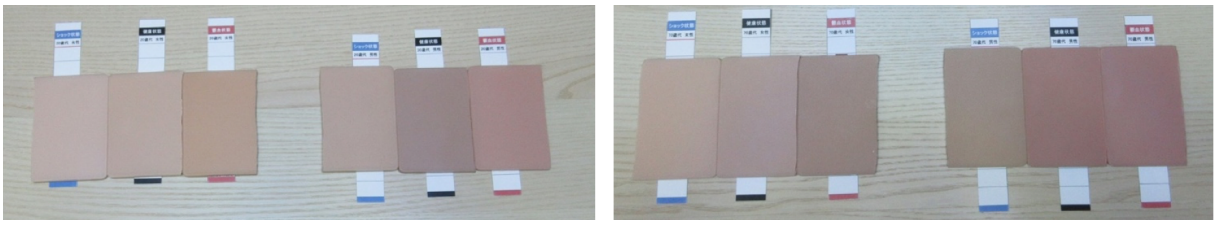
In an effort to assist development of such light sources, a database of spectral reflectance data of circulatory dysfunctional skin colors was developed, taking age and gender into consideration, by measuring Japanese subjects' skins (at back of hands) which were artificially shocked or congested by controlling blood flow of an upper arms (Akizuki et al. 2013). Also, we conducted simulations to determine the spectral power distributions (SPD) of a theoretical LED source (three narrow bands) that maximize the color differences between healthy skin and shocked/congested skin for different age/gender groups, and conducted preliminary visual evaluation of the optimized spectra (chosen closest to the theoretical LED spectra as above) using NIST Spectrally Tunable Lighting Facility (STLF) (Akizuki and Ohno 2016). In this experiment, skin-color paper samples were used, referred to as "paper color chart", which are Munsell color samples selected to match the colors of real skin for different circulatory dysfunctional conditions for gender and age groups. Their spectral reflectance factor curves, however, were not close to real skins' data especially in the region longer than 580nm, and the results of visual evaluation was not satisfactory.

In this study, new skin model samples using urethane have been developed for different circulatory dysfunction conditions for improved spectral reflectance characteristics as well as sample's visual appearance, texture, and structures to be closer to real human skins. The characteristics of these urethane samples have been evaluated with colorimetric calculations

and by two vision experiments, to examine suitability for use in evaluating light sources for distinguishing human skin colors under circulatory dysfunction conditions. The experimental methods for evaluating light sources using these skin model samples have also been evaluated.

2 Development of Urethane Skin Model Samples and their characteristics

The developed urethane skin model samples are shown in Figure 1. They are 5 mm thick, with the size of 100 mm × 70 mm, and made of two layers of urethane providing appearance with surface texture similar to real skins, with colors matched to those of three different circulatory dysfunction conditions (healthy, shocked, and congested) for four gender/age groups (young female, young male, elderly female, and elderly male). Table 1 shows the L^*, a^*, b^* color coordinates of these samples (under D65) measured with a spectrophotometer. The expanded uncertainties (k=2) of the measured L^*, a^*, b^* values were estimated to be 0.2, 0.1, 0.1, respectively, and of ΔE^*_{ab} to be 0.2. Figure 2 shows the spectral reflectance factor data of these samples. In Table 1 and Figure 2, the data of real human skins (Akizuki et al. 2013) and data of the paper color charts (for young female's skin color) used in our previous study are also included for comparison. The spectral reflectance factor curves of the skin model samples are closer to real skin data than the paper color charts at longer than 580 nm, but they still do not match sufficiently.



Young female Young male Elderly female Elderly male

Figure 1 – Urethane skin model samples. Each set is placed in the order of shocked (left), healthy (center), congested (right).

Table 1 – Color data of real human skin, urethane skin model samples and paper color chart measured with a spectrophotometer under CIE standard illuminant D65. ΔE*ab was calculated between real human skin and urethane skin model or paper color chart.

		Young Female			Young Male			Elderly Female			Elderly Male		
		Healthy	Shocked	Congested	Healthy	Shocked	Congested	Healthy	Shocked	Congested	Healthy	Shocked	Congested
Real Human Skin	L^*	65.2	68.3	61.9	60.5	62.6	57.8	60.8	63.8	59.0	55.8	59.6	54.5
	a^*	7.4	4.1	11.1	8.8	6.5	12.6	7.9	5.0	11.5	10.5	5.8	12.3
	b^*	17.8	19.2	19.1	17.8	21.3	19.9	16.9	20.1	18.4	18.9	21.4	18.2
Urethane Skin Model Sample	L^*	64.9	69.5	61.3	59.8	62.0	58.3	61.0	61.5	58.1	54.9	59.0	54.6
	a^*	8.9	10.0	10.2	10.9	8.2	11.8	8.3	8.1	8.9	14.2	8.0	13.6
	b^*	17.0	16.6	20.8	14.8	16.5	14.4	15.7	15.9	17.2	16.1	18.4	14.1
ΔE^*_{ab}		1.7	6.6	2.0	3.8	5.1	5.6	1.3	5.8	2.9	4.8	3.7	4.4
Paper Color Chart	L^*	60.2	70.7	60.2									
	a^*	7.5	4.5	11.9									
	b^*	15.8	18.6	18.2									
ΔE^*_{ab}		5.3	2.5	2.1									

These urethane skin model samples were used as evaluation targets in the experiments by using NIST STLF. The same set of light spectra on the NIST STLF used in the previous study (Akizuki and Ohno 2016) was used. These SPDs are shown in Figure 3. The three-band spectra (labeled 6500 K LED and 2700 K LED in the figure) are called "optimized LED lights" in this paper, and they were tuned as close as possible to the theoretical SPDs that were determined to produce the largest color differences in the real skin colors in the different circulatory dysfunction conditions, within the range of D_{uv} (distance from Planckian locus on CIE u', 2/3 v' coordinates, with + sign above, - sign below Planckian locus) for acceptable white light and color rendering for lighting (D_{uv} from -0.02 to 0.01). The broadband spectra (labeled 6500 K Daylight and 2700 K Incandescent in the figure) are called "reference lights" in this paper, and they were tuned close to Daylight illuminant D65 and incandescent light at 2700 K,

respectively, at varied D_{uv} levels. Note that the peak around 550 nm of the optimized LED lights is broad (though it should ideally be narrowband) because there are no narrowband high-power LEDs available around this wavelength and this peak is one of the green phosphor LEDs used in STLF.

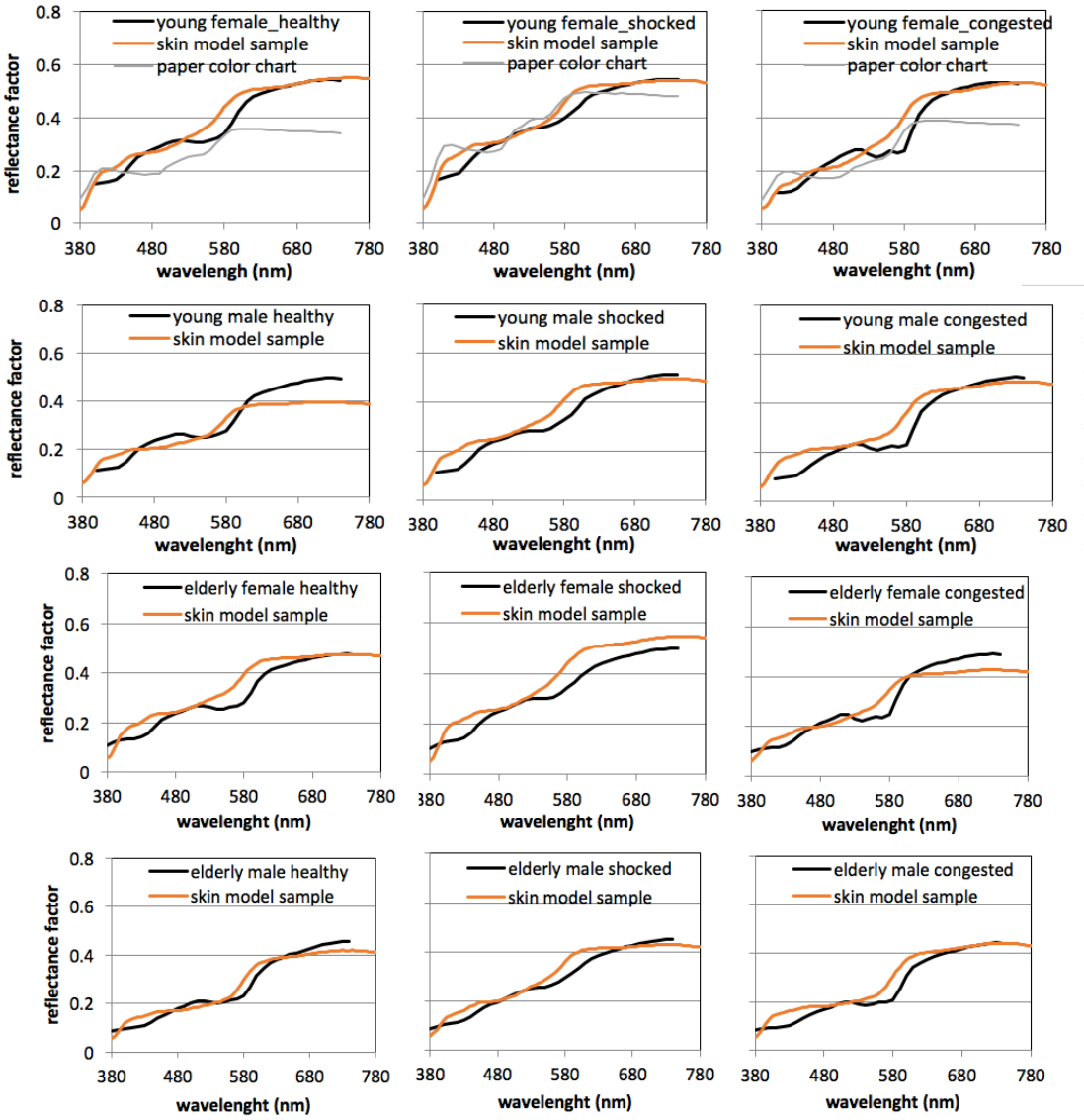


Figure 2 – Spectral reflectance factors of real human skin (Japanese), urethane skin model samples and paper color chart, for different gender and age groups.

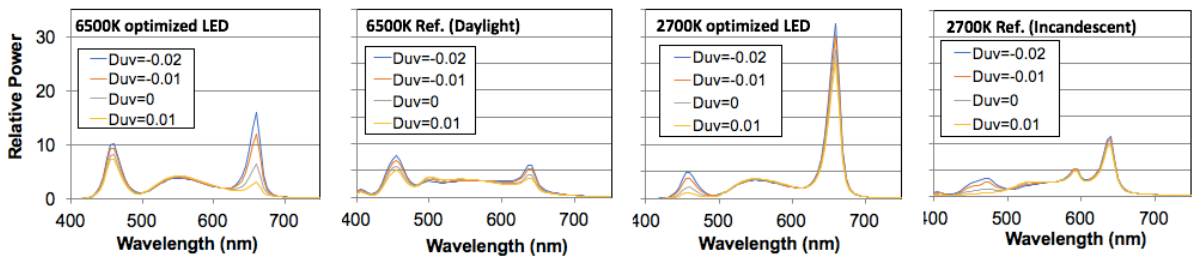


Figure 3 – Spectral power distributions of light sources used in the analysis

Figure 4 shows an example (for young female) of calculated color differences ΔE^*_{ab} between healthy and shocked conditions (written as "H-S" in the figure) or healthy and congested conditions ("H-C" in the figure), for real human skin, paper color charts and urethane skin model samples, under different SPD lighting conditions in Figure 3. Ideally, the curves for skin model

samples should be close to those for real skin. This example shows that the color difference is very large for paper chart H-S condition for all sources. The color differences for urethane sample H-S condition also have some shift from real skin, but shift is much smaller than the paper color chart. Other conditions (young male, elderly female, elderly male) showed similar range of variations of the curves. From these, we judge that urethane model samples are improved from the paper color chart (closer to real skin) in terms of relative color differences.

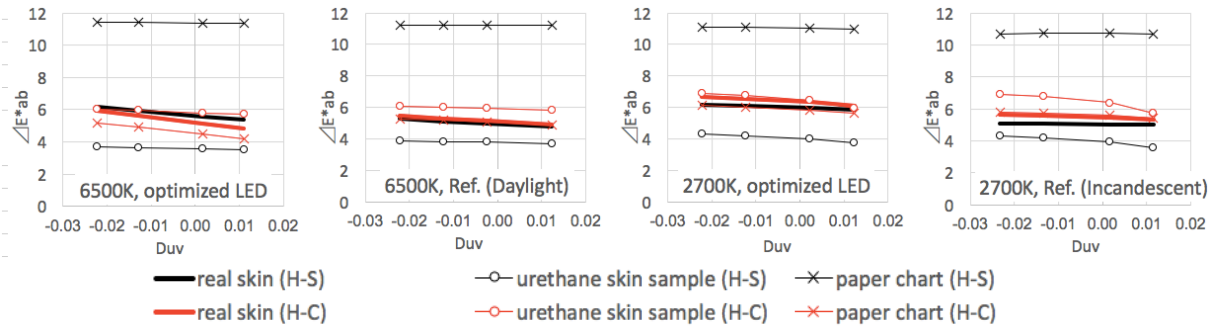


Figure 4 – Comparison of calculated color differences between healthy and shocked or congested conditions for young female's visual targets under light spectra in Figure 3.

Figure 5 (a) and (b) show calculated color differences between healthy and shocked or congested conditions, for each visual target (human real skin, urethane samples, paper samples) for each age and gender group, under the different types of SPD in Figure 3. "t-LED" and asterisk plots in Figure 5 indicates the theoretical LED by 3 narrow-band LED spectra (including 550 nm narrow peak) described in our previous paper (Akizuki and Ohno, 2016). For real human skin, as expected, the color differences under theoretical LEDs are largest in all cases. The optimized LEDs were designed using real available LEDs as used in NIST STLF to be close to the theoretical LEDs and to produce maximum color differences, therefore their results of color differences should be larger than the ones under the reference lights. This is clearly shown for real skins, but the differences for urethane samples are much smaller. Also, the optimized LEDs, in many cases, show color differences increasing when D_{uv} shifts to negative direction (toward -0.03). Some data of the urethane skin model samples and paper color charts show similar tendency, but other results show much smaller slopes of the curve. These results show that these developed urethane skin model samples need further improvements.

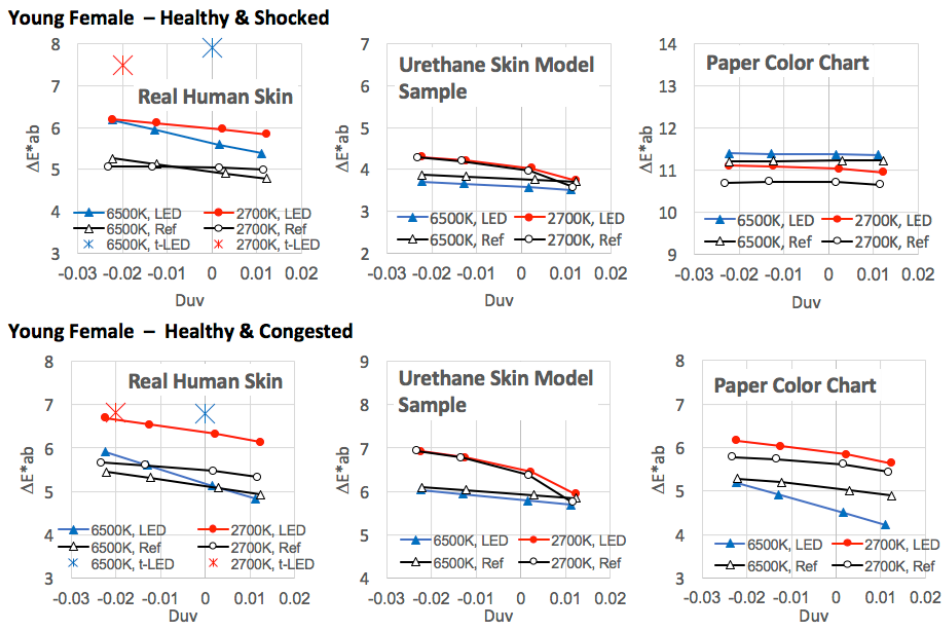


Figure 5 (a) – Calculated color differences between healthy and shocked or congested conditions, for young female, under different lighting spectra with varied D_{uv} in Figure 3 and the theoretical LED.

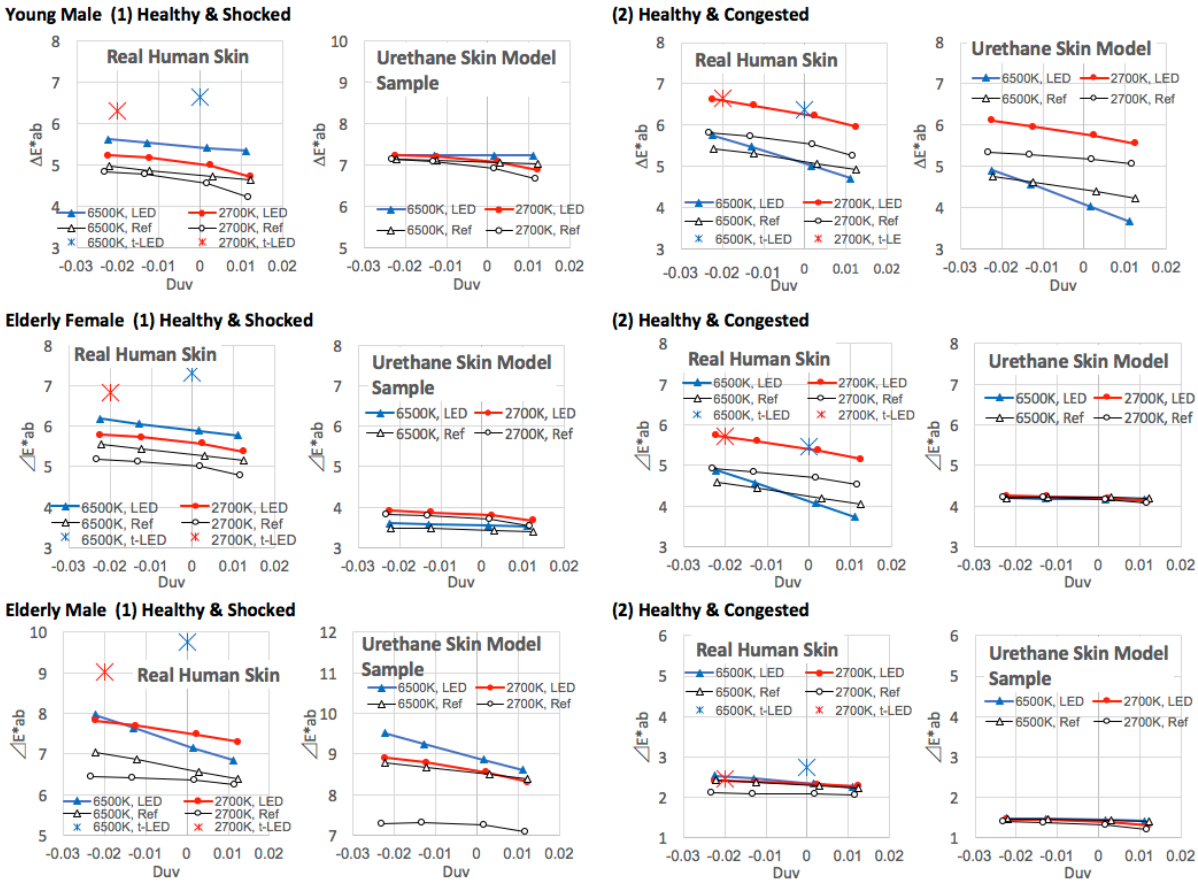


Figure 5 (b) – Calculated color differences between healthy and shocked or congested conditions, for young male and elderly female and male, under the lighting spectra with varied D_{uv} in Figure 3 and the theoretical LED.

3 Consideration of Experimental Methods for Evaluating Effective Light Sources

Although the developed urethane skin model samples need further improvements as mentioned in Section 2, these are better skin samples to simulate the circulatory dysfunction conditions than paper color charts and any other samples at this time. Therefore, we used these urethane skin model samples for consideration of the appropriate experimental methods for evaluating effective lighting spectra to distinguish the color differences of human skin under circulatory dysfunction conditions.

Two different experiments have been conducted for this purpose. Experiment-1 used the same procedures in the previous study (Akizuki and Ohno 2016), and its purpose was to judge the naturalness of lights at different D_{uv} levels, and the most effective levels of D_{uv} of the optimized LED lights for distinguishing skin model sample colors at different conditions. The optimized LED lights (three-band SPD) and reference lights (broadband SPD) on STLF shown in Figure 3 were used in the experiment. Experiment-2 directly compared naturalness and distinction of sample colors between the optimized LED lights and the reference lights and its purpose was to verify whether the optimized LED lights can distinguish different skin model sample colors better than the reference lights, at varied D_{uv} levels. In both experiments, the same D_{uv} values (from -0.02 to +0.01) and the same correlated color temperature (CCT) (2700 K and 6500 K) of the lights shown in Figure 3 were used.

3.1 Subject

The subject was one female with normal color vision in her 40s (first author). This subject was well acquainted with Experiment-1 in the previous study, and trained thoroughly. At both experiments, the subject sat on a couch placed at a room of STLF, which had a simulated interior room environment with a table, a bookshelf, and other objects. Pictures of the

experimental scene are shown in Figure 6. For facilitating the experimental operation easier by herself, the controller of STLF, the evaluation sheet, and visual targets were placed on the same table. In the experiments, the urethane skin model samples and the paper color charts were arranged side by side with three different circulatory dysfunction conditions (left-shocked, center-healthy, and right-congested) by each age and gender groups (see also Figure 1).

Figure 6 – Experimental scene

3.2 Procedure of Experiment-1

The procedure of Experimental-1 was the same as those used in the previous study (Akizuki and Ohno 2016), and the purpose was to examine naturalness of different D_{uv} lights for skin color as well as distinction of model skin samples under different D_{uv} levels.

The illuminance level on the center of the table in the STLF room was set to 200 lx and kept within ± 2.5 % during the course of experiment. At each combination of CCT and SPD, the subject was first adapted to the illumination at one end of D_{uv} (D_{uv}= 0.01 or -0.02) for five minutes in order to be adapted to the illumination completely. And then, a pair of lights, which had a D_{uv} level higher or lower than 0.005 from the adapted light (e.g., D_{uv}=0.015 and 0.005 for the adapted light at D_{uv} =0.01) was presented. The pair of lights was flipped at about three seconds interval and repeated several times, while the subject selected which light in the pair for the four questions listed below. The answers were forced choice, and if the judgement was difficult, she reported that also.

Q1: Which light presents the color of the back of her left hand more natural?

Q2: Which light presents the urethane skin model samples more natural?”

Q3: Which light presents the color differences of two combinations of the paper color charts (healthy and shocked, healthy and congested) larger?

Q4: Which light presents the color differences of two combinations of the urethane skin model samples (healthy and shocked, healthy and congested, for each group) larger?

Then, next D_{uv} was presented (e.g. D_{uv}=0) and the subject was adapted to the illumination for one minute, and the same trial with a pair of lights (D_{uv}=0.005 and -0.005 for adapted light at D_{uv}=0) was made. This was repeated for four adapted D_{uv} levels (0.01, 0, -0.01 and -0.02), which completed one run for each SPD type (6500 K optimized LED, 6500 K reference as daylight, 2700 K optimized LED, and 2700 K reference as incandescent). Then another run for the same condition was conducted in reverse order of D_{uv} (start from D_{uv}=-0,02 and ends at D_{uv}=0,01). These two runs (ascending order and descending order) were repeated for all SPD types.

3.3 Procedure of Experiment-2

The experiment-1 does not compare the distinction of colors of samples between the optimized LED lights and the reference lights. In Experiment-2, the subject compared the optimized LED lights directly with the reference lights for natural appearance of real skin and for distinction of colors of the model samples for different circulatory dysfunction conditions at different D_{uv} levels.

The purpose of Experiment-2 was to find the most effective D_{uv} conditions of the optimized LED lights than the reference lights,

The illuminance level on the table in the STLF room was set to 200 lx, too. After adaptation to the first reference light for five minutes, the optimized LED light and the reference light having the same D_{uv} and CCT were presented sequentially, and subject answered the four questions described in 3.2. If the judgement was difficult, she reported that also. Further, she answered the degree of naturalness or degree of distinction of the optimized LED light compared with reference light in five evaluation scales as shown below.

-2: definitely Light A, -1: rather Light A, 0: uncertain, 1: rather Light B, 2: definitely Light B

The D_{uv} value of the optimized LED and reference light were set to eight levels (-0.025, -0.02, -0.015, -0.01, -0.005, 0, 0.005, 0.01), and the subject was adapted to five minutes for the first light (D_{uv}= -0.025 or 0.01) and to each point afterwards for one minute before making judgment. The order of presentations of these D_{uv} levels were done in ascending and descending directions for each session as in Experiment-1.

3.4 Results of Experiment-1

Tables 2 and 3 show the raw results of Experment-1. In these tables, “ascending” means that the presented order of the D_{uv} condition was from -0.02 to 0.01 (upward in the table), and “descending” means from 0.01 to -0.02 (downward in the table). “Lower D_{uv}” means that the subject chose the light with lower D_{uv} value (chromaticity shift in pinkish direction from the adapted D_{uv} point) in the pair for the answer, and “higher D_{uv}” means that the subject chose the light with higher D_{uv} value (in yellowish direction). The asterisk mark (*) means that the subject had difficulty in judgement. Although the subject should make a binary choice “lower D_{uv}” or “higher D_{uv}” under difficult situation mandatorily, we considered the difficulty answer meant “uncertain” and did not treat the D_{uv} direction.

Table 2 shows the raw results of natural appearance (see 3.2 Q1 and Q2). The selected D_{uv} direction (lower or higher D_{uv}) tend to change from lower to higher in ascending direction, and from higher to lower D_{uv} in descending direction. The D_{uv} level where this cross-over occurs is considered to be most natural D_{uv} level (Ohno and Oh, 2016), and it is around D_{uv}=-0.005 for real skin color, and it is around D_{uv}=0 for urethane skin model samples, which is close to the results for real skin.

Table 2 – Row results of Experiment-1 on natural appearance.

(1) Natural-appearance of hand's skin color

	6500K LED		6500K Ref. (Daylight)		2700K LED		2700K Ref. (Incandescent)	
Duv	ascending	descending	ascending	descending	ascending	descending	ascending	descending
0.01	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv
0	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	**Higher Duv**	lower Duv	lower Duv
-0.01	*	lower Duv	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**
-0.02	**Higher Duv**	lower Duv	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**

(2) Natural-appearance of urethan skin model samples

	6500K LED		6500K Ref. (Daylight)		2700K LED		2700K Ref. (Incandescent)	
Duv	ascending	descending	ascending	descending	ascending	descending	ascending	descending
0.01	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	*
0	lower Duv	**Higher Duv**	**Higher Duv**	**Higher Duv**	lower Duv	*	*	*
-0.01	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	*	**Higher Duv**	**Higher Duv**	**Higher Duv**
-0.02	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	lower Duv	**Higher Duv**	**Higher Duv**	**Higher Duv**

Table 3 shows an example of raw results of distinction of urethane skin model samples for young female in different circulatory dysfunction conditions (see 3.2 Q3 and Q4). In Figure 5 presented in section 2, some graphs show larger falling slopes of the curves of color difference vs. $D_{uv.}$ while other graphs show fairly flat curves. If the slope is large, lights with lower D_{uv} produce larger color differences and “lower D_{uv}” should be chosen in this experiment. If the curve is flat, the judgement is difficult and “higher Duv” and “lower D_{uv}” answers should be mixed, and “difficult” answer should increase.

Table 3 – Example raw results of Experiment-1: distinction of colors of urethane skin model sample for young female

	6500K LED		6500K Ref. (Daylight)		2700K LED		2700K Ref. (Incandescent)	
Duv	ascending	descending	ascending	descending	ascending	descending	ascending	descending
0.01	lower Duv	lower Duv	*	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv
0	*	**Higher Duv**	lower Duv	**Higher Duv**	lower Duv	lower Duv	*	lower Duv
−0.01	lower Duv	lower Duv	**Higher Duv**	**Higher Duv**	lower Duv	*	lower Duv	lower Duv
−0.02	lower Duv	*	**Higher Duv**	**Higher Duv**	lower Duv	lower Duv	lower Duv	lower Duv

To check this consistency of subject evaluation, the frequency distribution of subject answers was calculated. Figure 7 shows the ratio of "lower D_{uv}" (black) and "uncertain (*)" (white) to the total number of answers (eight) for each condition. These results show that the subject evaluated the changes of color differences with D_{uv} correctly or not. If the slope of the curve in Figure 5 is large, the "lower Duv" ration should be high. If the slope of the curve in Figure 5 is flat, the "lower Duv" ratio should be low (less than 50 %) and ratio for uncertain" should be high. For example, many of the curves for 6500 K reference for urethane skin model samples in Figure 5 are nearly flat, which is consistent with the 6500 K reference results (white bar dominant) in Figure 7. Also, many of 2700 K LED in Figure 7 for urethane skin model samples show larger slopes of the curves, which is consistent with the 2700 K LED results (high black bars) in Figure 7. However, these results do not provide optimum Duv levels for distinction of color differences. There are also some cases where results are not consistent between calculation (Figure 5) and visual evaluation (Figure 7). Experiment-1 is considered to be useful to find suitable Duv levels for natural appearance of skin, but not for evaluating distinction of color differences of model samples.

3.5 Results of Experiment-2

Table 4 shows an example of raw results of Experiment-2. The upper part of each table (reference or LED) means that subject chose the reference light or the optimized LED as the answer. Asterisk mark (*) means that judgement was difficult. In the lower part of each table, the numbers (1, -1, etc.) show the evaluation value in the scale for degree of naturalness or distinction of the optimized LED light compared with the reference light in five evaluation scales (see 3.3). These results are consistent with the results in the upper part of the table (simple choice of which light) and showing more detailed information.

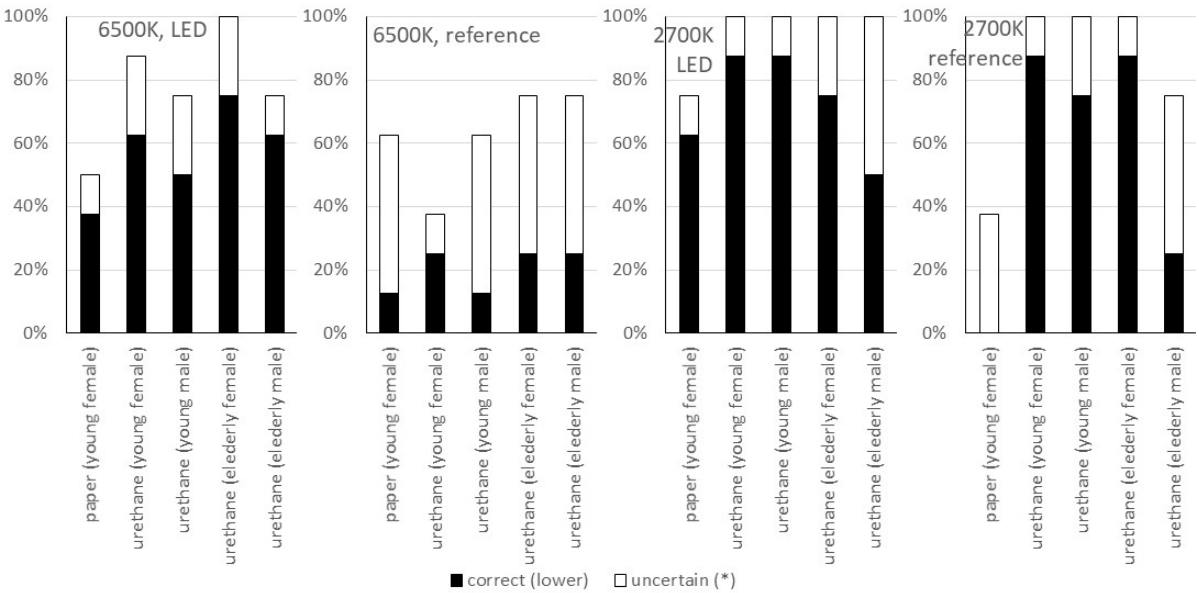


Figure 7 – Summary results about distinction evaluations of Experiment-1

Table 4 – Example raw results of Experiment-2 (naturalness of hand' skin color)

Duv		−0.025	−0.02	−0.015	−0.01	−0.005	0	0.005	0.01
6500K	ascending	reference	LED	reference	*	*	reference	reference	reference
	descending	reference	reference	reference	*	reference	reference	reference	reference
2700K	ascending	reference	reference	reference	reference	reference	reference	reference	reference
	descending	reference	reference	reference	reference	reference	reference	reference	reference

Duv		−0.025	−0.02	−0.015	−0.01	−0.005	0	0.005	0.01
6500K	ascending	−1	1	−1	0	0	−1	−2	−2
	descending	−2	−1	−1	0	−1	−1	−2	−2
2700K	ascending	−1	−2	−1	−2	−2	−2	−2	−2
	descending	−2	−2	−2	−2	−2	−2	−2	−1

Judging from the comparison between ascending order and descending order, it seems that Experiment-2 (the direct comparison of the optimized LED to reference) produced more stable results than Experiment-1 (the judgment of color differences of the samples between different D_{uv} levels).

Figure 8 (1) shows the plots of the degree of naturalness and Figure 8 (2) to (6) show distinction of the sample colors in the five number scales (as the example shown in the lower part of Table 4) for comparing the optimized LED light and the reference light at each D_{uv} level. The results of ascending and descending results were averaged in these plots. Q2 (naturalness of the model samples) was not included in Experiment-2 because Experiment-1 already showed that the results of urethane samples were close to the results of real skin, and it was also considered that judgement of naturalness of a piece of artificial sample in a scale would be difficult. In the case of natural appearance of real hand's skin color as shown in Figure 8 (1), the reference lights produced more natural appearance than the optimized LED lights at any D_{uv} levels. This may be due to the fact that the optimized LED lights have high chroma increase (in red-green direction) and skin color appears slightly more reddish than the reference light. This is considered as a trade-off point with increased color contrast with such chroma-enhanced sources.

In the case of distinction of paper color charts shown in Figure 8 (2), the optimized LED lights (both 6500 K and 2700 K) produced higher distinction than the reference. These results are mostly consistent with the calculation data in Figure 5, except 6500 K LED for healthy and congested, predicting opposite result. In this case, the healthy and shocked comparison shows consistent theoretical data. The results could have changed depending on which combination of samples the subject paid attention to when making judgment.

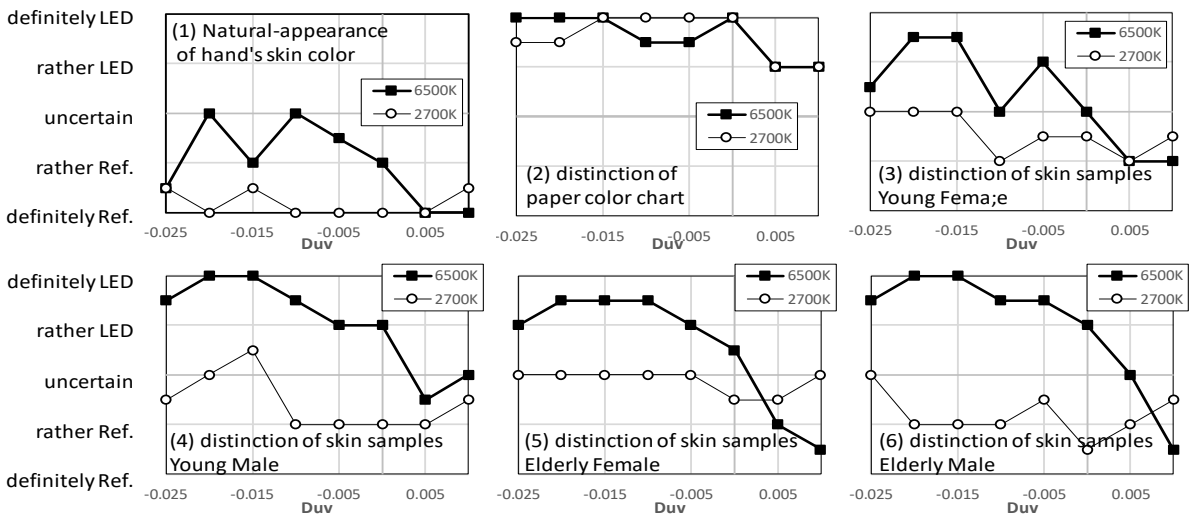


Figure 8– Summary results of Experiment-2

In the case of the distinction of urethane skin model samples shown in Figure 8 (3) to (6), the two CCT conditions had different tendency. For 6500 K, LED lights were chosen for higher distinction of samples, especially at negative Duv levels. For 2700 K, the results were less certain and reference lights were rather chosen for higher distinction. These results do not agree well with the results shown in Figure 5, where differences (between LED lights and reference lights) are very small in many cases, and 2700 K

LEDs rather show higher color differences (young male – healthy and congested, also elderly male – healthy and shocked) than 6500 K LED lights.

It should be noted that the results in Figure 5 show very different tendencies between the two graphs for each gender/age group, healthy and shocked, and healthy and congested, particularly in young male and elderly male. Depending on which two samples (shocked and healthy, or congested and healthy) the subject pay attention to, the results could be different. This is considered to be one of the reasons for inconsistent results. Also, judging from the data presented in Figure 5, the calculated color differences (between LED lights and reference lights) are very small in many cases and judgment must be very difficult.

4 Conclusion

Urethane skin model samples were developed to be possibly used for visual evaluation of light sources for distinction of circulatory dysfunction conditions of skin color. These are better skin model samples than the paper color charts. The samples are found useful for evaluation of naturalness of light sources. The spectral reflectance characteristics are found not sufficiently matched to real human skin for these conditions. However, the visual evaluation of distinction of color differences did not agree well with the calculation results. Therefore, skin model samples need to be improved for spectral reflectance curves matched closer to those of real human skin.

It is demonstrated that Experiment-2 provided more information on evaluation of the LED sources including comparison to the reference sources (it is not covered in Experiment-1), and found to be a useful evaluation method.

There were large variations of results in this experiment, so more refined experimental methods are needed, e.g., improved method of presenting visual target separately for shocked and healthy, and for congested and healthy conditions. In both experiments in this study, pair of lights (optimized LED and reference) were presented alternately in time sequence. Another experimental method to compare two lights simultaneously by haploscopic vision may further improve reproducibility of results.

Experiments were conducted only with one subject to evaluate experimental methods. Further experiments with a larger number of subjects are needed for evaluation of LED light sources for use in practical rescue sites.

For a longer term, it is also desired to have narrow-band green emission to make the theoretical LED to realize more effective light sources for distinguishing different circulatory dysfunction conditions of skin color.

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