Discovery of global common denominators of skin reflectance that enhance attractive impressions -Paradigm shift in benefits of foundations to bring out individual beauty-

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Abstract

Background: In response to the global need to respect diverse individuality in terms of skin features, minds, and social attributes, desirable foundations have changed from those that simply conceal imperfections to those that bring out the beauty in individuality. Previous research with Japanese participants has shown that the spectral reflectance of skin is closely related to the impression that it creates. However, the relationship between impression and spectral reflectance has never been investigated for global skin tones. In this study, we aimed to comprehensively elucidate the relationship between skin spectral reflectance and impressions for the development of foundations that enhance attractive impressions envisioned by each individual.

Methods: We firstly classified global skin tones using a statistical method based on unique parameters derived from spectral reflectance. Secondly, we investigated the distinctive spectral reflectance patterns that can accentuate a specific impression in respective skin tone categories, using an observation room for precise control of participant's spectral reflectance closely matching the living environment.

Results: We found new global common denominators of three spectral reflectance patterns that enhance attractive impressions, and we identified the conditions for maximizing these impressions while maintaining the "natural-look" of each bare skin. We also discovered that foundations controlled to achieve these three spectral reflectance patterns had the same impression-enhancing effect as in the light source manipulation experiment.

Conclusion: We believe that these findings can create a paradigm shift in the benefits of foundations to enhance individual beauty by providing tailor-made products that match skin conditions and impression preferences.

Keywords: global skin tones; individual beauty; impression evaluation; spectral reflectance; foundations

1. Introduction

In response to the global need to respect diverse individuality in terms of skin features, minds and social attributes [1], the cosmetic industry is faced with the important challenge of bringing out individual beauty. Our recent survey (conducted during 2 weeks in 2021 with 3,000 participants worldwide) revealed how individuals want to express their inner personality or way of life through having a desired skin complexion, such as "Healthy (46%)", "Lively (35%)", and "Elegant (25%)" (The percentage is the response rate in the multi-answer). Previous studies interestingly have a relation with these needs, showing that the profile of reflected light from the skin is closely related to impressions evoked by a complexion [2]. For example, strengthening the reflection of blue colour from the skin was found to create an elegant impression in Japanese participants [3].

We have focused on optimizing "the colour balance of the reflected light from the skin" (hereafter, skin spectral reflectance) by applying foundations to achieve an individual's desirable impression. We have started the investigation of the relationship between skin spectral reflectance and impressions while adhering to three important requirements.

Requirement 1: The impression evaluation experiment must be carried out in a real indoor light environment, because people are known to have skin-specific colour perception and they are very sensitive to the surrounding conditions [4].
Requirement 2: The range of colour difference from a bare skin must be precisely controlled in order not to deviate from an individual's natural skin tone.
Requirement 3: A comprehensive study of an entire range of global skin tones is required in order to propose a variety of foundations that are inclusive of each individual.

Previous studies on skin spectral reflectance and impressions showed that enhanced reflectance of light in wavelengths of 600-700 nm made the skin even and favorable appearance [5], and reducing light in 500-600 nm made the skin a ruddy complexion [6]. However, these studies did not consider the environmental conditions for evaluating impressions (Requirement 1), nor adjusting the light to match the participant's natural skin tone (Requirement 2). In addition, participants were Japanese only and they did not include global skin tones (Requirement 3).

The most important of these to consider is the environmental conditions (Requirement 1), which have a critical influence on impressions. For example, if an impression evaluation is conducted in a dark room with spot lighting only on the face, the impression will appear excessively good and correct quantitative evaluation cannot be performed. Therefore, we have considered it necessary to create an evaluation room which is uniformly illuminated by diffused light from the ceiling so that there is no illuminance gap between a participant's face and the surrounding space.

The purpose of this study was to comprehensively clarify the relationship between skin spectral reflectance and impressions in a real indoor light environment in order to develop foundations that enhance the impression envisioned by each individual. To achieve this goal, we firstly classified global skin tones using a statistical method based on unique parameters derived from spectral reflectance. Secondly, we set up a Multi-Wavelength Observation Room equipped with 16 types of LED element light on the ceiling and a chin rest for fixing the face to keep the precise position, with surrounding reflectors to diffuse light uniformly throughout the room (Figure 1). The illuminance around the face was set at 150 lx, considering the illuminance in a real indoor light environment [7, 8]. This evaluation room enabled us to conduct precise impression evaluations, to reproduce a numerous combination of spectral reflectance patterns on a participant's face, and furthermore, to

control the colour difference from a participant's bare skin to keep a natural complexion. Using this Multi-Wavelength Observation Room, we could precisely and comprehensively investigate the relationship between skin spectral reflectance and impressions of all global skin tones. Thirdly, we developed foundations with the optimized balance of spectral reflectance, and evaluated their impression-enhancing effects.

Herein, we report on the key parameters for the classification of global skin tones based on skin spectral reflectance and the characteristics of each skin tone category. We also report on the spectral reflectance patterns that enhance a desirable impression in the respective skin tone categories, and the impression-enhancing effects of foundations that imitate these spectral reflectance patterns.

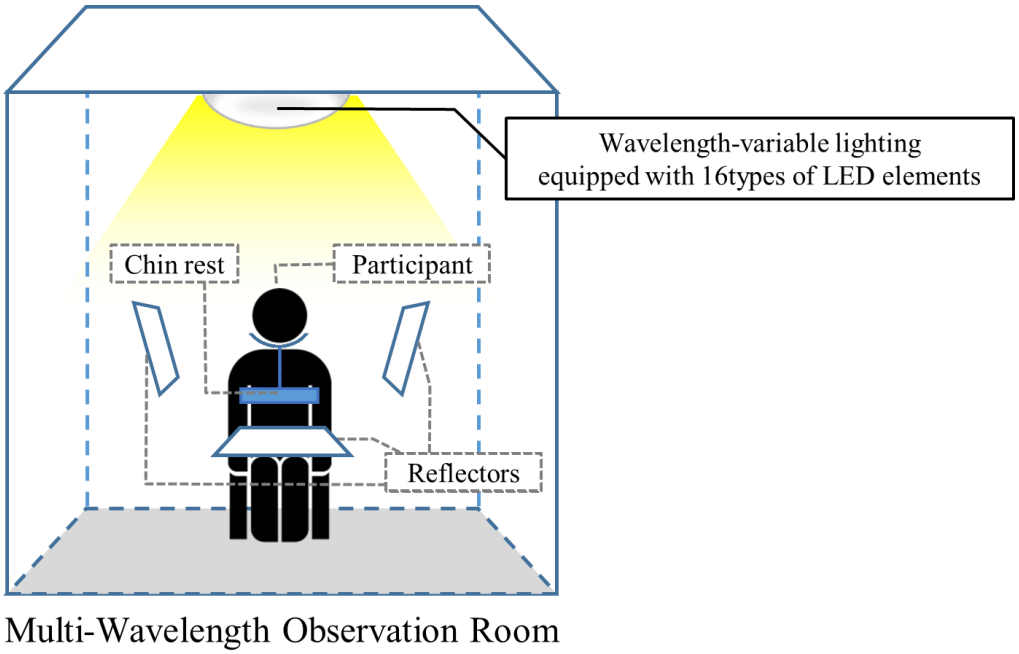

Figure 1. Appearance of the Multi-Wavelength Observation Room.

2. Materials and Methods

2-1. Global skin tone classification based on spectral reflectance

Spectral reflectance data (400-700 nm, 10 nm pitch) were obtained for a total of 698 people (exemplified as Japanese, Chinese, Thai, Indian, Caucasian, and African American) from Standard Object Colour Spectra Database (ISO/TR16066:2003). Using this dataset, we determined 37 categorical parameters, 9 based on colour index values and 28 based on spectral reflectance characteristics:

- Colour index: CIELAB colour space, Tristimulus value (X, Y, Z), RGB colour space (9 in total)
- Reflectance ratios of hemoglobin absorption peaks at 400-420 nm and 510-610 nm (11 in total)
- Area ratios for each wavelength region (17 in total)

These parameters were subjected to principal component analysis, and the principal component scores were used in a hierarchical clustering analysis (Ward method) to classify the data into 6 global skin tone categories, C1 to C6.

2-2. Impression evaluation test in the Multi-Wavelength Observation Room

Participants

In order to recruit participants for all six skin tone categories classified in 2-1, the spectral reflectance data from the forehead area of the participant candidates were obtained using a spectrophotometer (CM-700d, KONICA MINOLTA, INC.). Using a k-nearest neighbor algorithm, the participants were assigned to one of the six skin tone categories. A total of 44 participants from each skin tone category were selected for the impression evaluation test (Number of participants in each skin tone category are C1=7, C2=8, C3=8, C4=7, C5=8, and C6=6).

Impression terms

Impression evaluation terms were important to determine based on customer needs. We selected the impression terms from the product claims that had already been launched in the global market. From a survey in which 3,000 people were asked to choose desirable impressions, 6 impression terms were selected by more than 15% of the respondents, and these were then used for the impression evaluation test. The impression terms are shown in Table 1 with the definitions, which were also extracted from the customer perceptions in the survey.

Table 1. Impression terms and their definitions.

Impression terms	Definition
Elegant skin	The skin has a pink undertone and glow to it.
Clear skin	The skin has a glow and is without dullness.
Bright skin	The skin has a glow to it.
Warm skin	The skin has yellow, orange or red undertones.
Lively skin	The skin has a ruddy complexion and is bright.
Healthy skin	The skin has a ruddy complexion and is even.

Spectral reflectance patterns illuminating on a participant's face

In this experiment, the "STD", which mimics the spectra of the standard indoor LED lighting with a relative colour temperature of 5000 K, was used as the standard light [7, 8]. In terms of reducing the physical burden on the participants, it was necessary to select within 10 spectral reflectance patterns to be investigated from a numerous combination of 16 different LED elements. We selected 5 spectral reflectance patterns by the following procedure.

(1) We selected 7 LED elements with output peaks in the 400-700 nm.
(2) We conducted an impression evaluation test by 10 expert evaluators on participants C1 and C6 (n=1 for each) when the intensity of each LED element selected in (1) was increased respectively. 4 LED elements were selected from this preliminary test that were identified by five or more evaluators as being enhanced in any of the impression terms listed in Table 1.
(3) We conducted an impression evaluation test by 3 expert evaluators on participants C1 to C6 (n=1 for each) when illuminated with 15 spectral reflectance patterns, which were a total combination of the 4 LED element enhancement patterns selected in (2) (a single element and a combination of 2-4 elements). The impression terms shown in Table 1 were evaluated, and patterns that gave the same evaluation results were excluded to avoid duplication, and the remaining 5 patterns were finally selected (Table 2).
Figure 2 shows a conceptual diagram prepared for better understanding of the experimental

conditions, with simulated images of the representative spectral reflectance patterns illuminated to each participant of skin tone categories C1 and C6, generated by a colour simulation system of a spectroradiometer (Topcon Technohouse Corporation).

Table 2. The characteristics of 5 spectral reflectance patterns to be illuminated in the impression evaluation tests.

Spectral reflectance pattern	Intensified wavelength range	
	Peak (nm)	Range（nm）
Violet-UP	435	410-470
Blue-UP	455	430-490
Orange-UP	600	570-620
Red-UP	640	610-670
Blue and Red-UP	455 640	430-480 610-670

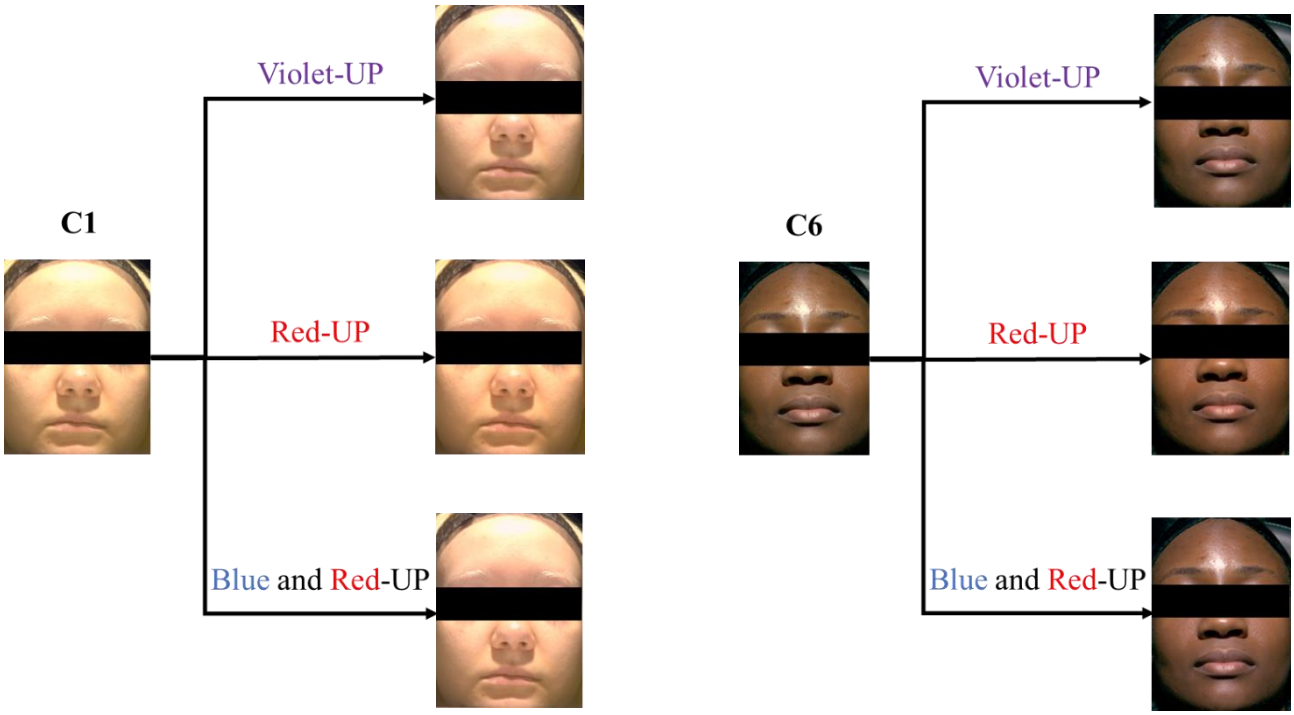

Figure 2. Conceptual diagram of the experimental conditions, with simulated images of the representative spectral reflectance patterns illumined to each participant.

For all of the spectral reflectance patterns, the intensity of each LED element was adjusted for each participant so that the difference of lightness value (CIELAB) was within 1.0 from the bare skin. This meant that the change in lightness of skin was eliminated from the impression evaluation. The colour difference from the bare skin (hereafter, ΔE) was determined by a preliminary survey of three representative participants from the six skin tone categories (18 in total). In this survey, the intensities of each spectral reflectance were changed by 5 steps from that of STD to find out the optimal ΔE range in order not to deviate from the individual's natural skin tone. We set the optimal ΔE range as 4.5 to 5.0 which produced a change in impression but did not generally deviate from the natural skin tones.

Impression Evaluation Method

Participants washed their face before the test and acclimatized for 15 minutes at 25°C temperature and 50% humidity, and entered the Multi-Wavelength Observation Room. Participants sat in a chair and placed their face on a chin rest for fixing the face, with a fixed 1.5 m distance between a participant and the evaluators. 10 expert evaluators scored the degree of change in the impressions compared to the impressions under STD illumination, for the previously mentioned 5 spectral reflectance patterns. The impression evaluation tests were conducted under conditions in which the evaluators were not informed which pattern was being illuminated and the order of illumination was randomized. A darkening period was inserted when changing to a light with a different spectral reflectance pattern. We ensured that the eyes were acclimated to a new light before the evaluation.

Each impression term was scored according to the following rules.
Score +3 : The impression was obviously enhanced compared to STD.
Score +2 : The impression was relatively enhanced compared to STD.
Score +1 : The impression was slightly enhanced compared to STD.
Score 0 : The impression was not different from STD.
Score -1 : The impression was slightly decreased compared to STD.
Score -2 : The impression was relatively decreased compared to STD.
Score -3 : The impression was obviously decreased compared to STD.

In each impression evaluation test, the expert evaluators confirmed that there was no deviation from the participants' natural skin tone. The evaluation score was eliminated from the analysis if more than 2 evaluators out of 10 pointed out unnaturalness due to a deviation.

Analysis of evaluation results

The mean values of impression evaluation scores for each spectral reflectance pattern were calculated. Since the Shapiro–Wilk tests indicated the scores for the impression evaluation test were not normally distributed, the Wilcoxon signed-rank test was indicated as a preferred test.

For easier understanding of the results, each mean value of the impression evaluation scores was listed according to the following abbreviations.

－: The mean value was less than -0.5
0: The mean value was -0.5 or higher, and less than 0.5
+: The mean value was 0.5 or higher, and less than 1.5
++: The mean value was 1.5 or higher
NR: The mean value was not rated due to a deviation from the participants' natural skin tone, with more than 2 evaluators pointed out a deviation.

2-3. Creation of a foundation with controlled spectral wavelengths and evaluation of its impression-enhancing effect

C2 and C6 (n=1 for each) were selected as representative participants from all six skin tone categories. 3 samples of liquid foundations with a different spectral reflectance pattern were prepared for each participant. In order to obtain knowledge that can be widely applied in the cosmetic industry, the commonly used pigments (titanium dioxide, iron oxide, Red 30, and Blue 1 Lake) were used to

formulate the liquid foundation. The colour difference (ΔE) between the foundation applied skin and the bare skin was set at 3 to 4.5. The impression evaluation test was conducted by applying these liquid foundations to the participant's face, comparing the impression with bare skin. The impression evaluation and analysis procedures were the same as previously described in 2-2, except for the impression scoring rules. Each impression term was scored according to the following rules.

Score +3 : The impression was obviously enhanced compared to bare skin.
Score +2 : The impression was relatively enhanced compared to bare skin.
Score +1 : The impression was slightly enhanced compared to bare skin.
Score 0 : The impression was not different from bare skin.
Score -1 : The impression was slightly decreased compared to bare skin.
Score -2 : The impression was relatively decreased compared to bare skin.
Score -3 : The impression was obviously decreased compared to bare skin.

3. Results and Discussion

3-1. Global skin tone classification based on skin spectral reflectance

The results of principal component analysis of 37 categorical parameters derived from the spectral reflectance database for a total of 698 people are shown in Table 3. The cumulative contribution ratio of principal components 1 through 3 (95.2%) indicated that these three principal components are sufficient for capturing global skin tone characteristics. Principal Component 1 was strongly associated with the lightness value and reflectance intensity in the entire visible light region (400-740 nm). Principal Component 2 was associated with the characteristics of red hemoglobin, such as a*-value (CIELAB) and the area ratio between 540 and 600 nm. Principal Component 3 was associated with the characteristics of melanin, such as the b*-value (CIELAB), the intensity ratio between 400 nm and 700 nm, and area ratio between 600 and 630 nm.

Table 3. Eigenvalues and cumulative contributions of each principal component, and factor loading matrix of Principal Component 1-3.

No.	Skin tone parameter	Principal Component		
		1	2	3
1	Approximate area total	0.989	0.010	0.143
2	Area 400-430 nm	0.979	0.060	-0.151
3	Area 460-490 nm	0.994	0.016	-0.030
4	Area 540-570 nm	0.965	-0.232	0.109
5	Area 570-600 nm	0.972	-0.161	0.165
6	Area 600-630 nm	0.969	0.073	0.232
7	Area 660-690 nm	0.921	0.144	0.353
8	L*	0.966	-0.109	0.221
9	Area ratio of 540-570 nm	0.391	-0.914	-0.008
10	Area ratio of 570-600 nm	0.107	-0.937	0.185
11	Intensity ratio of 610 nm	-0.526	0.803	0.240
12	a*	-0.382	0.846	0.308
13	Intensity difference of 700 nm and 400 nm	0.465	0.122	0.842
14	Area ratio of 600-630 nm	-0.376	0.458	0.712
15	b*	-0.443	-0.427	0.739
Eigenvalues [-]		25.7	5.5	4.0
% of variance		69.5	15.0	10.7
Cumulative %		69.5	84.5	95.2

Principal component scores for each data were plotted in three dimensions, with Principal Component 1, Principal Component 2, and Principal Component 3 as axes (Figure 3 left-upper). Using these principal component scores, a hierarchical clustering analysis was performed to classify the data into 6 categories from C1 to C6. The average reflectance value for each wavelength was calculated from the spectral reflectance data of each global skin tone category. The average spectral reflectance and representative skin tones for each skin tone category are shown in Figure 3. C1 is the highest lightness value, with a dent at 540-580 nm that is similar to the spectral reflectance of hemoglobin. C2 and C3 are the second highest lightness values. The difference between C2 and C3 is the reflectance ratio in the range 540-580 nm and 580-700 nm. C2 has a red undertone with relatively high reflectance in 580-700 nm while having a dent at 540-580 nm as in C1, while C3 has a yellow undertone with relatively high reflectance in the 540-580 nm. The lightness values decrease in the order of C4, C5 and C6. C4 has a relatively red undertone with the lower reflectance ratio in 400-580 nm compared to that of C3. C5 and C6 are characterized by a linear increase from 400-580 nm with a sharp increase after 580 nm.

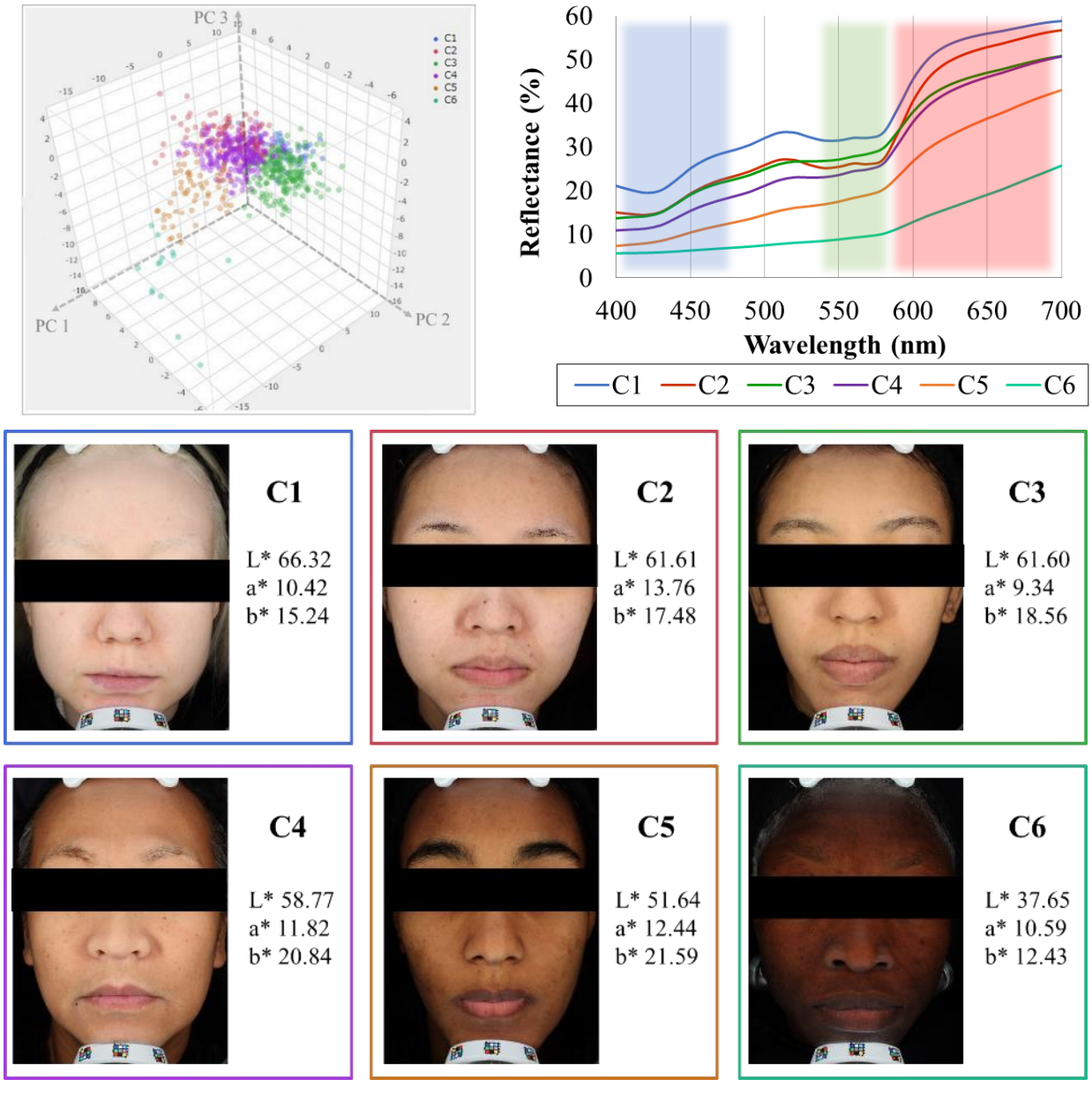

Figure 3. 3D plot of each principal component score with principal components 1-3 on the axes (upper-left); average spectral reflectance for each skin tone category (upper-right); and the representative skin tones for C1-C6 (bottom).

From these results, global skin tones could be classified and characterized based on the spectral reflectance. It is suggested that this classification method is suitable for comprehensively clarifying the relationship between skin spectral reflectance and impressions.

3-2. Impression evaluation test in the Multi-Wavelength Observation Room

Table 4 shows the result of the impression evaluation test with 5 spectral reflectance patterns. This result of the relationship between spectral reflectance patterns and impressions revealed for the first time that there were three types of spectral reflectance patterns that could enhance various impressions. Specifically, PATTERN 1 (Violet-UP or Blue-UP) resulted in significantly higher mean values of "Elegant skin", "Clear skin", and "Bright skin" impressions. Furthermore, PATTERN 2 (Orange-UP or Red-UP) resulted in significantly higher mean values for "Warm skin" impressions. Moreover, PATTERN 3 (Blue and Red-UP) resulted in significantly higher mean value for all impressions with particularly high means for "Lively skin" and "Healthy skin".

Table 4. The results of impression evaluation of 5 spectral reflectance patterns for global skin tone categories from C1 to C6.

—: The score was less than -0.5, 0: The score was -0.5 or higher, and less than 0.5
+: The score was 0.5 or higher, and less than 1.5, ++: The score was 1.5 or higher
NR: The score was not rated due to a deviation from the participants' natural skin tone.

Spectral reflectance pattern		Skin tone category	Impression terms					
			Elegant skin	Clear skin	Bright skin	Warm skin	Lively skin	Healthy skin
PATTERN 1	Violet-UP	C1	++	++	++	0	++	++
		C2	++	++	++	0	++	++
		C3	++	++	++	+	++	++
		C4	++	++	++	0	+	++
		C5	++	++	++	0	+	+
		C6	NR	NR	NR	NR	NR	NR
	Blue-UP	C1	++	++	++	0	+	+
		C2	++	++	++	0	++	+
		C3	++	++	++	0	+	+
		C4	++	++	++	0	+	+
		C5	++	++	++	0	+	+
		C6	+	++	++	0	0	0
PATTERN 2	Orange-UP	C1	—	—	—	++	+	+
		C2	—	—	—	++	+	+
		C3	0	—	—	++	+	+
		C4	—	—	—	++	+	+
		C5	0	—	—	++	+	+
		C6	0	—	0	++	+	+
	Red-UP	C1	0	—	0	++	++	++
		C2	NR	NR	NR	NR	NR	NR
		C3	0	0	0	++	++	++
		C4	NR	NR	NR	NR	NR	NR
		C5	0	0	—	++	++	++
		C6	NR	NR	NR	NR	NR	NR
PATTERN 3	Blue and Red-UP	C1	++	++	++	+	++	++
		C2	++	++	++	++	++	++
		C3	++	++	++	++	++	++
		C4	++	++	++	+	++	++
		C5	++	++	+	+	++	++
		C6	++	++	++	+	++	++

Surprisingly, the "apparent brightness" of PATTERN 1 was obviously higher than that of STD, even though the lightness value (CIELAB) was the same as STD. As previously described, people are known to have skin-specific colour perception [3], and it was assumed that the results of higher "apparent brightness" in Violet-UP and Blue-UP could be a new discovery of such perception. As a

result of this higher perception of brightness, the impressions of "Elegant skin", "Clear skin" and "Bright skin" were enhanced. Next, the reason for the higher mean values of "Warm skin" in PATTERN 2, was thought to be that the spectral reflectance approached that of hemoglobin with particularly high in the region 600-700 nm, resulting in a ruddy complexion. Furthermore, the reason for the higher mean values of all impressions in PATTERN3 was thought to be that the apparent brightness of skin was higher and the skin appeared a ruddy complexion. Among them, "Lively skin" and "Healthy skin" were especially enhanced, due to the synergistic effect of the higher perception of brightness and ruddy complexion.

As a result, we discovered the global common denominators of the following three spectral reflectance patterns that could enhance attractive impressions.

PATTERN 1 (Violet-UP or Blue-UP): Enhanced impression of "Elegant skin", "Clear skin" and "Bright skin".
PATTERN 2 (Orange-UP or Red-UP): Enhanced impression of "Warm skin".
PATTERN 3 (Blue and Red-UP): Enhanced impression of all, especially "Lively skin" and "Healthy skin".

Next, the optimal conditions that maximize the mean values of impressions for each skin tone category are shown in Table 5. The maximum mean value of each impression was higher than +1.7 compared to STD for each skin tone category. "Elegant skin" had the highest mean values in Violet-UP for C1 to C5. "Elegant skin" also had the highest mean values in Blue and Red-UP for C4 to C6. "Clear skin" and "Bright skin" were the highest mean values in Violet-UP for C1 to C5. "Clear skin" also had the highest mean values in Blue-UP for C1 and C6, while "Bright skin" also had the highest mean values in Blue-UP for C6. Furthermore, "Warm skin" had the highest mean values in Red-UP for C1, C3, and C5, and the highest mean values in Orange-UP for C2, C4, and C6. Finally, "Lively skin" and "Healthy skin" had the highest mean values in Blue and Red-UP for all skin categories. "Healthy-looking" was also maximized in Red-UP in skin tone categories C1 and C3 whose reflectance in the red region (630-700 nm) is low relative to the whole spectral reflectance.

Table 5. Spectral reflectance patterns that maximize the mean value of impression evaluation score for each skin tone category and impression.

Skin tone category		Elegant skin	Clear skin	Bright skin	Warm skin	Lively skin	Healthy skin
C1	Pattern	Violet-UP	Violet-UP Blue-UP	Violet-UP	Red-UP	Blue and Red-UP	Blue and Red-UP Red-UP
	Score	+2.3	+2.4	+2.4	+2.6	+2.1	+2.1
C2	Pattern	Violet-UP	Violet-UP	Violet-UP	Orange-UP	Blue and Red-UP	Blue and Red-UP
	Score	+2.1	+2.3	+2.2	+2.2	+2.1	+2.1
C3	Pattern	Violet-UP	Violet-UP	Violet-UP	Red-UP	Blue and Red-UP	Blue and Red-UP Red-UP
	Score	+2.2	+2.5	+2.3	+2.5	+2.0	+1.9
C4	Pattern	Blue and Red-UP Violet-UP	Violet-UP	Violet-UP	Orange-UP	Blue and Red-UP	Blue and Red-UP
	Score	+1.9	+2.2	+2.2	+1.9	+1.9	+1.9
C5	Pattern	Blue and Red-UP Violet-UP	Violet-UP	Violet-UP	Red-UP	Blue and Red-UP	Blue and Red-UP
	Score	+2.0	+2.4	+2.2	+2.6	+2.1	+2.1
C6	Pattern	Blue and Red-UP	Blue-UP	Blue-UP	Orange-UP	Blue and Red-UP	Blue and Red-UP
	Score	+1.7	+1.9	+2.1	+2.0	+2.0	+1.7

Through this research, we succeeded in comprehensively clarifying the optimal conditions that maximize various impressions in each skin tone category, while maintaining their natural skin tones. We also quantitatively demonstrated that the impression-enhancing effect was sufficient to express the impression envisioned by each individual, by showing that there was a significant improvement in the mean values from +1.7 to +2.6. This knowledge enables us to create a custom-made foundation that achieves an individual's desirable impression by following the development process.

(1) Interview a consumer for a desirable impression and attribute the impressions to PATTERN 1 to 3. Measure the spectral reflectance of bare skin.
(2) Simulate the target spectral reflectance based on the optimal conditions shown in Table 5.
(3) The type and amount of pigments formulated in the foundation are determined by performing a fitting calculation to the target spectral reflectance using a data of spectral reflectance of each pigment, while considering the spectral reflectance of bare skin and the thickness of the foundation layer.
(4) Based on the pigment formula determined in (3), a custom-made foundation is created for each individual.

3-3. Impression-enhancing effect of a foundation that controls spectral reflectance pattern

As the representative participants in all skin tone categories, C2 and C6 participants were recruited. The spectral reflectance of each participant's bare skin and foundation applied skin is shown in Figure 4. When PATTERN 1 foundations (Violet-UP and Blue-UP) were applied, the spectral reflectance of each participant was relatively high at 420-480 nm compared to the bare skin. With application of PATTERN 2 foundations (Orange-UP and Red-UP), the spectral reflectance of C2 and C6 at 570-660 nm were found to be increased. When PATTERN 3 foundations (Blue and Red-UP) were applied to each participant, both 420-480 nm and 570-660 nm regions were relatively high compared to the bare skin.

Table 6 shows the results of the impression evaluation test with the application of the developed foundations, compared to those obtained in Table 4 with the Multi-Wavelength Observation Room. When the PATTERN 1 foundations (Violet-UP and Blue-UP) were applied, the mean values for "Elegant skin", "Clear skin", and "Bright skin" were higher compared to the bare skin for each participant. With the application of the PATTERN 2 foundations (Orange-UP and Red-UP), the mean values for "Warm skin" were higher both in C2 and C6. In addition, mean values for all impressions were found to be higher for PATTERN 3 foundations (Blue and Red-UP), with particularly higher values of "Lively skin" and "Healthy skin" for C6.

These results have shown that each impression was successfully enhanced by applying the foundations developed based on our knowledge of the comprehensive relationship between skin spectral reflectance and impressions.

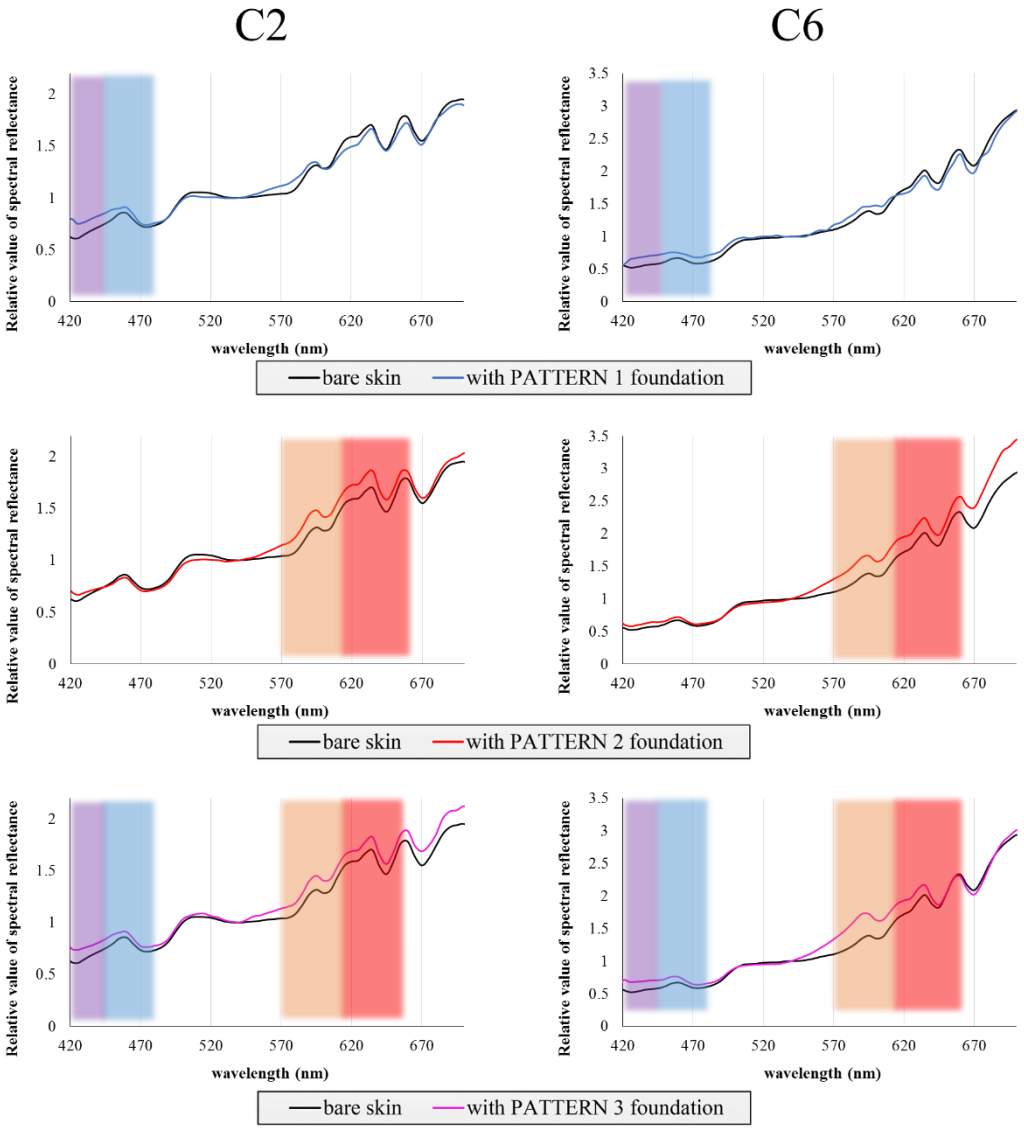

Figure 4. The spectral reflectance of C2 (left row) and C6 (right row) with the foundation developed for each participant. These charts show the intensity at 540 nm set to 1 in order to compare the relative difference in intensity at each wavelength.

Table 6. The results of impression evaluation test of foundation application (left) and those with the Multi-Wavelength Observation Room (right).

Foundation

Skin tone category	FD type	Impression terms					
		Elegant skin	Clear skin	Bright skin	Warm skin	Lively skin	Healthy skin
C2	PATTERN1 (Violet-UP, Blue-UP)	+	++	+	—	0	0
	PATTERN2 (Orange-UP, Red-UP)	+	0	0	++	+	++
	PATTERN3 (Blue and Red-UP)	++	++	++	+	+	+
C6	PATTERN1 (Violet-UP, Blue-UP)	+	+	++	0	0	0
	PATTERN2 (Orange-UP, Red-UP)	0	0	0	++	+	++
	PATTERN3 (Blue and Red-UP)	++	+	+	+	++	++

Multi-Wavelength Observation Room

Skin tone category	Spectral reflectance patterns	Impression terms					
		Elegant skin	Clear skin	Bright skin	Warm skin	Lively skin	Healthy skin
C2	PATTERN1 (Blue-UP)	++	++	++	0	+	+
	PATTERN2 (Orange-UP)	—	—	—	++	+	+
	PATTERN3 (Blue and Red-UP)	++	++	++	++	++	++
C6	PATTERN1 (Blue-UP)	+	++	++	0	0	0
	PATTERN2 (Orange-UP)	0	—	0	++	+	+
	PATTERN3 (Blue and Red-UP)	++	++	++	+	++	++

When the developed foundations were applied, the C2 participant commented that "I feel my skin looks bright when applying PATTERN 1 foundation (Violet-UP and Blue-UP), while the skin looks healthy with a ruddy complexion when applying PATTERN 2 foundation (Orange-UP and Red-UP). I particularly like PATTERN 3 foundation (Blue and Red-UP) the best for looking both bright and healthy". The C6 participant also commented that "When I apply PATTERN 3 foundation (Blue and Red-UP), I feel my skin has the proper brightness and warmth, but I like PATTERN 2 foundation (Orange-UP and Red-UP) the best because it gives a warm impression". Both participants were very satisfied that these three types of foundations could give a variety of impressions, and had the potential to expand the range of expression of their individual beauty.

We successfully concluded our study that by creating a foundation based on our novel knowledge of the comprehensive relationship between skin spectral reflectance and impressions, the desirable impression envisioned by each individual could be achieved while making the most of the natural skin tone. This discovery is bound to bring a paradigm shift in the benefits of foundations, as a valuable method to bring out individual beauty.

4. Conclusion

In this study, our investigations led to a new discovery of the global common denominators of three spectral reflectance patterns that can enhance an individual’s attractive impression. We also succeeded in comprehensively clarifying the optimal conditions of the spectral reflectance patterns that maximize various impressions in each skin tone category, while maintaining their natural skin tones. Furthermore, each desirable impression was successfully enhanced by applying the foundations developed based on our knowledge of the comprehensive relationship between skin spectral reflectance and impressions.

We successfully concluded our study that by creating a foundation based on our novel knowledge, the desirable impression envisioned by each individual could be achieved while making the most of the natural skin tone. This discovery is bound to bring a paradigm shift in the benefits of foundation to bring out individual beauty, by offering custom-made products that are tailored to the skin conditions and desirable impression. Furthermore, our study can serve as an important knowledge not only for make-up products but also in various beauty industries, such as skincare, online counselling, and residential lighting that contribute to beauty in individuality. We believe our knowledge will encourage people around the world to express their individuality more proactively and respect diversity.

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6. Conflict of Interest Statement

NONE

7. References

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