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VIDEO LUMINANCE LEVELS FOR HUMAN SKIN TONES IN HYBRID LOG-GAMMA VIDEO

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ABSTRACT

In this paper, the author presents current work undertaken by the BBC to look at the representation of human skin tone in ITU-R BT.2100 High Dynamic Range video systems. Specifically, the author presents luma values for a range of skin tones, categorised by the Fitzpatrick Scale, which can be used as a line-up guide by cameramen, racks/shader operators and colourists. The effect of make-up is also covered.

1. Introduction

When creating video in live situations or for pre-recorded shows with minimal post-processing, cameramen rely on knowing the correct video luma level to place objects within the scene. Traditionally, television cameramen have relied on knowing the correct level to place grass or skin tone under varying lighting conditions and some cameras have had visual aids (known as zebras) to help with this placement (see Roberts (1)).

This paper presents results for skin tone tests undertaken to understand how skin tones should be displayed in ITU-R BT.2100 HLG.

1.1 Regional differences in skin tone

Regional differences in skin tone exist due to evolution - skin tone is optimised for the local UV radiation levels (Jablonski (2)). UV levels change throughout the year, but are generally highest between the Tropics of Cancer and Capricorn. Local effects such as shade, vegetation canopies, altitude and presence of bodies of water effect the average annual amount of UV an individual receives.

The skin tone reflectance is directly related to the amount of a pigment called melanin present in the skin. In the skin, melanin acts as an optical and chemical photoprotective filter, reducing the penetration of all wavelengths. The optimal amount of melanin for a given environmental average amount of UV light is small enough to allow adequate production of Vitamin D (needed to produce healthy bones – a lack of vitamin D causes Rickets) and large enough to prevent the UV radiation altering a sufficient amount of skin cell DNA to cause cancer (2).

1.2 Differences in skin tone across the body

Research suggests that persons at either end of the range of human reflectances are quite uniform across the body and are unaffected by the process of tanning, but in the middle of the range it is expected that significant differences may exist between areas exposed to the sun regularly and the covered torso (2).

Where differences do exist, these change over the course of the year as atmospheric UV levels change.

A second reason for differences in reflectance across the body is perspiration and oily secretions. For a given, fixed skin tone, damp areas of skin reflect more light than dry areas. Table 1 shows the density of human eccrine sweat glands in different areas of the body (see Taylor and Machado-Moreira (3)). It can be seen that, for a person with a uniform skin tone, we would expect the forehead to reflect more light than the cheek, which in turn will reflect more light than the forearm. These reflections (from damp skin) may be specular in nature.

Site	Gland Density (glands/cm^2)
Axilla	93
Chest (Sternal)	88
Head (Forehead)	155
Head (Cheek)	113
Head (Eyebrow)	61
Head (Scalp: Hairy)	195
Head (Scalp: Non-Hairy)	70
Forearm (Dorsal)	108

Table 1: Anatomical distribution of densities of human eccrine sweat glands (3)

1.3 Application of television-style make-up

According to Langer (4), television make-up is applied for the following reasons:

- to combat the effect of strong television lighting which alters the perception of facial colours and contours (luma and chroma contrast), and
- to aid in the creation of a character by changing physical appearance, e.g. making an actor appear older.

We can therefore expect that make-up will be used to reduce specular highlights caused by perspiration and to enhance contours and colours on the face.

It should be noted that the use of make-up alters the perception of facial colours and brightnesses. Kiritani et. al. (5), Kobayashi et. al. (6) and Kiritani et. al. (7) report on experiments looking at the perceptual effect of lipstick and eye shadow. All report a perceived change in skin brightness as the colour of the lips and eyes are changed.

2 Measuring skin tones for HLG signals

When using the ITU-R BT.709 video system, there is an accepted level at which Caucasian skin tones should be placed (1). Cameramen utilise this information, and a knowledge of the offset required for differing skin tones to produce correct video signals. No such levels exist for Hybrid Log-Gamma (HLG). So the author decided to undertake tests to define suitable luma values for a range of skin tones.

2.1 Method 1: Using a skin tone database and an ideal model of a camera

Initial tests were undertaken using a skin tone reflectance database from the US government National Institute of Standards and Technology (NIST) (Cooksey (8)).

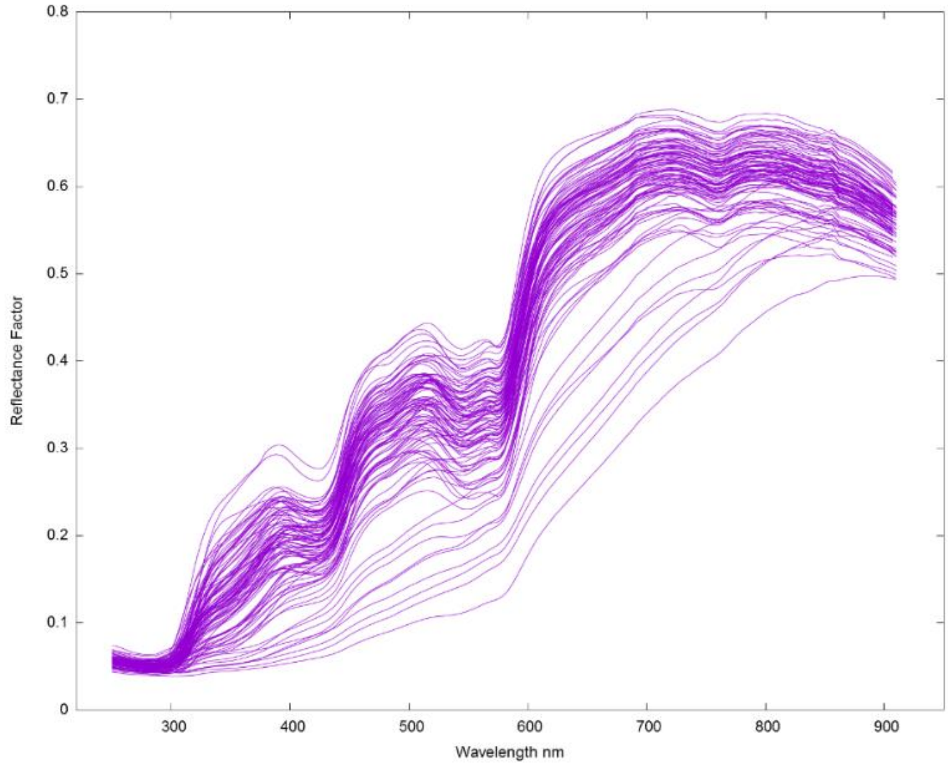

Figure 1: NIST dataset – each line corresponds to one skin sample

The database covers a wide range of skin tones, however when comparing the 685 nm reflectances with those given in Jablonski, it can be seen that it does not cover the full range of expected global reflectances.

The NIST database contains measures of skin reflectance of the inner forearm at a number of wavelengths. This dataset is shown in figure 1.

We used a software model of an ideal camera and lighting scenario (illustrated in figure 2) to generate values for HLG luma.

The model consists of a sample multiplied by the spectral curve of an ideal D65 illuminant (CIE (9)), fed through an aperture (a fixed scalar). A set of CIE 1931 2 degree observer LMS to XYZ curves (CVRL (10)), are then used to convert to a known imaging format. These XYZ values are then converted to ITU-R BT.2100 (11) linear RGB values and the HLG Opto-Electronic Transfer Function (OETF) is applied. Finally, the luma value is calculated for the HLG R'G'B' values.

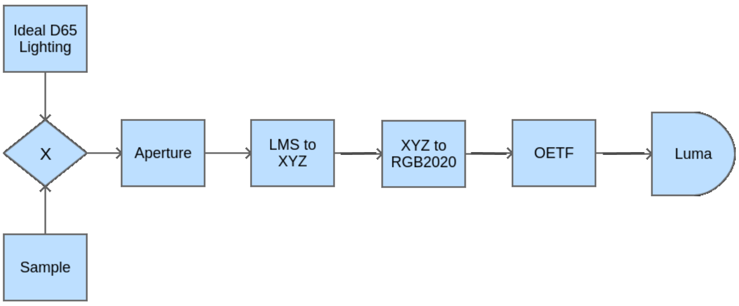

Figure 2: Block diagram of ideal camera model

The NIST data set, ideal D65 illuminant curves and LMS to XYZ curves all used different wavelength step sizes in presenting the data. So, where data points did not align, a linear interpolation was used.

The first step in using the model was to calculate the required input aperture. By setting the input sample to a fixed value of 1.0 at all wavelengths to represent diffuse white, we can adjust the aperture (a scalar) such that HLG luma is equal to 0.75, the HLG signal level for HDR Reference White (12). This value of aperture is then used for all further samples.

The second step is to apply the model for each skin reflectance curve given in the NIST dataset. The results of this are shown graphically in figure 3. Luma values are plotted against the skin reflectance at 685 nm to allow comparison with regional labelling from (2).

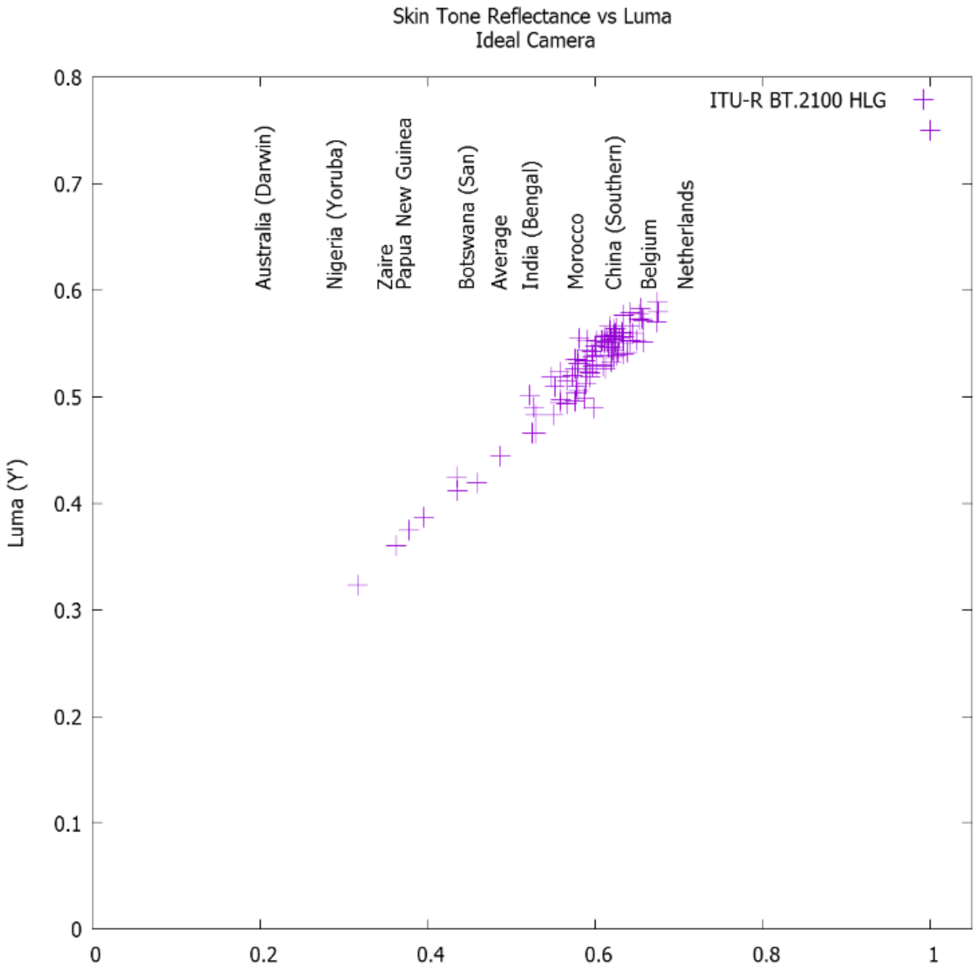

Figure 3: Skin tone reflectance vs HLG luma for ideal camera with region labels from (3)

A further graph of skin tone reflectance vs screen emittance for a 1000 cd/m^2 HLG display is given in figure 4. A 1000 cd/m^2 display is chosen as it is the accepted “Bridge point” for transcoding between the HLG and PQ HDR television formats.

2.2 Method 2: Using Human Subjects and a RAW recording camera

In conjunction with the European Broadcasting Union (EBU), we conducted a second experiment using real subjects and a DSLR Raw-recording camera. To categorise the subjects, we used the Fitzpatrick Skin Tone Scale, ARPNSA(12). The Fitzpatrick scale was originally developed to estimate the response of different types of skin to ultraviolet light. It also provides a convenient classification method for the range of skin tones encountered in television production.

Stage 1 of the experiment was to calculate the reflectance of a small test chart that could be used in shot when photographing test subjects, under practical D65 LED lighting. Using a Konika-Minolta CS2000 photospectrometer, we measured the reflectance of the test chart white and black patches, a magnesium carbonate reference (97.5% reflectance) and a Gregory hole reference (black velvet lined box – 0% reflectance). The test chart white patch reflected 81.2% of light, the black patch 3.9%.

The processing chain for the images was designed to closely replicate the ideal camera workflow shown in figure 3. This is shown in figure 5. To convert the camera raw file to linear XYZ, the open source package dcraw (13) was used. This file was then processed to:

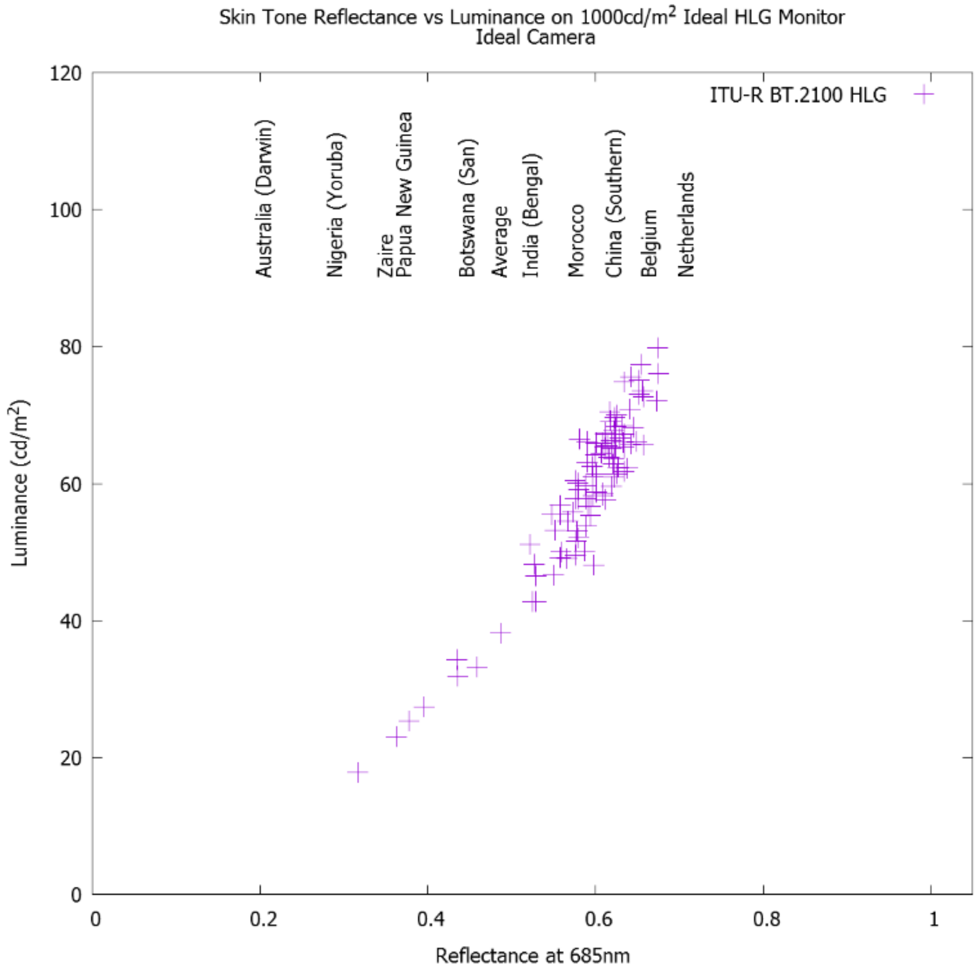

Figure 4: Skin tone reflectance vs HLG luminance on an ideal 1000cd/m² display for ideal camera

1. Convert the XYZ values to ITU-R BT.2020 linear RGB values and then to CIE Yu'v'
2. Scale Y such that the average black patch pixel value equalled 3.9% and the average white patch pixel value equalled 81.2% then convert back to ITU-R BT.2100 (11) linear RGB values
3. Crop two 50 pixel by 50 pixel areas of skin tone (forehead and cheek). (Care is taken to ensure that the chosen areas are co-planar with the physical luminance ramp test chart)

4. Apply the HLG OETF to each pixel and calculate the Y' luma channel average for each square.

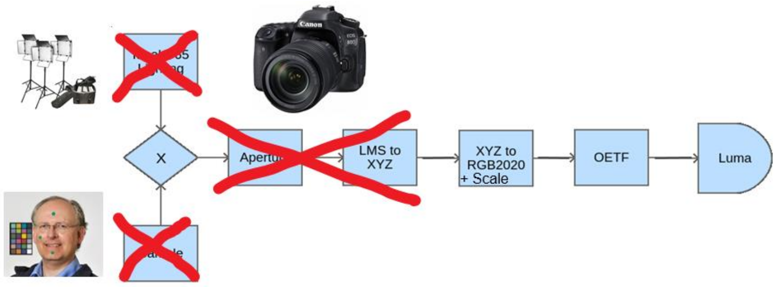

Figure 5: Real-life human skin tone measurement

In order to match the test subject to the Fitzpatrick Scale classifications, a questionnaire from the Australian Government Radiation Protection and Nuclear Safety Agency was used to allow subjects to self-classify (13).

The results of these photographic tests are shown in figure 6. Skin tone measurements range from approximately 26% HLG to 67% HLG dependant on skin tone. It can also be seen that there is an issue with two peoples' replies to the questionnaire. Both individuals are deeply pigmented and should either be type V or VI but have self-identified as type IV. Following discussions with these individuals, and others identifying as type IV, V or VI, it appears that there is an issue with the questions relating to tanning – people either decided they were permanently tanned or that they never tanned which led to changes in result. Finally, it can be seen that there is a small difference across the face, with the forehead being more reflective than the cheek for people with skin types II to IV.

Full results for use in television production are shown in Table 2. In formulating the values, the author has recategorized the two people discussed previously in this section at category VI, this gives values consistent with those presented in figure 3. To accurately represent the majority of the exposed skin which does not exhibit issues with perspiration shine, the ranges are chosen to cover the majority of the cheek skin tone measurements for each category, ignoring obvious outliers. A small amount of leeway is allowed at the bottom end of the ranges for categories I-IV to allow for summer tanning. Camera zebras should be set 2-3% above these ranges to take account of perspiration shine. Values are chosen to be easily used by productions using waveform monitors only. It should be noted that the event at which measurements were taken occurred in the Northern Hemisphere during winter (so few people were tanned at the time) and the attendee demographic was skewed towards categories II, III and IV.

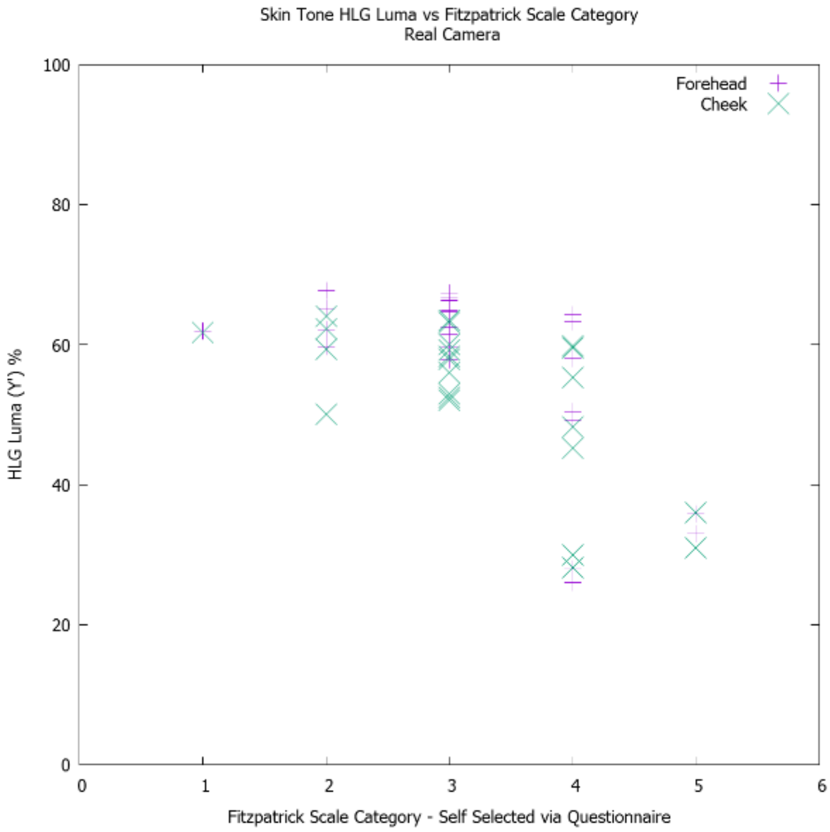

Figure 6: HLG signal levels measured from human subjects

<table>
<tr><th rowspan="3">Reflectance Object</th><th rowspan="3">Nominal Luminance cd/m² (PQ & 1000 cd/m² HLG)</th><th colspan="6">Signal Level</th></tr>
<tr><th colspan="6">%HLG</th></tr>
<tr><th>I</th><th>II</th><th>III</th><th>IV</th><th>V</th><th>VI</th></tr>
<tr><td>Skin Tones</td><td>~15 - ~85</td><td>60-65</td><td>55-65</td><td>50-60</td><td>45-55</td><td>30-45</td><td>25-35</td></tr>
</table>

Table 2: Results of skin tone tests for HLG video

3 Effects of television-style make-up on facial luminance

Images of two television presenters were taken before and after make-up was applied. The set-up was similar to that shown in figure 5.

- The subject was lit with a single, high CRI halogen video lamp.
- The images were taken with a DSLR camera, recording to a Raw format.
- The images were white balanced using dcraw (14)
- The images were converted to 16-bit portable network graphics files with a linear transfer function and ITU-R BT.709 colour primaries using dcraw (14) – ITU-R BT.2020 was not available at the time of testing.

- The images were scaled such that the MacBeth Chart black equalled 0,0,0 and the Macbeth chart white equalled 1,1,1 using Darktable (15), an open source high bit depth Raw and linear image converter.
- The skin tone areas were masked and a histogram of luminance created using G'mic (16), an open source image filter and analysis suite.

In figure 7, a normalised, linear light histogram of luminance levels in the recorded image, it can be seen that the television-style make-up:

- Removes extreme areas of brightness caused by perspiration,
- Slightly increases the mean of the facial reflectance,
- Increases the standard deviation of the facial reflection by the addition of shadow and highlight detail.

It should be noted that, on the female presenter, the make-up added some significant specular highlights to both the lips and the eyelids. These are outside of the range of the histograms which show from diffuse black to diffuse white.

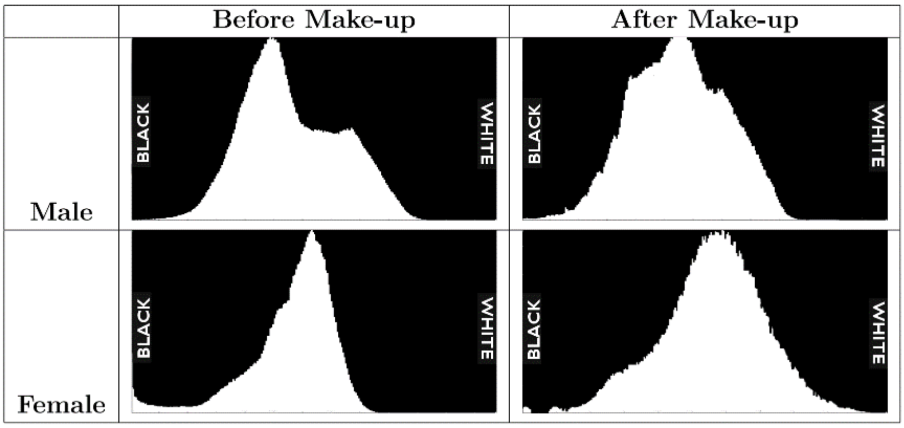

Figure 7: The effect of television-style make-up on male and female presenters.

4 Conclusions and further work

Ranges of HLG luma level have been calculated for each skin type defined in the Fitzpatrick Scale. These are shown in table 2. These luma levels provide information to cameramen, racks/shader operators and colourists to allow them to correctly expose images where the main level reference is a person's skin.

In addition, we found:

1. HLG Luma levels measured with the DSLR camera (method 2) seem similar to those calculated in the initial computer modelling phase (method 1).
2. Results are valid when the sample is from areas of skin co-planar with the physical test chart. Due to using a single light source, there is a marked drop off in

reflectance when moving away from areas of the face that are co-planar. In one instance, the side of the face reflects less light than the black test colour on the chart.

3. There is an issue with “Forehead Shine” in the results caused by both perspiration under the studio lights and a matching of the angle of incidence and reflection such that light is reflected directly towards the camera. This can be reduced using make-up.
4. From comments made by some of the subjects who undertook the tests, it is apparent that the Australian Government questionnaire is designed to suggest levels of skin protection required in the southern hemisphere tropics and, therefore, seems to be most suited to Fitzpatrick Skin Types I-IV. For example, some questions focus on the amount, frequency and severity of tanning which makes less sense for types V and VI than for types I to IV.
5. Television-style make-up seems to have a significant effect on reducing perspiration-induced shine. It has a smaller effect on the average luminance level of a face, but the change is not large enough to require an alteration to the new table. Make-up can also cause specular reflections.
6. When assessing skin tone luma values, a waveform monitor is advised. Assessing brightness by eye may lead to over- or under-estimation due to perceptual effects.

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