# Characterisation of skin spectra in a Caucasian and Oriental sample

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## Abstract

*Accurate spectral measurements of facial skin are important for numerous medical applications including the diagnosis and treatment of cutaneous disorders and the provision of maxillofacial soft tissue prostheses. In this study we obtained calibrated facial and body skin spectra (forehead, cheek, neck) from two ethnic groups (Caucasian and Oriental) with a view of establishing a new skin spectral database for medical and cosmetic applications. Skin spectra for 188 subjects were measured using a Tele-spectroradiometer (PR650) in a large viewing booth with controlled lighting. The grand mean of skin spectra for Caucasians and Oriental females were calculated and their spectral difference between different ethnic groups and body areas were assessed. Our main findings are: (1) The shape of the skin spectra reflectance functions is similar for both ethnic groups, but differs across body locations. (2) Spectral variation (expressed as RMSE) between different body areas is significantly larger in the Oriental compared to the Caucasian sample (by a factor of ~2). (3) Largest ethnic differences occur in the neck area, and the smallest in the cheek.*

## Introduction

Accurate skin colour measurements and databases are important for numerous technological and medical applications [1,2]. In medical imaging, multispectral imaging technology is often used to obtain spectral skin data since spectral information of human skin can be related to chromophores such as melanin and hemoglobin; concentrations of these chromophores vary for different ethnicities and are useful diagnostic indicators for skin diseases [3]. An accurate characterization of the spectral skin properties of different ethnicities and different facial locations is a prerequisite for these medical imaging applications [4].

The purpose of this study is to provide the ground truth for spectral skin data and to characterize the spectral variations within and across different ethnicities (Oriental, Caucasian) and different facial locations (forehead, neck, cheek). The measurements are obtained while adhering to a standardized measurement protocol to ensure that the measurements are commensurate.

## Methodology

### Skin measurement and database

A TSR (Photo Research SpectraScan PR650) was used to measure spectral power distribution of the facial skin and a white diffusor, so that the skin spectral reflectance can be calculated using Equation 1. For the TSR, spectral data were obtained from 400 to 700 nm with a 4nm spectral interval. The measurements are then interpolated to 1nm spectral intervals using 5th Sprague Interpolation [5].

$$R_S = \frac{S_s}{S_w} R_w \qquad (1)$$

$R_S$ represents the skin reflectance function, $S_S$ and $S_w$ the spectral power distribution of the skin and the white diffuser, and $R_w$ the reflectance of the white diffuser. The latter is measured using a Konica Minolta CM 700d spectrophotometer and interpolated to 1nm spectral data using the same interpolation technique.

To achieve uniform lighting, a VeriVide DigiEye® light booth was used, which was painted with a mid-grey matte colour and was illuminated by a D65 fluorescent simulator offering evenly diffused illumination. During the measurements, the participant was asked to sit on an adjustable chair in the viewing cabinet and move their position until their target facial area was within the TSR lens. The measurement angle was fixed to 0o; the measurement distance was 100 cm.

Overall, 188 subjects participated in this study, including 86 Oriental (41 females and 45 males), 79 Caucasian (65 females and 14 males), 13 South Asian (6 females and 7 males) and 10 African (5 females and 5 males). Three facial body areas, forehead, check and neck were measured. To allow a comparison between ethnicities, only measurements of female subjects within a narrow age group (20 - 35 years of age) were used (37 Oriental and 50 Caucasians females).

### Skin spectra between different ethnics and body areas

A total of 261 spectral reflectance functions were recorded and the mean and standard deviations were calculated.

To assess the spectral difference between the Oriental and Caucasian participants, their median mean and standard deviation were compared for each body area separately. Body area differences were analysed by comparing median means and standard deviations between different body areas.

For each ethnic group, the root mean square error (RMSE) was calculated to reflect the spectral difference between the average data for forehead (FO), cheek bone (CH) and neck (NE). Similarly, for each facial area, the RMSE was calculated between the average data of 37 Oriental and 50 Caucasians.

## Results and Analysis

### Skin spectra

Figure 1 shows the spectral reflectance functions of 261 skin samples (dotted blue lines). The median mean of all spectra is shown by solid red line. It can be seen that the spectral reflectance function is very smooth and of similar shape across ethnicity and body location. From 400 nm to 580 nm there is gradual increase in spectral reflectance; beyond 580 nm the increase is steeper.

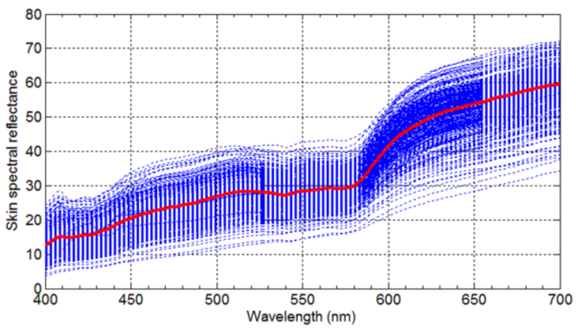



Fig.1 Spectral reflectance of human skin samples in two ethnics groups and thee body areas

Figure 2 shows the variability in skin spectra as a function of wavelength. Variability in spectral reflection follows approximately the same pattern as the mean spectral distribution (Figure 1): larger variability is found in the long-wavelength-range (> 580nm) and in the short/medium-wavelength-range with a peak at about 500nm.

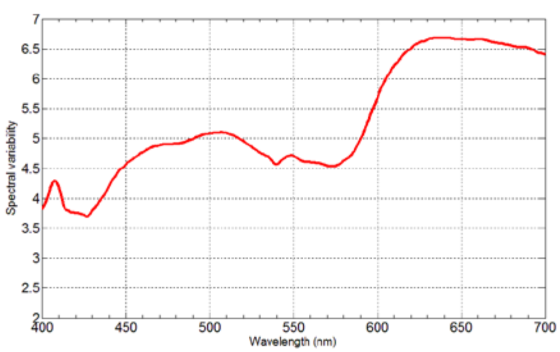



Fig.2 Spectral variability in the reflectance functions of human skin

### Body area differences

Figure 3 shows the mean spectral reflectance curve for cheek (red – top curve), forehead (green- middle curve) and neck (blue – bottom curve) for Orientals (Fig. 3a) and Caucasians (Fig. 3c). Mean spectra and two standard errors of the mean are shown. There are systematic differences in spectral reflectance between different body parts, in particular in the long-wavelength range (> 600nm; Fig. 3a,c). In the oriental group spectral reflectance is always greater in the cheek compared to the forehead, which is greater than the reflectance in the neck area (Figure 3a); in the Caucasian group, the difference between Cheek and Forehead is only apparent in the medium-wavelength range (520-580nm; Fig. 3c). Interestingly in the medium-wavelength range (530-580nm) the pattern is reversed for the Caucasian and oriental group (cf Fig. 3a with 3c).

Figures 3b and 3d show the variability of the spectral reflectance curves. In both groups, cheek spectra show the highest variation and forehead spectra the lowest variation. Variability is always highest in the long-wavelength range (Fig. 3b,d).

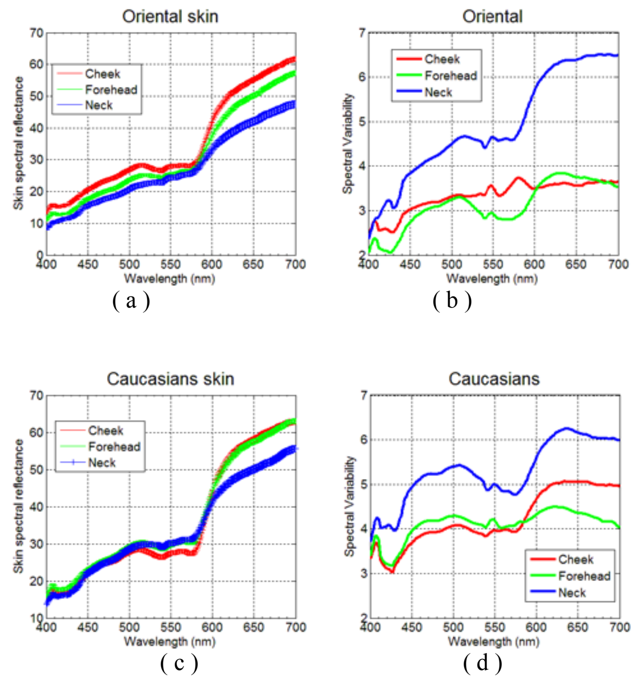



Fig. 3 Body area difference: (a) spectral distribution of Oriental skin, (b) spectral variability of Oriental skin, (c) spectral distribution of Caucasians skin (d) spectral variability of Caucasians skin

To quantify the differences in spectral reflectance, root mean square errors (RMSE) between different body areas for both Oriental and Caucasians skin spectra were calculated (Table 1). Largest spectral variation occurs between cheek and neck (RMSE = 6.48) and the smallest one between cheek and forehead. Across all three body areas, variation in the oriental group is higher than in the Caucasian group.

**Table 1. Root mean square error of skin spectral for different body area**

| RMSE | Cheek vs. Forehead | Cheek vs. Neck | Forehead vs. Neck | Mean |
|---|---|---|---|---|
| Oriental | 3.59 | 8.43 | 4.98 | 5.67 |
| Caucasians | 1.48 | 4.52 | 4.09 | 3.36 |
| Mean | 2.53 | 6.48 | 4.54 | 4.52 |

### Effect of ethnicity

Figure 4 (left panel) shows the mean spectral distributions for the three body areas (Fig 4a-c) with ethnicity as a parameter. Large spectral differences are found in the forehead and the neck (Fig 4b,c), whereas the cheek distributions are very similar (Fig. 4a). For both forehead and neck, spectral curves for Caucasians are always above the oriental curves, corresponding to a larger lightness value in Caucasian skin colour. The right panel in Figure 4 shows the corresponding variability in cheek, forehead and neck. Variability is almost always higher in the Caucasian group, with the exception of the long-wavelength range in the neck spectra.

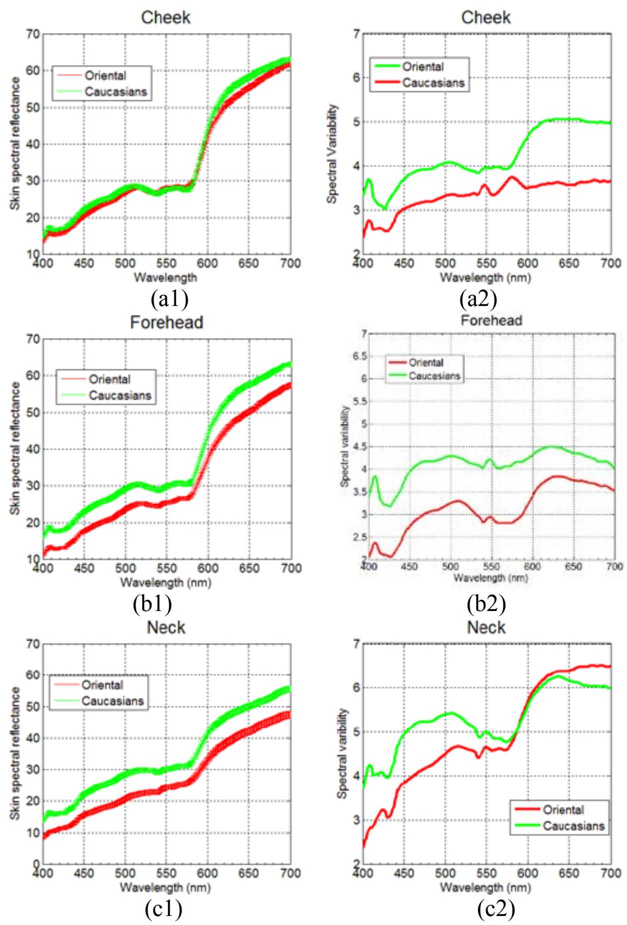



Fig.4 Ethnic group differences for skin spectra: (a1) spectral distribution for Cheek, (a2) spectral variability for cheek. (b1) spectral distribution for Forehead, (b2) spectral variability for Forehead, (c1) spectral distribution for Neck, (c2) spectral variability for Neck

The RMSE (difference between Caucasian and Oriental) for three body areas are listed in Table 2. Variation in the neck spectra is higher by a factor of 4 compared to the cheek.

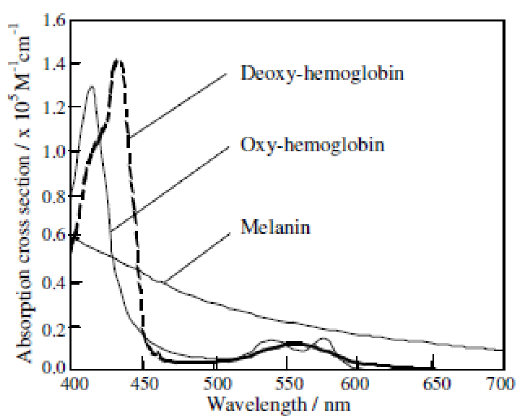
**Table 2 Root mean square error of skin spectra between Oriental and Caucasians**

| RMSE | Cheek | Forehead | Neck | Mean |
|---|---|---|---|---|
| Oriental vs. Caucasians | 1.71 | 5.72 | 7.09 | 4.84 |

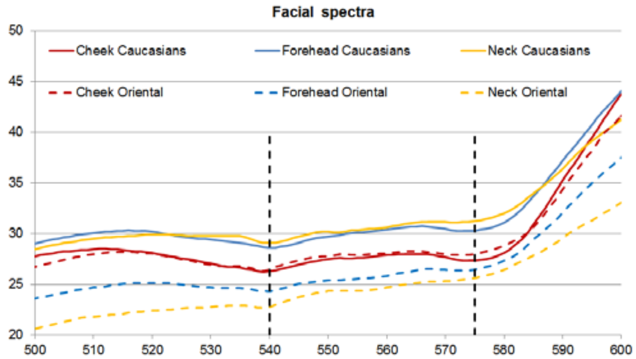
## Discussions

Human skin colour is controlled by both genetic and environmental influences. Skin pigmentation has evolved primarily to regulate the amount of ultraviolet radiation penetrating the skin [6]. The single most important pigment affecting skin colour is melanin which is the main determinant of skin colour in darker-skinned individuals. For lighter-skinned individuals, skin colour is partly determined by the bluish-white connective tissue under the dermis and by the hemoglobin circulating in the veins and capillaries of the dermis. Hemoglobin concentration and oxygenation affect skin colour in different ways. Greater hemoglobin oxygenation leads to a specific pattern in the spectral reflectance of skin, namely a more 'W' feature in the middle-wavelength range, which results in the skin looking more reddish. Figure 5a shows the absorption spectra of the skin chromospheres [7]. The absorption spectrum for melanin is very smooth. For Oxy-hemoglobin, there are two peaks in light absorption around 540 and 575 nm and the difference between Deoxy- and Oxy-hemoglobin is maximum at these wavelengths. It has been argued that the peak sensitivity of the L and the M cones has been shaped by this difference in oxygenation, since it allows the human visual system to detect small changes in skin redness, which is diagnostic for an individual's health and mood [8].

This 'W' feature is also present in our skin spectra with troughs at about 540nm and 575nm (Figure 5b). Interestingly, this difference in oxygenation of hemoglobin is only apparent in the cheek and to a lesser degree in the forehead, but not in the neck area. This finding is consistent with the hypothesis that the change in oxygenation in the cheek area is of diagnostic value for an individual's mood or health state, as indicated by blushing or blanching. Secondly, the cheek spectra are almost identical for both ethnic groups, as opposed to the neck and forehead. This invariance across ethnicity makes this facial area a prime candidate for signaling information about the mood or health of the individual. Further studies are necessary to evaluate whether this finding generalizes to other ethnicities.




( a )




( b)

Fig.5 (a) Spectral absorption of melanin, Oxy-hemoglobin and Deoxy-hemoglobin (b) mean skin spectra for the three body locations for both ethnicities.

## Conclusion

In this paper, spectral skin differences of two ethnic groups and three body areas have been characterized using a novel spectral skin data base. This database and the analysis provide important ground truth for medical imaging applications including the estimates of skin chromophores.

## Acknowledgment

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## Author Biography

*Kaida Xiao received his PhD in colour science from the Colour and Imaging Institute, University of Derby (2007). Since then he worked in the Samsung Advanced Institute of Technology, Tru-Colour Limited, The University of Sheffield and now he is working in University of Liverpool as a Senior Research Fellow. His research interest covers colour appearance, image quality enhancement, 3D colour image reproduction and colour and appearance in medicine and dentistry.*