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White Balance preference under multiple light sources

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Abstract

White balance is one of the key processes in a camera pipeline. Accuracy can be challenging when a scene is illuminated by multiple color light sources. We designed and built a studio which consisted of a controllable multiple LED light sources that produced a range of correlated color temperatures (CCTs) with high color fidelity that were used to illuminate test scenes. A two Alternative Forced Choice (2AFC) experiment was performed to evaluate the white balance appearance preference for images containing a model in the foreground and target objects in the background indoor scene. The foreground and background were lit by different combinations of cool to warm sources. The observers were asked to pick the one that was most aesthetically appealing to them. The results show that when the background is warm, the skin tones dominated observers' decisions and when the background is cool the preference shifts to scenes with same foreground and background CCT. The familiarity and unfamiliarity of objects in the background scene did not show a significant effect.

Introduction

One of the key steps involved in the camera image processing pipeline is White Balancing, which basically compensates for human visual chromatic adaptation, keeping "white" objects appearing "white" in a given lighting condition. Camera pipelines estimate the scene illumination and apply a gain factor to the three color components of the raw sensor data. This becomes especially challenging under multiple or mixed lighting conditions. What illumination should the scene be white balanced to? Or, do we balance the scene locally? Therefore, lighting, either natural or artificial, has a pronounced impact on how the final color will be reproduced for an object. The focus of our experiment is to investigate the white balance appearance preference of a scene with more than one light source.

The human face is a common subject in photography, and the main subject of imagery for our experiment. A study has shown that skin tone serves as a better target than a gray wall or a color checker [1] for studying color rendering preferences under different light sources. Many smart phone manufacturers know how important correct and pleasing human skin tone rendering is for customer satisfaction. In the research community, however, there has been not enough focus on studying different skin tones. Due to the importance of evaluating the effects of varied skin tones on perceived performance, our experiment included a range of skin tones in the foreground of the scene.

Although digital cameras have achieved good color image quality, sometimes they produce unsatisfactory results, as described by Hubel [2]. So it is necessary to examine human perceptual behaviour when implementing white balance in a camera or display pipeline. Past studies have shown that the preferred color reproduction is different from the actual color for many observers, particularly for memory colors including skin tone [3, 4, 5]. Scene neutrals are also important memory colors. In a study examining the preference of the white point under different illuminations, including artificial and natural light, the variation range of the acceptable white point was closely related to the "colors" of natural light sources [6]. Additionally, the authors' previous work on white balance preference for applications using virtual backgrounds showed that preference was based on the virtual background scene content when the foreground model rendering was constant whereas the primary preference focused on the skin tone of the model when rendered under different CCTs [7].

One of main aims of our experiment is to investigate the preference of white balance for human skin tones under multiple light sources and also study the impact of familiarity of the target objects in the background. In our experiment we used an 2AFC protocol in which observers judged two different images per trial, choosing the one image that they prefer.

Imaging Studio

We designed an imaging studio with calibrated LED light sources. The lab has no windows and all walls are painted black, allowing complete control over the scene illumination. The light sources used were three tunable Arri LED luminaires with the capability of producing a wide range of CCTs. Figure 1 shows the imaging studio, which included two *ARRI SkyPanel S30* LEDs that were focused on the model with a shallow angle from the sides and one *ARRI SkyPanel S60* LED that was focused on the scene background, which was isolated from the foreground. These LEDs were tested for range of illumination, CCT and uniformity. The foreground and the background were lit separately, generally by two different CCTs. These lights were controlled by MATLAB via a 5 pin DMX cable. The spectral radiance of each light source, foreground and background illuminants were measured using a PR655 spectroradiometer shown in top of Figure 2. Their CCT and Duv are reported in bottom of Figure 2. These multi-primary lighting systems were tuned so that, for each CCT setting $duv \leq 0.0001$. The Illuminating Engineering Society (IES) TM-30 is used to evaluate the simulated spectra with fidelity index R_f and gamut index R_g [8]. IES TM-30 value for each light setting shown in the Table , which ensured that the light sources were good proxies for the real world illumination conditions.

Table 1: IES TM-30

	3000K	3500K	4000K	5000K	6500K	9000K
R_f	83	93	93	92	91	90
R_g	99	102	102	102	101	100

There were total of eight models: two each having Caucasian, Indian, Asian, and African American skin tones. All the models were provided with the same neutral color t-shirt during the pic-

Figure 1: Light Studio setup with the LEDs and the background scene

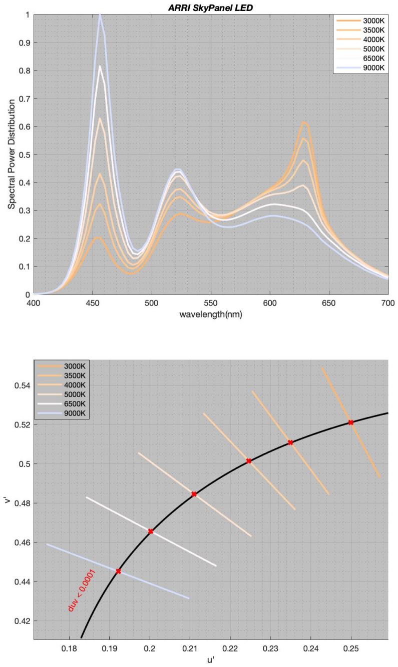

Figure 2: Spectral Radiance and *duv* of the LEDs mounted in the Light Studio used as a light sources for the scene for the subjects photography session.

ture taking session and were instructed to not wear any makeup. The models were asked to sit on the chair and look at the camera keeping a neutral expression.

To assess the difference with and without memory color objects in the background there were two settings to capture the skin tone. The subject in foreground with familiar objects in the background and the subject in foreground with unfamiliar objects in the background as shown in Figure 4. The subject in foreground with familiar objects in the background had objects like a color checker, green plant, sunflower, Coca Cola can, Rubik's cube, Sprite bottle, Crayola crayons, tennis ball, Chips Ahoy, Cheerios, and pumpkin. The subject in the foreground with unfamiliar objects in the background had objects such as mugs, books, and paintings, which do not have commonly defined colors with which the observer would be familiar. All of the COVID-19 guidelines were followed for each photography session. This picture taking process was approved by the RIT Institutional Review Board (IRB) for Human Subjects Research. Consent was obtained from all of the models to have their images and skin tone reflectance data used as part of the experiment.

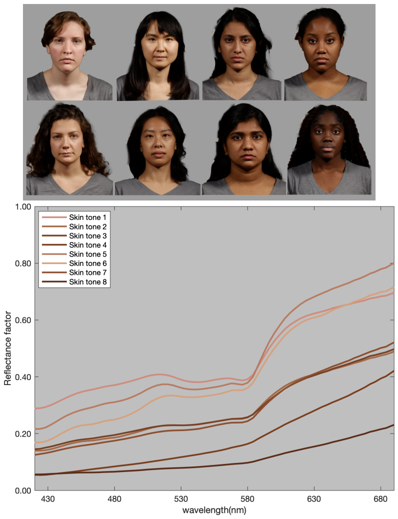

Figure 3: (Top)Eight models with Skin tone number, top left to bottom right referenced as: 1 to 8 (bottom)The spectral reflectance of all the models with their respective skin tone number. The spectral reflectance of each subjects skin was measured using the *Photo Research PR655* in the picture taking light studio.

The test images were captured with a Fujifilm XT100 camera and images were saved in RAW format. The raw files were converted to linearized 16-bit images using the RAWDigger tool [9]. The first step was to convert the linearized 16-bit Camera RGB to tristimulus XYZ values. The 3x3 transformation matrix was calculated using a standard MacBeth ColorChecker to convert camera RGB to XYZ. These XYZ images were then transformed to cone-like responses $\rho\gamma\beta$ using the CAT02 matrix. The von Kries adaptation transformation was applied to white balance the images to the display D65 white point using the scene illuminant. These D65 white balanced $\rho\gamma\beta$ were then converted back to the tristimulus XYZ value and to display driver values.

Experimental Setup

For our experiment we featured 2 models with 3 different background CCTs. (For Model 1, 3000K, 4000K and 6500K were used and for Model 2, 3500K, 5000K and 9000K. Two different sets of CCTs were chosen to cover a wider range of illumination.) In the foreground, each model was illuminated in a scene with 6 different foreground CCTs: 3000K, 3500K, 4000K, 5000K, 6500K and 9000K. The workflow is illustrated in Figure 5. The experiment was performed in the Munsell Color Science Lab at RIT. A MacBook Pro laptop was connected to an Eizo CG248 color display, which was used to present the stimuli to the observers. The display was characterized using the Day, et al. model [10] using a PhotoResearch Spectrometer PR-655 for measurement. The wall behind the monitor was painted gray (Munsell N5) and was illuminated by a D65 metal halide lamp filtered to have a luminance level equivalent to that of the average image rendered on the display, 70 cd/m^2. This setting is recommended by CPIQ standards to reduce observer fatigue compared to a completely darkened surround. The display and the experiment lab

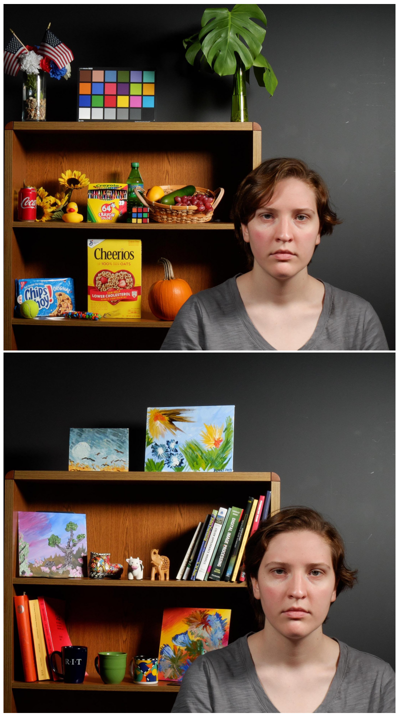

Figure 4: (Top)The familiar background objects. (Bottom)The unfamiliar background objects.

light source were switched on 30 minutes before the experiment was started to maintain uniform illumination. Other lights in the laboratory were turned off to avoid stray light. The table on which the display was placed was covered with a gray sheet of paper to make the observer's field of view as uniform as possible. The observers were seated 85 cm from the display. A MATLAB driven Graphical User Interface (GUI) was used to present the stimuli for both experiments. The background of the GUI was set to a similar gray to that of the wall and the table sheet.

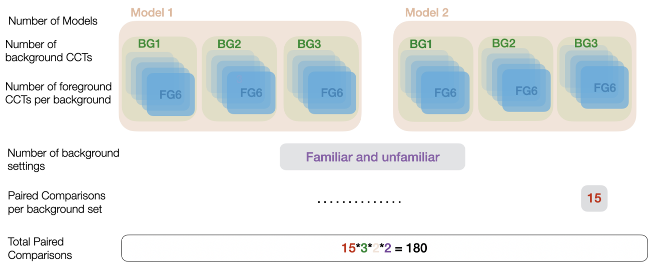

Figure 5: (Top)The familiar background objects. (Bottom)The unfamiliar background objects.

Observers

For this study there were 10 observers, 70% of the observers were experts with color or imaging science background and the others were naive observers. All of the observers were tested for color vision using the Ishihara plate test. All observers had normal color vision and normal or corrected to normal visual acuity.

Observers were presented with a pair of images per trial and instructions along the top of the screen to select the one that is most aesthetically pleasing. The left and right arrows on the keyboard were used to make the selection. The observers were adapted to the lab lighting while reading a set of instructions that explained the goal of the experiment and the task that they were to perform, along with obtaining their consent, all of which took a few minutes. No information was provided about the scenes or the subjects. The average time taken to complete the experiment was 20 minutes. The experiments were approved by the RIT Institutional Review Board for Human Subjects Research.

Results

In this experiment observers were asked to assess images with a model in the foreground and a background scenes, using a 2AFC approach. Figure 6 shows the foreground CCT preferences as a function of background CCT for Model 1 (top) and Model 2 (bottom). We see that as the background CCT gets cooler, the foreground preference CCT shifts cooler, too. The overlap of blue and red lines shows that the familiarity of the background target objects does not influence the decision making. This could be explained possibly due to the skin tones dominance in observers' decisions, as other studies have shown that skin done dominates a scene [11, 12].

We can see from results in Figure 7 top plot that, for Model 1, the preference foreground CCT for 3000K and 6500K background CCTs are significantly different. However for 4000K background the preference foreground CCT is within the mean decision limits and is not statistically significant different, likely due to the high variance among the observers' preferences. For Model 2, the foreground preference for all background CCTs shows significant differences, which indicates that the CCT of the background illumination influences the decision of the foreground preference. The overall preference CCT is 5300K and 5800K for Model 1 and 2, respectively.

The results from this experiment will be used to inform the setup for a subsequent experiment that will further explore the effect of multiple light sources on preferred white balance. The present study showed that the image with the 3000K foreground model setting was almost never selected as the preferred one. This setting will, therefore, be excluded from foreground and background CCT combinations that will be included. To study the how preference changes for different skin tones, this experiment will feature a wider range of skin tones by using all of the models from figure 3) as well as a more diverse set of observers.

Conclusion

In this paper we discussed an experiment conducted to explore preferred white balance under multiple light sources. The foreground, which features a model, and background, with the target objects, were illuminated by different CCTs. We performed a 2AFC psychophysical study where observers were asked to pick the image that preferred. The results indicate that the background illumination affects the foreground preference results, which is statistically confirmed by ANOM analysis. White balance preference in an indoor scene under multiple light sources is independent of the familiarity of the background target objects. This is likely because the model is the dominant subject in the scene and the preference results focus on making the skin tone look pleasing.

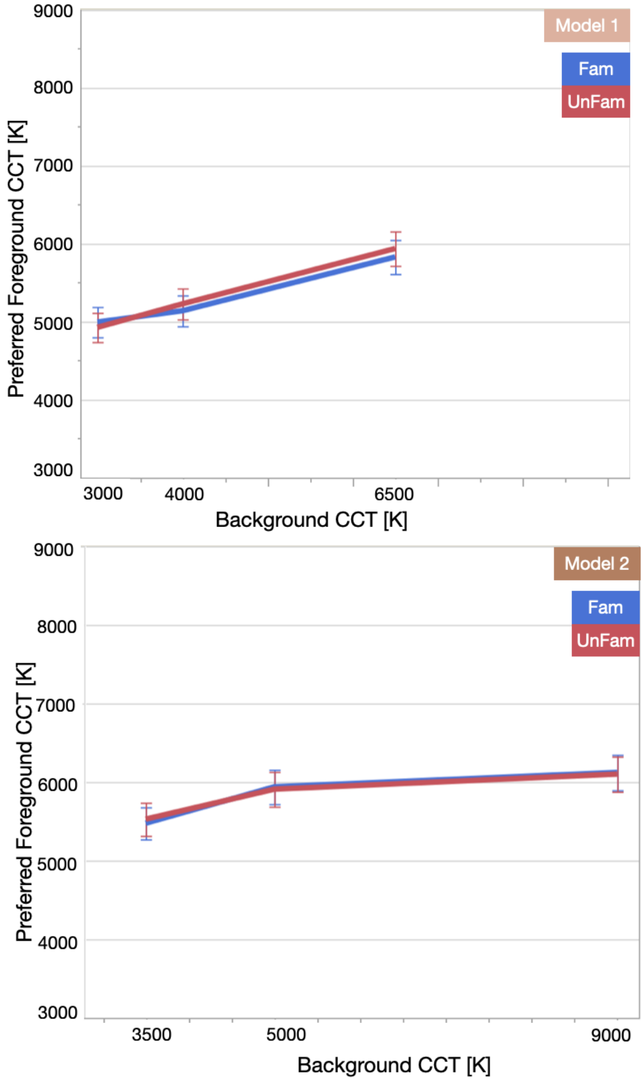

Figure 6: TThe x-axis is the Background CCT and the y-axis is the preferred foreground CCT. The blue and red line are for familiar and unfamiliar target objects in the background, respectively. The error bars represents 95% confidence interval.

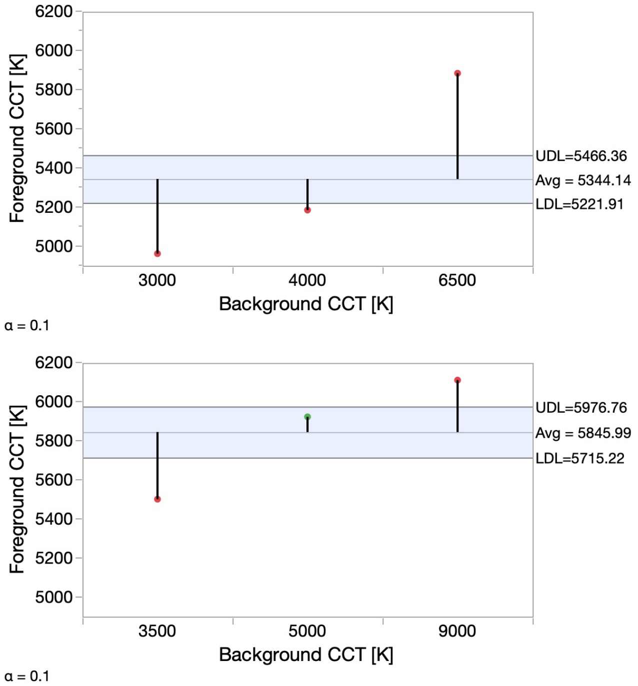

Figure 7: Statistical Analysis of Means (ANOM) for Model 1 (top) and Model 2 (bottom). The x-axis is the Background CCT and the y-axis is the preferred foreground CCT. The UDL is the upper decision limit and LDL is the lower decision limit.

Acknowledgment

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