Background and the Perception of Lightness

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ABSTRACT

A simultaneous equisection experiment using a CRT in a dark surround was performed to investigate the relationship between a uniform background and the perception of lightness. The resulting curves for different backgrounds show both exponential properties, for black and white backgrounds, and sigmoidal characteristics, for intermediate grays. The sigmoidal properties are due to crispening and roughly intersect the diagonal or identity at the lightness of the background. The simultaneous contrast is greatest for the middle gray and decreases as the device white and black points are approached. An example equation is provided to fit the observations. This equation has as its input the L* of the stimuli and the background and has two fitting parameters. The issue of lightness scaling for backgrounds is also considered and finally extensions to this research are briefly mentioned.

Keywords: Lightness, background, appearance modeling, simultaneous equisection, crispening, simultaneous contrast, tone reproduction

1. INTRODUCTION

Lightness has been defined as the perceptual attribute that corresponds to how bright a color is relative to a white or highly transmitting reference.[1] The lightness attribute has also been described as "a significant aspect of the mental picture of our surroundings".[2] The background is the area immediately surrounding the stimulus and subtends roughly ten degrees.[3] There are numerous references to how background influences the lightness of a given stimulus but these results have been difficult to compare directly or only implicitly model this phenomena. This paper begins with a brief review of earlier and current research[4-17] in the area of background and the perception of lightness.

Godlove[4] proposed the square root of a polynomial to model the effect of background on lightness. The resulting curves are similar to CIECAM97s,[5] which uses an exponential function to model the effect of background. Takasaki[6] gathered data and derived a model for a visual phenomena he refered to as crispening or the increased sensitivity to lightness differences as the stimuli lightness approaches the lightness of the background. Semmelroth[7,8] modeled the crispening and simultaneous contrast effects using a two-piece function with exponential terms and also the absolute value of the difference between the background and the stimulus. This equation predicts equally large simultaneous contrast effects for light, medium and dark gray backgrounds. It also has a sudden transition for the crispening effect such that there is considerable overlap for the upper and lower envelope of the family of curves. Braun and Fairchild[9] and Holm[10] have looked at image based tone reproduction and have used variations on sigmoidal functions to account for differences in image key. While image key is not strictly speaking the same as background, they are similar concepts and therefore it is interesting to consider these results as well. Finally, vision models such as those proposed by Land and McCann[11,12] also implicitly model how various larger spatial configurations of lightnesses impact the stimuli lightness. Using the test backgrounds and stimuli described later in this paper with the Retinex formulations provided by Funt, Ciurea and McCann[13] suggest that a white background will not change stimuli lightness and for darker backgrounds stimuli are only made lighter. It is interesting to consider how all of these results exhibit exponential and sigmoidal characteristics and which combinations of background and stimuli yield identity values.

Whittle[14] also used a simultaneous equisection experiment to study brightness and crispening. The experimental method presented in this paper differ from those of Whittle in that fewer test patches were used, the viewing condition was a dark surround, lightness was adjusted using unreferenced buttons instead of a palette and a larger number of observers were tested. In addition, this paper specifically addresses the influence of background by testing five different background lightnesses. The relationship of the results to the effect of simultaneous contrast is also clearly stated and one of the functions fit to the data is relative to L* or CIE lightness. Munsell[15] also used a version of simultaneous equisection but for papers with differing reflectances on a single background. Godlove extended Munsell's results but focused on modeling of lightness perception on different backgrounds and did not provide specific data for the different backgrounds. Both Whittle and Munsell found consistency between J.N.D. experimental results and the results from simultaneous equisection. Results by Belaid and

Martens[16,17] have confirmed Whittles results and have further explored the psychophysical implications for modeling these effects. They also have discussed the relevance of these results to digital imaging.

2. EXPERIMENTAL

In order to better understand and compare the extensive prior research in this area, a specific simultaneous equisection experiment was conducted. Fifteen color normal observers participated in a uniform lightness partitioning experiment. This experiment required the observer to make multiple individual stimulus adjustments in order to uniformly partition the lightness scale. Munsell[15] referred to this technique as a value step method and Whittle[16] called it equal-interval scaling. Gescheider[18] describes this technique as simultaneous equisection although the author finds the term partitioning a useful description of the observer task. A SONY MultiScanTC CRT in a dark surround was used as the test device. The CRT was configured to approximate the sRGB[18] specification. The test stimulus consisted of eight squares of approximately 2 degree subtense on a uniform background. Two of the squares were anchors of device black furthest to the left and device white furthest to the right. The intermediate squares were randomly initialized to an intermediate lightness and were separated from each other by approximately 2 degrees, as can be seen in figure 1. The observer task was to uniformly partition the lightness from left to right. Each of the six intermediate squares had individual buttons to lighten or darken the squares as needed. The increment was 5 digital counts in the native 8-bit RGB color space and stepped through the achromatic patches. This increment was derived during preliminary experiments and provided a reasonable trade-off between precision and the time required to complete the experiment. The user interface and data collection was performed using a TCl/Tk program. Five background luminances were used in an observer specific random sequence. The five backgrounds consisted of device white, device black and three intermediate lightnesses. The luminances for the backgrounds were 0.05, 30.0, 13.3, 25.4 and 65.7 cd/m^2.

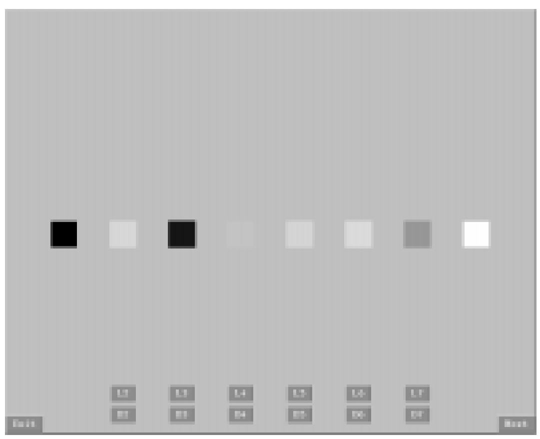

Figure 1. Example of an initial screen for the visual experiment.

3. RESULTS

The simultaneous equisection experiment provided a fast, simple and low noise method of determining the effect of background on the perception of lightness. There was a very low amount of inter- and intra-observer variability. Munsell noted that the value step method had twice the precision compared to the J.N.D. method for 3 observers and 4 replications. Whittle stated “seeing all the stimuli at once allows subjects to avoid some kinds of inconsistency, such as errors of order.” The results were then plotted with the measured lightness on the x-axis and the lightness partition on the y-axis. Figure 2 shows the five different curves, one for each of the backgrounds. The white and black backgrounds were roughly exponential and consistent with the LUTCHI results. However, the backgrounds of intermediate lightnesses were sigmoidal and intercepted the 45-degree line at roughly the lightness of the background. The author lacks a satisfactory explanation for the small upward shift for the data for the background with an L* of 25. The observed data can be modeled using the equation:

$$L' = 100\left(2l_S - l_S^{\left|l_S - \left(c_1 + {l_B}/{c_2}\right)\right|}\right) \quad (1)$$

Where l_S and l_B are CIE L* normalized to the range 0 to 1 for the stimuli and background, respectively. The variables c_1 and c_2 are free parameters and can be used to fit the observations. L' is the background corrected lightness values for the stimulus. The results shown in Figure 2a and 2b were fit using values of 0.8 and 0.6 for c1 and c2. This equation is provided as an example only and while it fits the data with an r^2 of 0.95, it should be understood to be one of many functions that result in a similar family of curves. Specifically, equation one does not necessarily have a psychophysical or physiological basis. Such considerations are important but for the purposes of this paper the focus is the manifestation or characteristics of the visual phenomena and not the underlying mechanisms. An alternative approach is to fit the derivative of the results using a second order polynomial whose terms are also second order polynomials.

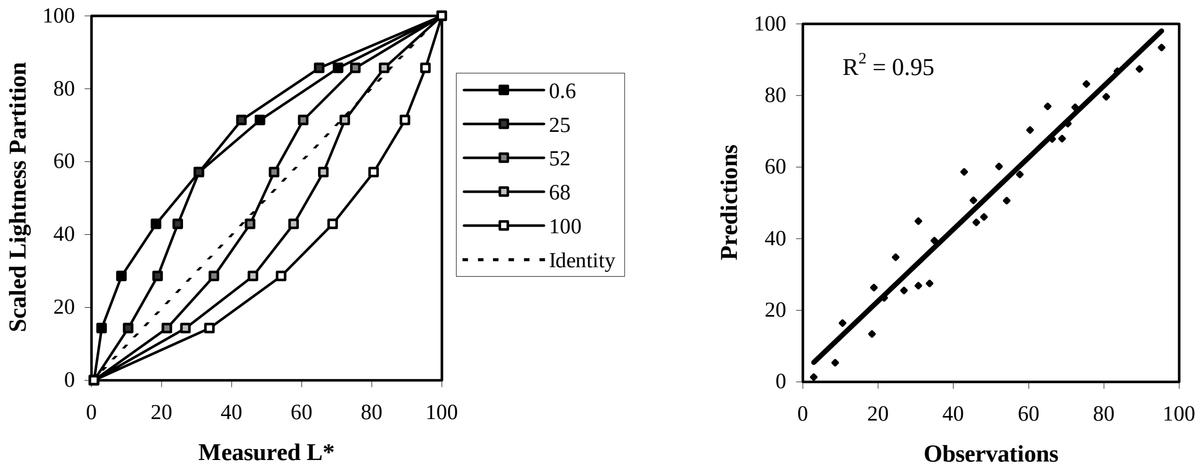

Figure 2a and 2b. Averaged results for the visual experiment, on left, and model fit for observed data, on right. The legend for the plot on the left lists the measured L* value for the uniform background.

4. DISCUSSION

The results shown in figure 2a clearly show both simultaneous contrast and crispening. The simultaneous contrast is evident in the range of stimulus lightnesses that result in a middle gray. Crispening is the inflection of the curve as the lightness of the stimulus approaches the lightness of the background. The curves have been extrapolated to connect the curves to the white and black points. This extrapolation follows the trends in the data well and fits practical imaging constraints in which white and black points cannot be adjusted. This family of curves also has interesting implications for lightness scaling of backgrounds. For example, the curves roughly intersect the diagonal identity at the lightness of the background.

The CIECAM97s color appearance model[5] was not designed to compute perceptual attributes for the background. However, as a thought experiment it is useful to consider how the model might be inverted given only the lightness or J value of the background and stimuli. Assuming the backgrounds are scaled to a luminance of 20 or a gray world assumption, then different luminance values could be computed given the same lightness for the background and stimuli. On the other hand if the lightness of the background is used to determine the corresponding Yb value, then this implies background lightness perception does not follow the gray world or Y_b of 20 stimuli lightness perception. The set of curves in Figure 2a show how the lightness scaling of backgrounds might be roughly equivalent to the gray world lightness scaling of stimuli. However, additional testing is required to verify this hypothesis, especially given the small deviation in the data for the background with an L* of 25.

Whittle[14] notes that crispening can be reduced or eliminated by including a border around the stimuli. The author has also repeated the previously described experiment using non-uniform black and white noise backgrounds and with the stimulus patches side by side. Both of these arrangements also reduce the effect of crispening. Whittle debates the importance of crispening relative to other visual phenomena. Belaid, Van Overveld, and Martens[17] investigate this question using digital images and conclude that the results are relevant for imaging. The author also finds that while crispening can be reduced in certain spatial configurations of stimuli, it should not be ignored with respect to digital imaging. A simple example might be the perceived tonal detail in bright clouds. According to a fixed global lightness scaling, such as modified cube-root function used in L*, these lightness differences should not be perceptible. However, relative to the overall high luminance of the cloud smaller luminance differences result in larger lightness differences than they would otherwise.

Finally, the author finds the simultaneous equisection technique to be a simple, efficient and low noise method to quantify a perceptual attribute. Additional testing is underway using this technique to investigate how the uniformity of the background, the lightness of the white and black anchors, ambient illumination and viewing distance impact the results. The author is also gathering data for a modified version of the experiment using reflection prints. Finally, there is ongoing work to apply the technique to other perceptual attributes, such as chroma.

5. CONCLUSIONS

The results of a simultaneous equisection experiment provided experimental data indicating how lightness perception for a CRT in a dark surround is influenced by the lightness of a uniform background. Crispening is evident as a sigmoidal inflection as the stimulus lightness approaches the lightness of the background. Simultaneous contrast is also present and diminishes as the stimuli approaches the device white or black points. These results could provide a more complete model of lightness perception for use in color appearance modeling. Lastly, in spite of giving the observers more control, the experimental technique of simultaneous equisection appears to be an efficient and low in noise method for deriving a scale for a single perceptual attribute.

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