STUDY ON SPECTRAL CHARACTERISTICS FOR IDENTIFICATION OF SKIN COLOUR OF INJURED JAPANESE PERSONS AT DISASTER SITES

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Abstract

In order to develop suitable light sources for disaster medical work, we first determined the skin colour and spectral reflectance of injured or sick persons under shocked or congested states. Using the NIST Color Quality Scale (CQS) simulation model, we theoretically determined appropriate spectral power distributions (SPD) of a light source which is effective in distinguishing colour differences among various skin states. Moreover, in order to evaluate the colour rendering, a subjective qualitative evaluation was conducted with lights of similar SPDs to the theoretical SPDs in the NIST Spectrally Tunable Lighting Facility.

Keywords: colour rendering, skin colour, disaster medical work, spectral characteristics

1 Introduction

There are many disasters in Japan every year. It is widely known that the critical response time for saving injured persons alive is within 72 hours, so the rescue and medical teams operate for entire days and nights. The limited performance of light sources used for rescue work makes it more difficult for rescue workers to observe situations, especially at night and in confined spaces. During relief efforts in confined spaces after earthquake disasters, it is important to diagnose injured persons as a case of crush syndrome or not, based on their skin colour.

Light emitting diode (LED) lights are increasingly used for such rescue work, but some medical relief workers are concerned that LED lights make it difficult to observe an injured person’s skin colour, as they have distinct spectral power distributions (SPD) dissimilar to incandescent or florescent lamps. In our previous research, we used a questionnaire to survey visual problems experienced by disaster relief workers. Many rescuers and medical staff members indicated that major problems of personal lighting equipment were due to the lack of luminous flux, narrow spatial distribution of light, and poor colour rendering (Akizuki et al. 2011). These results revealed that relief workers were well aware of those serious visual and lighting problems, as they work on the front line of disaster relief efforts.

In order to develop suitable light sources for disaster medical work, it is first necessary to determine the skin colour of injured or sick persons under shocked or congested states. Next, we need to determine appropriate SPDs for light sources, which are effective at distinguishing colour differences among various skin states. Our research goal is to create more effective lighting equipment and environments in disaster sites. In this paper, we propose a basic method of analysis to determine the spectral characteristics of light sources for the identification of injured or sick persons’ skin colour in a qualitative experiment.

2 Spectral Reflectance of Japanese Injured or Sick Persons’ Skin Colour

In the preceding research, we carried out an experiment for collecting skin’s spectral reflectance data under artificially-produced shocked or congested state of healthy subjects (Akizuki et al. 2013, 2016). The skin colour of critical patients in shock conditions changes widely over time. Therefore, we artificially produced the injured skin colour, which was the most prominent symptom of shock from distal ischemia in healthy subjects. The previous study is summarized below.

Subjects consisted of Japanese students at the University of Toyama: 22 young female subjects with an average age of 22 years old and 15 young male subjects with an average age of 20 years old. Moreover, registered members of the Toyama Silver Human Resources Center were recruited as additional experimental subjects: 15 elderly female subjects with average age of 69 years old and 15 elderly male subjects with an average age of 72 years old. Their blood pressure, heart rate, and the percentage saturation of oxygen were measured to check for health conditions before the experiments. All subjects wore a thin shirt with long sleeves during the experiments.

The experimental timetable is shown in Figure 1. Before each experimental session, a subject sat on a chair quietly for 60 s. Then, the subject put his or her hand on a table and the skin colour of the back of the hand between the first metacarpal and the second metacarpal was measured as the "healthy skin state" by a spectrophotometer. After the experiment started (*t*=0 s), the subject raised his or her upper arm, held it in that position for 90 s in order to reduce the flow of blood to peripheral portions, such as the hand. The upper arm was wrapped with a sphygmomanometer cuff (UM-101, AND). After 90 s of maintaining the position (*t*=90 s), the upper arm was brought to 200 mmHg pressure by the sphygmomanometer cuff, and the pressure was maintained for 60 s. Internal bleeding was not observed. After that (*t*=150 s), the subject slowly pulled his or her arm down on the table, and remained in that position for 60 s. Then (*t*=210 s), the skin colour of the same portion of the hand was measured as the "ischemia-shocked skin state" by the spectrophotometer. When a total of 240 s elapsed from the beginning of the experiment (t=240 s), the pressure of the sphygmomanometer cuff was reduced to 0 mmHg, and the skin colour of same part of the hand was measured as "the reperfusion-congested skin state" in 10 s intervals for 240 s. Both hands of a subject were measured on separate trails. At first, the right hand was measured for three skin states and then the left hand was measured. In this experiment, we measured spectral reflectance of three skin states: healthy skin, shocked skin, and congested skin. By using these spectral reflectance data, we calculated XYZ tristimulus values under the standard illuminant D65. We defined the spectral reflectance data which showed the lowest Y value between t=240 s to t=480 s as "the congested skin state" spectral reflectance. The time at which the skin exhibited this "the congested skin state" varied between individuals. Figure 2 shows the experimental setup.

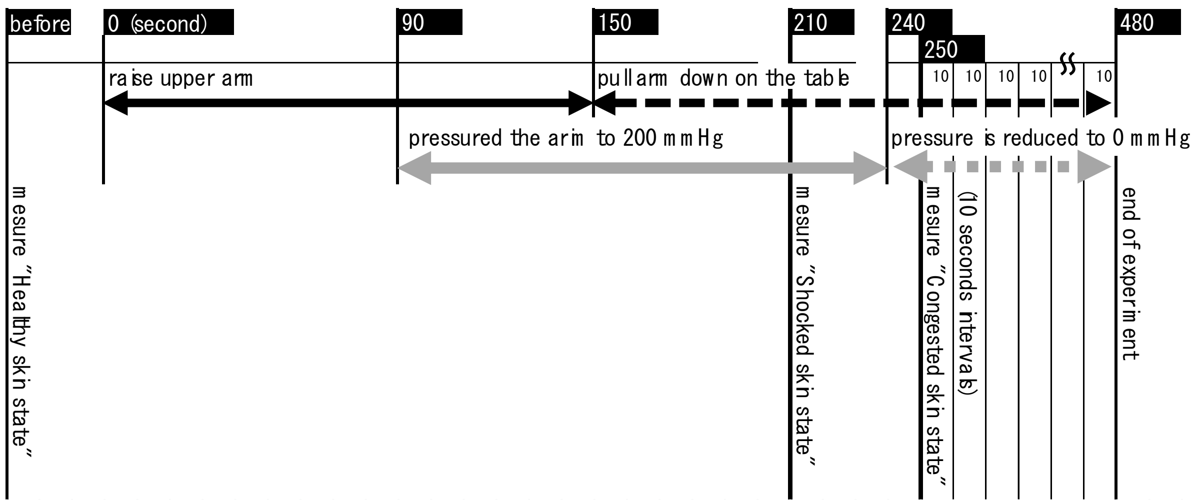


Figure 1 – Experimental Timetable for Measuring Injured Skin Colour

(1) Starting Position (2) Measurement Position (3) Skin Colour Example

Figure 2 – Experimental Setup

When compared with the healthy skin, the shocked skin tended to be more yellowish and to have higher lightness, and the congested skin tended to be more reddish and to have higher saturation and lower lightness. These tendencies were found in most subjects. Therefore the fundamental principle in the selection process for the skin colour database of this research was that the order of Y values was “Shocked state”>”Healthy state”>”Congested state”. If the order of Y values was not same as this general finding, the result was discarded. We collected more than 22 skin states’ data for each age and gender group.

Since the values of Munsell Colour System obtained by the spectrophotometer under the standard illuminant D65 were reported by the instrument as decimal numbers, we rounded these off to integer values. With consideration for parameters of the commercially available skin colour charts made by Japan Color Enterprise Co. Ltd., such as “the series of Skin Colour 75”[1], we set up the Munsell Hue 2,5 interval, Munsell Value 1.0 interval, and Munsell Chroma 1,0 interval for our skin colour chart of injured or sick Japanese persons. We categorized all the results by three skin states (healthy, shocked, and congested skin) and subject groups. Typical results are shown in Table 1. There were significant differences between age, gender and skin state groups ($p<0,05$).

Table 1 – Typical Skin Colour of Injured or Sick Japanese Persons according to Age and Gender (illuminated by standard light source D65)

	Healthy Skin		Shocked Skin		Congested Skin	
	Munsell	ratio	Munsell	ratio	Munsell	ratio
Young Female	7,5YR6/3	47% (≒17/36)	10YR7/3	53% (≒19/36)	5YR6/4	44% (≒14/32)
Young Male	7,5YR6/3	26% (≒ 6/23)	10YR6/4	52% (≒12/23)	5YR6/4	41% (≒ 9/22)
Elderly Female	7,5YR6/3	63% (≒17/27)	10YR6/3	57% (≒16/28)	5YR6/4	32% (≒ 9/28)
Elderly Male	5YR5/4	42% (≒10/24)	10YR6/3	33% (≒ 8/24)	5YR5/4	44% (≒10/23)

Next, we selected the typical subject spectral skin colour for each of the four subject groups. The results are shown in Figure 3. They had the same skin colour of Munsell values as Table 1. According to a typical result of the young female subjects in Figure 3 (upper left), the spectral reflectance of the shocked skin was whitened or higher than healthy skin, especially within the range from 500 nm to 600 nm. On the other hand, the spectral reflectance of the congested skin was lower than other skin states. There were significant differences of spectral reflectance between 500 nm to 600 nm in all groups.

[1] Specific firms and trade names are identified in this paper to specify the experimental procedure adequately. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

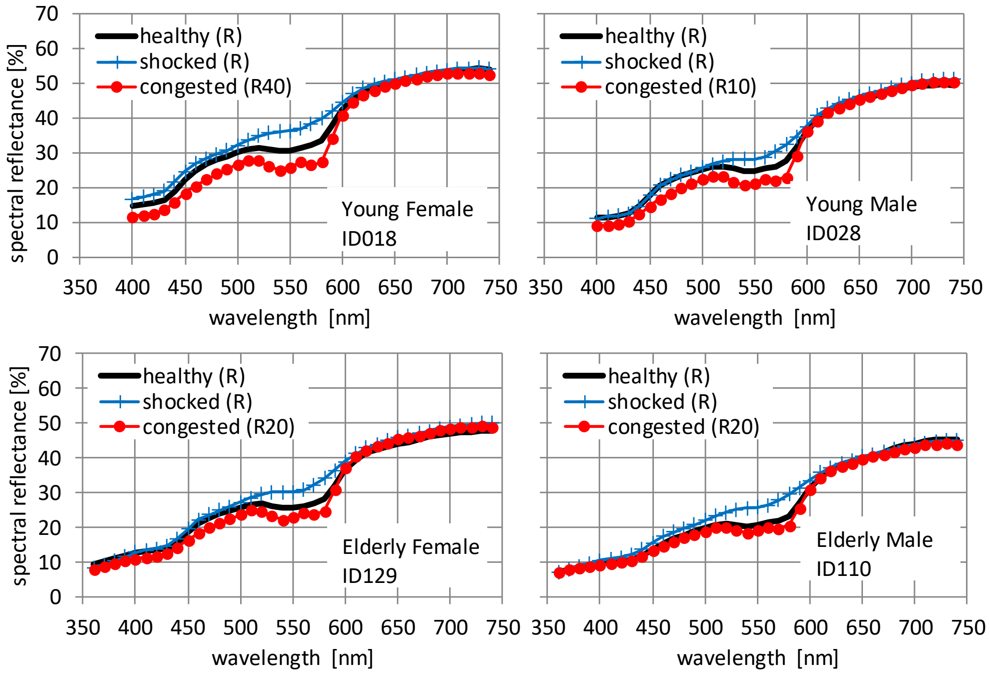


Figure 3 – Spectral Reflectance of Typical Subjects' Skin Colour

Unlike the real skin's spectral reflectance distribution, the commercially available skin colour charts made by Japan Color Enterprise Co. Ltd. has spectral reflectance distributions with lower reflectances than real skin colours at 600 nm and above, even with same tristimulus values (YXZ) (see Figure 4). Therefore we should use the real skin data of Figure 3, instead of the skin colour charts, in order to determine SPDs of light sources for identification of skin colour of injured or sick Japanese persons.

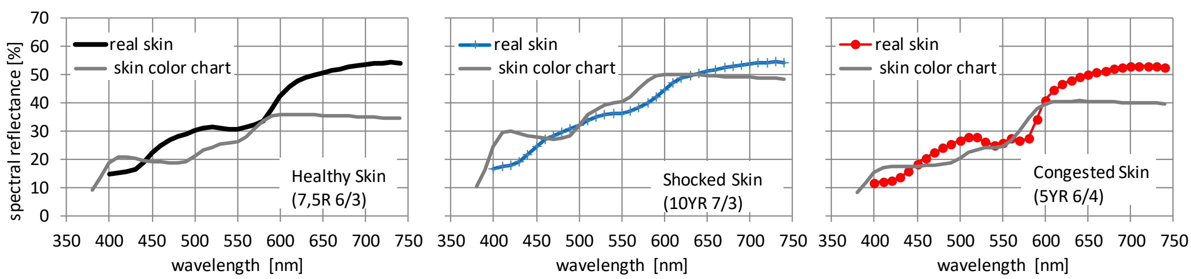


Figure 4 –Comparison of Spectral Refelctance Between Real Skin and Skin Colour Chart (Young Female Subject ID018)

3 Theoretical Spectral Power Distribution for Identification of Skin Colour

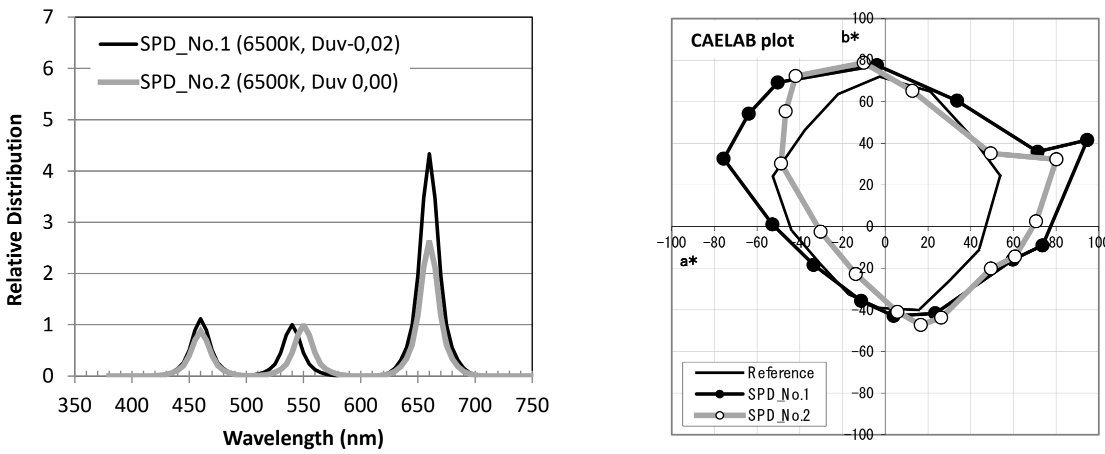
3.1 Simulation Procedures

In order to determine a theoretical ideal light source SPD, which produces the maximum colour difference ΔE^{*}_{ab} between the healthy skin and the shocked skin or congested skin, we used a spreadsheet program developed for Color Quality Scale (CQS) (Davis and Ohno 2010). This program provides calculation results of colour quantities, such as the CIE Colour Rendering Index (CRI) and the values of CQS for given light source SPDs. Moreover, this program can simulate a white LED SPD made of three-LED or four-LED chips. On both simulation models, with the minimization tool in the spreadsheet, we can determine various optimized LED SPDs just by entering the values of target correlated colour temperature (CCT), target (ANSI, 2015), the LEDs' peak wavelengths and spectral width (full width at half maximum), and so on.

In this research, we fixed the LEDs' spectral width at 20 nm. Target CCT was set at 6500 K and 2700 K. Colour differences were measured for LEDs' peak wavelengths at every 10 nm within the range from 450 nm to 660 nm and for Duv at every 0,01 within the range of -0,02 to +0,02. We used the real skin data shown in Figure 3 to calculate the colour difference ΔE^{*}_{ab} between the healthy skin and the shocked skin or the congested skin per person.

3.2 Results based on the White LED Simulation Model by three-LED chips

By using the white LED simulation model for three-LED chips, we determined the theoretical SPDs that produced the maximum ΔE^{*}_{ab} at a CCT of 6500 K. The results are shown in Figure 5, Table 2 and Table 3. The right image in Figure 5 shows a CIE 1976 *L*a*b** plot of colour rendering performance with the 15 saturated reflective samples in the Colour Quality Scale (CQS) (Davis and Ohno 2010). Table 2 shows two indices of the CIE Colour Rendering Index (average CRI R_a and strong red's CRI R_9), and three CQS scales (general colour quality scale Q_a, colour fidelity scale Q_f, and gamut area scale Q_g). The spectrum "SPD_No.1" produced the maximum colour difference ΔE^{*}_{ab} between the healthy skin and the shocked skin (ΔH-S) or the congested skin (ΔH-C) in most combinations. Compared with the reference illuminant (blackbody at the same CCT), "SPD_No.1" produced more than 1,42 times ΔE^{*}_{ab}, and the average ratio of "SPD_No.1" and the reflectance was 1,59. However the colour rendering results of "SPD_No.1" were very poor, especially CRI R_9. Therefore, we optimized the theoretical SPDs again, the results of which had better colour rendering (CRI R_a>50) and produced a larger ΔE^{*}_{ab} ("SPD_No.2"), except for young male subject's ΔH-S, whose colour differences ΔE^{*}_{ab} decreased slightly. However, the colour rendering was improved significantly.



(a) Spectrum with three-LED chips **(b) Appearance of the CQS samples**

Figure 5 – Theoretical SPDs that produced the maximum ΔE^{*}_{ab} (6500 K, 3-LED)

Table 2 – Theoretical SPDs' Characteristics (6500K, 3-LED)

	peak wevelength (width)	CCT	Duv	CRI_Ra	CRI_R9	CQS_Qa	CQS_Qf	CQS_Qg
SPD_No.1	460(20) 540(20) 660(20)	6500	−0,02	10	−425	27	27	157
SPD_No.2	460(20) 550(20) 660(20)	6500	0,00	53	−201	73	71	120

Table 3 – Skin Colour Differences ΔE^{*}_{ab} with Theoretical SPDs (6500K, 3-LED)

	Young Female		Young Male		Elderly Female		Elderly Male	
	ΔH-S	ΔH-C	ΔH-S	ΔH-C	ΔH-S	ΔH-C	ΔH-S	ΔH-C
SPD_No.1	8,55	8,69	6,49	8,16	7,51	7,30	10,86	3,26
SPD_No.2	7,91	6,80	6,64	6,38	7,31	5,46	9,74	2,75
Reference	4,78	5,08	4,67	5,10	5,30	4,22	6,57	2,30

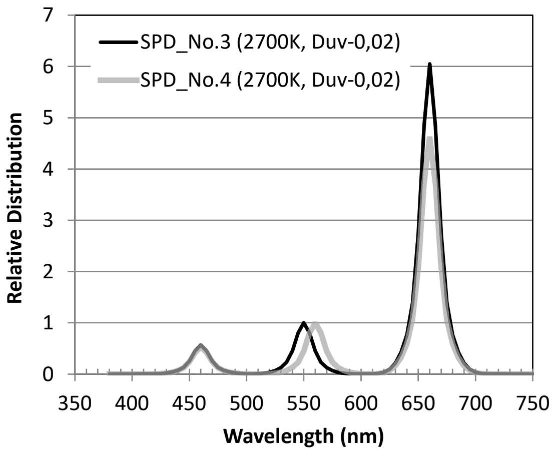
Next, we optimized the theoretical SPDs that produced the maximum ΔE^*_{ab} at a CCT of 2700 K. The results are shown in Figure 6, Table 4 and Table 5. Compared with the reference illuminant, “SPD_No.3” produced more than 1,26 times ΔE^*_{ab} and the average ratio of “SPD_No.3” and the reflectance was 1,40. However the CRI values of “SPD_No.3” was very poor. Therefore we optimized again, generating theoretical SPDs which had better colour rendering (CRI R_a>50) and produced larger ΔE^*_{ab} values (“SPD_No.4”), except for the ΔH-S of young male and elderly female subjects, whose colour differences ΔE^*_{ab} decreased slightly. However, the colour rendering was improved, especially CRI R_a and R_9.

Table 4 – Theoretical SPDs’ Illuminant Characteristics (2700K, 3-LED)

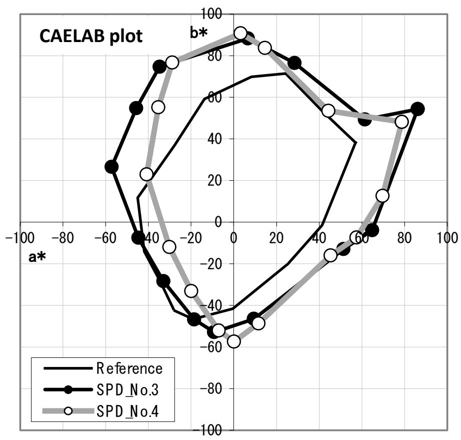
	peak wevelength (width)	CCT	Duv	CRI_Ra	CRI_R9	CQS_Qa	CQS_Qf	CQS_Qg
SPD_No.3	460(20) 550(20) 660(20)	2700	−0,02	19	−286	72	64	172
SPD_No.4	460(20) 560(20) 660(20)	2700	−0,02	54	−180	73	70	137

Table 5 – Skin Colour Differences ΔE*ab with Theoretical SPDs (2700K, 3-LED)

	Young Female		Young Male		Elderly Female		Elderly Male	
	ΔH-S	ΔH-C	ΔH-S	ΔH-C	ΔH-S	ΔH-C	ΔH-S	ΔH-C
SPD_No.3	7,93	7,83	6,05	7,55	6,80	6,63	9,57	2,63
SPD_No.4	7,49	6,82	6,29	6,64	6,83	5,71	9,03	2,44
Reference	5,02	5,48	4,57	5,53	5,06	4,72	6,42	2,09



(a) Spectrum with three-LED chips



(b) Appearance of the CQS samples

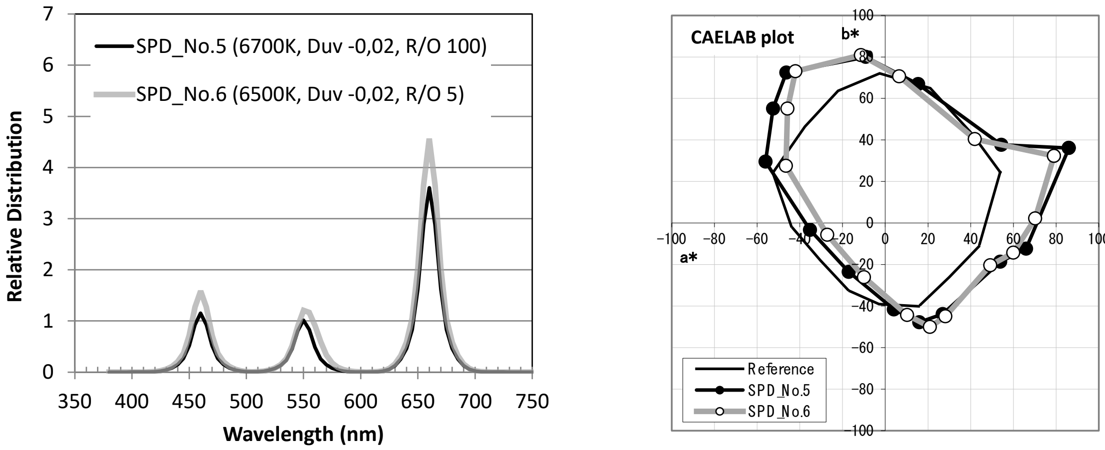
Figure 6 – Theoretical SPDs that produced the maximum ΔE*ab (2700 K, 3-LED)

3.3 Results based on the White LED Simulation Model by four-LED chips

Overall, the colour differences ΔE^*_{ab} at the CCT of 2700 K were lower than the ΔE^*_{ab} at the CCT of 6500 K. However, the colour rendering results at 2700 K were better than the ones at 6500 K. Moreover, it would appear that the spectral range between 540 nm to 560 nm might impact both the identification of injured or sick skin colour and the colour rendering.

Therefore, by using the white LED simulation model for four-LED chips, we optimized theoretical SPDs again, which produced the maximum ΔE^*_{ab} between healthy skin and shocked skin (ΔH-S) or congested skin (ΔH-C) at the CCT of 6500 K. For this simulation, we also had to set the spectral power ratio of the red LED to the orange LED (red to orange ratio). The results are shown in Figure 7, Table 6 and Table 7. Note that, in Figure 7, two LED peaks overlap and appear as three peaks. “SPD_No.5” produced the maximum colour difference ΔE*ab in this simulation. Compared with the reference illuminant, “SPD_No.5” produced more than 1,26 times

ΔE^*_{ab} and the average ratio of “SPD_No.5” and the reflectance is 1,46. Another theoretical SPD, which had better colour rendering (CRI R_a>50) and produced larger ΔE^*_{ab}, was derived (“SPD_No.6”). “SPD_No.6” produced the maximum ΔE^*_{ab}, while also having good colour rendering, of all theoretical SPDs generated.



(a) Spectrum with four-LED chips **(b) Appearance of the CQS samples**

Figure 7 – Theoretical SPDs that produced the maximum ΔE^*_{ab} (6500 K, 4-LED)

Table 6 – Theoretical SPDs’ Characteristics (6500K, 4-LED)

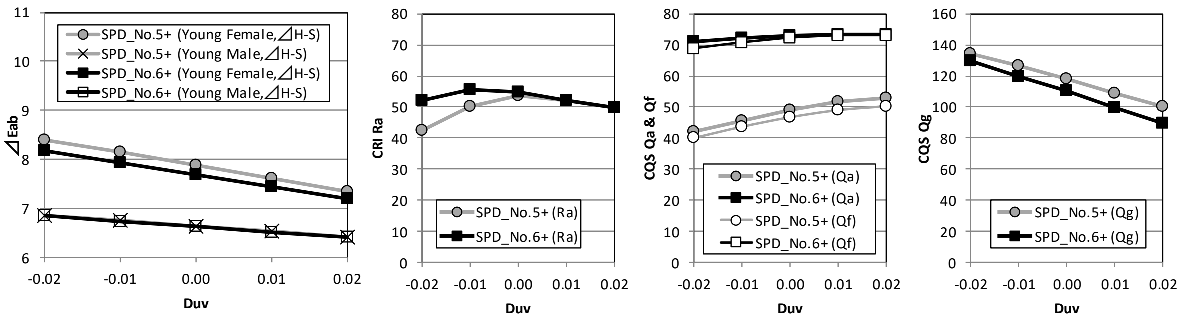
	peak wevelength (width)	R/O	CCT	Duv	CRI_Ra	CRI_R9	CQS_Qa	CQS_Qf	CQS_Qg
SPD_No.5	460 (20) 550 (20) 560 (20) 660 (20)	100	6500	-0,02	42	-306	70	66	141
SPD_No.6	460 (20) 550 (20) 560 (20) 660 (20)	10	6500	-0,02	52	-260	71	69	130

Table 7 – Skin Colour Differences ΔE^*_{ab} with Theoretical SPDs (6500K, 4-LED)

	Young Female		Young Male		Elderly Female		Elderly Male	
	ΔH-S	ΔH-C	ΔH-S	ΔH-C	ΔH-S	ΔH-C	ΔH-S	ΔH-C
SPD_No.5	8,41	7,32	6,84	6,87	7,59	5,98	10,34	2,89
SPD_No.6	8,18	6,91	6,84	6,49	7,52	5,60	10,05	2,80
Reference	4,78	5,08	4,67	5,10	5,30	4,22	6,57	2,30

3.4 Relationship among Colour Difference, Colour Rendering and Duv

The relationship among ΔE^*_{ab} between the healthy skin and the shocked skin (ΔH-S), Duv and colour rendering results are shown in Figure 8. The peak wavelength, spectral width and the red to orange ratio were not changed from the conditions of “SPD_No.5” and “SPD_No.6”, and only Duv values were changed for this simulation. Regardless of subject group, ΔE^*_{ab} decreased when Duv increased. The CQS results (Q_a, Q_f and Q_g) show a linear relationship with Duv. CRI R_a does not show a linear relationship with Duv, and the Duv value reaches a peak depending on the SPD. Future light source development for disaster medical works should take into consideration both the identification of diseased skin colour and the colour rendering of the surrounding environment. In any case, the results show the largest ΔE^*_{ab} at Duv=-0,02. While visual experimental data on Duv for general conditions are available (Ohno and Fein, 2014), the authors were concerned that such large shift in Duv with a very saturated color gamut may not appear natural for the surrounding environment, as well as for real skin colors. Thus, we conducted a preliminary visual evaluation experiment related to Duv shift, as reported in the next section.



(1) ΔE*ab of two subject groups (2) CRI Ra (3) CQS Qa & Qf (4) CQS Qg

Figure 8 – Relationship among ΔE^*_{ab}, Colour Rendering and Duv

4 Evaluative Experiment

To evaluate the acceptability of the Duv magnitude and perceived color quality of the theoretical SPD presented in the previous section, an attempt was made to simulate the SPD on NIST Spectral Tunable Lighting Facility (STLF), and visual evaluations on the interior room, skin tone, and the skin color charts, were conducted.

4.1 Experimental Procedures

The NIST STLF does not have efficient narrow-band green LEDs at a peak wavelength near 550 nm, as such LEDs are not available in the current market. Therefore, we could not reproduce the theoretical SPDs presented in the previous section. We produced spectra as closely as possible to the theoretical SPD using the STLF's 25 channels, and conducted visual evaluation experiments with one subject (the first author) with normal color vision. Since the spectra are not very close, this is a preliminary study for vision experiments in the future.

The NIST STLF consists of two illuminated rooms with off-white walls. The dimensions of each room are 2,5 m in width, 2,5 m in length, and 2,5 m in height. Both rooms have 25 channels of LED spectra with peaks from 450 nm to 650 nm. Spectral distribution, CCT, Duv and illuminance can be controlled independently. In this research, we used the right side room. The illuminant conditions are shown in Figure 9. The experiments were conducted with four SPDs and nine different Duv levels from Duv=-0,025 to Duv=0,015. The illumination characteristics (ΔE^*_{ab} between the healthy skin and the shocked skin (ΔH-S), and CRI Ra) are shown in Figure 10. All ΔE^*_{ab} values were lower than the theoretical SPDs in the preceding section. The illuminant "2700K LED" had the lowest colour rendering among the experimental illuminant conditions.

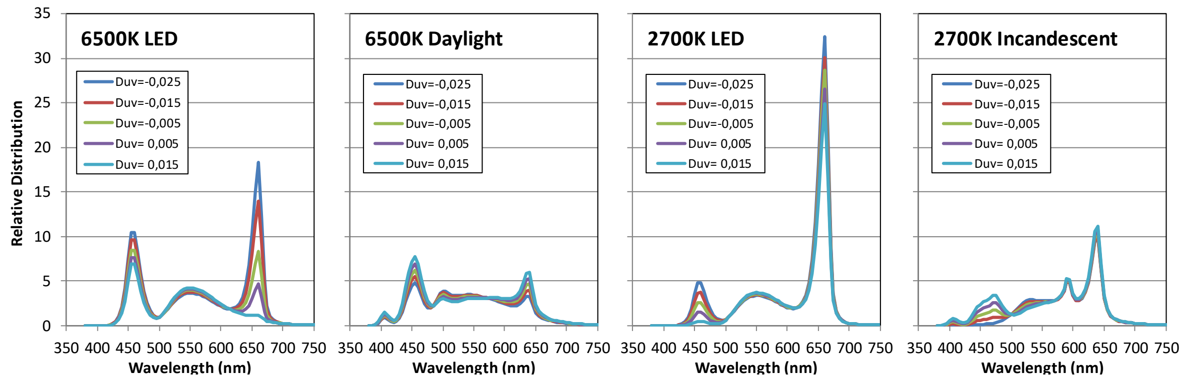
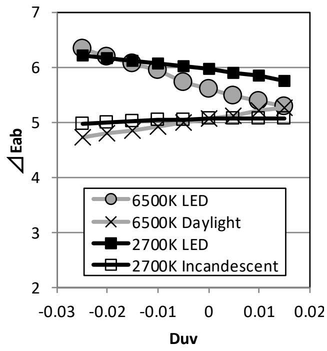
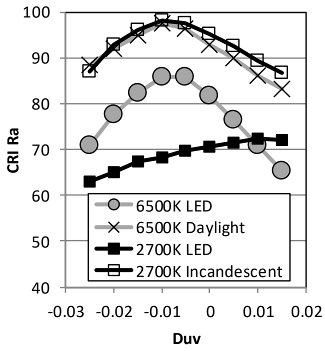


Figure 9 – Spectral Power Distributions in the Evaluative Experiments



(a) ΔE^*_{ab} of young female's H-C



(b) CRI R_a

Figure 10 – Illumination Characteristics

Figure 11 –Experimental Setup

The experimental setup is shown in Figure 11. This experimental procedures were similar to the previous research (Ohno and Fein 2014). The subject sat on a couch placed at the right side room of NIST STLF. The room has a simulated interior room environment with a table, a bookshelf with some books, artificial flowers, a mirror and two paintings in the room. Some artificial fruits and vegetables were on the table. The illuminance on the table was set to 200 lx. For each combination of CCT and SPD, the subject was first adapted to the illumination at one end of Duv (e.g., Duv=0,01) for five minutes in order to be adapted to the illumination completely. After adaptation, the subject was asked whether the lighting was acceptable or not. Then, a pair of lights, which had a Duv level higher or lower than 0,005 Duv (so in the case, Duv=0,015 and 0,005), was presented. The pair of lights was alternated three times, with each alternation accompanied by a sound from a computer. During the time, the subject was asked three questions; "Which light presents the whole interior more naturally?," "Which light presents your hand's skin colour more naturally?" and "Which light presents the skin colour charts (which had same Munsell values of young female in Table 1) more distinguishable?". Then, the next Duv was presented (e.g. Duv=0), the subject was adapted to the illumination for one minute, and another trial with a pair of lights (Duv=0,005 and -0,005) was made. This was repeated for four levels of adapting Duv (0.01, 0, -0,01 and -0,02), which completed one run of one combination of CCT and SPD. A similar run of the experiment was then conducted for the different combination of CCT and SPD. Then, another run with the first combination of CCT and SPD, but with the reverse order of Duv (start from Duv=-0,02 and ends at Duv=0,01) was conducted. A run for each Duv direction at each combination of CCT and SPD was repeated once. Therefore, there were two runs for each combination of CCT and SPD.

The results are shown in Table 8. In this table, "ascending" means that the presented order of Duv condition was from -0,02 to 0,01, and "descending" means that the order was from 0,01 to -0,02. "Lower Duv" means that the subject chose the lower Duv light (chromaticity shift in pinkish direction) in the pair as more natural, and "higher Duv" meant that the subject chose the higher Duv light (shift in yellowish direction) as more natural. The gray hatching illuminant condition means the subject had had much difficulty responding. “2700K LED” was not acceptable for any Duv. The subject felt that the whole interior was most natural when illuminated by light of around Duv=-0,015 for most lights. On the other hand, the subject felt that her hand’s skin colour was most natural when illuminated with light around Duv=-0,005, except for “2700K LED”. The results for the skin colour charts were similar to those for the whole interior, and different from those for subject’s real skin colour. This was possibly because the spectral reflectance of the skin chart does not accurately represent real skin (in Figure 4). “6500K LED” produced the maximum ΔE^*_{ab} with good colour rendering.

Table 8 –Raw Results for Subject

(1) Tolerance of the light

	6500K LED		6500K Daylight		2700K LED		2700K Incandescent	
Duv	ascending	descending	ascending	descending	ascending	descending	ascending	descending
0,01	not	**Accept**	**Accept**	**Accept**	not	not	not	not
0	**Accept**	**Accept**	**Accept**	**Accept**	not	not	**Accept**	**Accept**
-0,01	**Accept**	**Accept**	**Accept**	**Accept**	not	not	**Accept**	**Accept**
-0,02	not	**Accept**	not	not	not	not	**Accept**	**Accept**

(2) Natural-looking whole interior

	6500K LED		6500K Daylight		2700K LED		2700K 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	lower Duv	lower Duv	lower Duv
-0,01	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv
-0,02	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	lower Duv	lower Duv	**Higher Duv**	**Higher Duv**

(3) Natural-looking hand’s skin color

	6500K LED		6500K Daylight		2700K LED		2700K Incandescent	
Duv	ascending	descending	ascending	descending	ascending	descending	ascending	descending
0,01	lower Duv	lower Duv	lower Duv	lower Duv	**Higher Duv**	lower Duv	lower Duv	lower Duv
0	lower Duv	lower Duv	lower Duv	lower Duv	**Higher Duv**	**Higher Duv**	lower Duv	lower Duv
-0,01	**Higher Duv**	**Higher Duv**	lower Duv	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**
-0,02	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**	**Higher Duv**

(4) Identification of skin color charts

	6500K LED		6500K Daylight		2700K LED		2700K 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	0 (0)	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv
-0,01	lower Duv	**Higher Duv**	lower Duv	lower Duv	lower Duv	lower Duv	lower Duv	**Higher Duv**
-0,02	**Higher Duv**	**Higher Duv**	**Higher Duv**	lower Duv	**Higher Duv**	lower Duv	**Higher Duv**	**Higher Duv**

5 Conclusions

We theoretically determined the effective spectral characteristics for identification of skin colour of injured or sick Japanese persons. Highly realistic injured or skin colour samples, which have the same spectral characteristics as human real skin, are needed, as are quantitative subjective experiments, in order to obtain valid and universal results.

Theoretical LED SPDs increase the colour difference ΔE^*_{ab} between healthy skin and shocked skin or congested skin of typical subjects compared to reference light or actual LED light sources. Therefore, the development of narrow-band green LED emitters with peak wavelength around 550 to 560 nm is desired.

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