Estimating Chromatic Adaptation in a Museum Environment Using a Tablet Computer

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ABSTRACT

Colour constancy has been explored extensively in the past in lab environments, using a multitude of experimental arrangements and stimuli. Rarely has the phenomenon been investigated in real environments, natural or unnatural, due to the large number of uncontrollable variables and the methodological logistics involved. A potential method for testing chromatic adaptation point, using achromatic setting on a hand-held tablet computer, is proposed and explored.

1. INTRODUCTION

It is generally assumed that a person can adapt fully to light of any chromaticity within a reasonable distance of the daylight locus, meaning that the light itself will appear achromatic and that the colours of objects under such illumination will maintain their chromatic inter-relationships. This process occurs with such effortlessness and efficiency that observers are generally completely unaware of the process, or the extent of the objective change that it masks.

Colour constancy is probably never 'complete' in the general understanding of the term, however, and degrees of colour constancy vary with the methodology used to measure them. Factors include the question asked to the observer (Arend and Reeves, 1986), individual observer 'ability' (Lee and Smithson, 2016), available object types (Kraft and Brainard, 1999), and direction of illuminant colour shift (Pearce et al., 2014). As a result of these and other factors, the point of perceptual achromacy is generally agreed to be somewhere along the line connecting the chromaticity of an object of uniform reflectance in the 'pre-adaptation' illumination and chromaticity of the same object under the 'post-adaptation' illumination. Understanding colour constancy in museum environments is of particular interest because the choice of lighting chromaticity can have implications for conservation (CIE, 2004).

Figure 1. The UCL Grant Museum of Zoology.

Measurement of the state of an observer's chromatic adaptation in real world environments is rarely undertaken (although see Kuriki (2006), due to the complexity involved in creating or sourcing the necessary portable measuring equipment, and the difficulty in accurately monitoring the environment whilst performing such experiments. One method extensively used in the investigation of chromatic adaptation in controlled environments is 'achromatic setting', whereby an observer is instructed through some mechanism to vary the appearance of a stimulus until it appears achromatic. Smithson (2005) notes that the level of colour constancy achieved by human observers is typically less for simulated scenes than for real scenes, and that the typical performance with scenes presented on computer monitors suggests only

50% compensation.
The method proposed here implements achromatic setting in a convenient form that can be used in a range of environments, with the aim of probing the perceptual mechanisms that underlie colour constancy. After a description of the apparatus and method, we report on two initial experiments to explore its applicability.

2. PROPOSED METHOD

The proposed method uses a portable tablet computer, running psychophysical stimulus presentation software (Peirce, 2007), to present two-dimensional colour gradients across isoluminant a*-b* chromaticity space. Observers indicate the point on the display that best represents their personal notion of achromacy (grey) by touching the position with the tip of a finger. After completion of multiple trials, where the stimulus is randomly rotated and translated by ±1/3 of the width and height of the display, a mean and standard deviation are computed to represent the set of given responses. An alternative would be to present successive single dimensional gradients.

Figure 2. An illustration of the presentation device displaying the stimulus.

The question of how many trials need to be completed requires careful consideration. It is assumed that there are unknown variables, which could cause an observer to select a different point depending on the specific stimulus displayed (which varies between trials through rotation and offset), and also that input precision is limited by the input method. It is therefore prudent to take an average over multiple trials, and thus over time, but this assumes that the observer's responses to stimuli are stable throughout the test. If we imagine a session with 30 trials, where each response is made within 2 seconds of the stimulus becoming visible, the session would take no longer than one minute. This should not pose a problem when considering short-term colour constancy (Rinner and Gegenfurtner, 2000), but prior adaptation over longer time periods (MacDonald and Roque, 2013) might influence results. Further, an observer might develop a specific 'technique' as the experiment progresses.
It is unclear whether observers will treat this task as a 'paper match' type of test, or as a 'hue/saturation/lightness' (h/s/l) matching type of test. See Foster (2011) for a discussion of this distinction. A tablet computer screen is an emissive device which is minimally influenced by its surroundings, and thus one might expect a h/s/l type match to be made, and yet it is designed to replicate the functionality of paper, with a well-known reflective surface for which one might expect the natural response to be of a 'paper match' type. Further considerations for this method include the effect of specular reflections from the screen surface, the tendency of an observer to use the periphery of the display device as a colour matching aid (assuming it is neutral), and a tendency for spatial bias towards the physical centre of the presented range.

3. EXPERIMENTS

Two experiments were performed, both utilising the above method on a Dell Latitude 10 ST2 tablet computer with 'BROTECT' Matte Screen Protector (223x126 mm active screen area, 1366x768 pixels, with a pixel pitch of 0.16 mm). The stimulus was specified in CIE L*a*b* values (L*: 60 uniformly across field, a*: ranging linearly from -50 to 50 from one side of the field to the other, and b*: as for a*, but along the perpendicular axis) so that the stimulus was of uniform lightness and smoothly changing hue and chroma. L*a*b* values were converted to XYZ tristimulus values, basing reference white on the XYZ tristimulus values of the display at maximum white (with screen protector). Linearisation of the measured device-dependent values was achieved through the use of a look-up table, computed by spline interpolation of the measured outputs at 15 pixel value increments from 0 to 255. The above was accomplished within Matlab. The stimulus was then saved as an 8-bit tiff image, which could be easily loaded and manipulated by the psychophysical stimulus presentation software PsychoPy. The stimulus was randomly translated and rotated at each trial. Throughout each experiment ambient lighting measurements were taken with a GL Optis 1.0 Touch spectroradiometer.

3.1 Experiment 1

In the first experiment 23 observers, who were members of the public at the UCL Grant Museum of Zoology, performed 10 trials, followed by 10 touch calibration trials (where the observer was asked to touch an unambiguous point on the screen, which varied spatially in the same manner as the previous colourful stimulus). The aim of this experiment was to examine inter-observer variability. Non-identifying demographic data was gathered for later analysis. The museum is lit with a mixture of artificial and natural lighting from large windows (see Figure 1).

3.2 Experiment 2

In the second experiment, two of the co-authors of this paper, referred to as DG and LM, undertook an extended version of the above, with 190 core trials followed by 10 touch calibration trials, in various locations, across several days with repeats in controllable environments. The aims of this experiment were to assess intra-observer variability, and also to ascertain an appropriate number of trials for future participants. 13 full data-sets were collected.

4. RESULTS AND DISCUSSION

For analysis, all achromatic selection data has been converted to CIE L*u*v* co-ordinates relative to the display white, in order that comparisons to the illumination chromaticities can be made.

4.1 How many trials?

Computations were performed upon the data from Experiment 2 to query what number of trials would be required for future studies. For each of the 13 full data-sets (consisting of all u*v* values of selected achromatic point, corrected by spatial calibration, for a single observer in a single location and session), subsets were created by randomly sampling n points from a full set, with n=10 to n=190 progressively. For each new subset the standard deviation, standard error of mean (SEM) and 'confi-

dence interval - 95%’ (CI95) values were calculated, and averaged across all 13 full data-sets, see Figure 2. The CI95 value defines a region either side of the calculated mean, within which there is 95% confidence that the real mean lies. A low value of CI95 is preferable.
It can be seen that for only 10 observations the CI95 is roughly 1.8 u* units or 2.5 v* units either side of the mean. This level of uncertainty would be impractical for analysis of data where the differences in selection point approach these values, but might be acceptable if the levels of difference are greatly in excess of this. After approximately 35 trials, the CI95 drops to 1.0 u*, and after 60 trials the same value is attained for v* units. So 35 trials is probably acceptable in most situations, but for greater precision it can be seen that the CI95 continues to drop as the number of trials is increased further. In practice the estimates for low numbers of trials are likely to be high; due to the resampling method (random, which would ignore slow drifting trends) and the use of the mean rather than the median, as is used in further analysis.

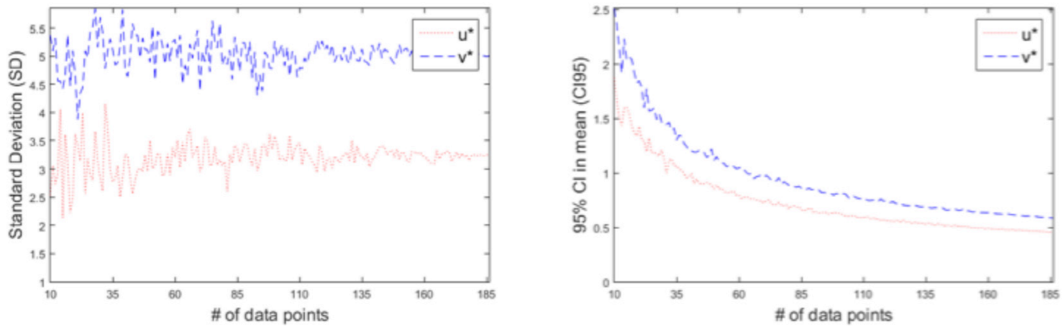

Figure 2. Standard Deviation and CI95 of progressively larger random samples of real data.

4.2 Inter-observer, intra-observer, and location-based variation

In Experiment 1 the standard deviations of the selected points (after data-cleaning where the single furthest data-point from the mean of the cloud was removed in order to filter out mis-selections) for each observer ranged from 1.5 to 14.5 for u* and 2.1 to 13.9 for v*. The standard deviation across observer sets (the apparent inter-observer variation) was 8.0 u* and 13.1 v*. The achromatic points cluster around the numerical neutral point of u*v* chromaticity space. It is not clear to what extent variations in selected neutral point in this dataset were due to inter-observer variation, system noise or variations in lighting conditions. For each observer trial 2 and trial 7 were undisclosed repeats of identical stimuli, and from this an indication of intra-observer variation was calculated: mean difference was 4.0 u*, 5.2 v*. The data gathered in Experiment 2 is presented in Figure 4, where ring centres represent median u* and v* values and the ring diameter equals standard deviation for each dataset. Lines project to the chromaticity of the ambient illumination in each environment, with u*v* values shown numerically. Standard deviations within this experiment range from 2.4 to 4.1 for u*, and 3.2 to 5.0 for v*. The environment with the most repeats was a basement room where there was no natural light ingress, and thus the lighting was constant (fluorescent tubes).

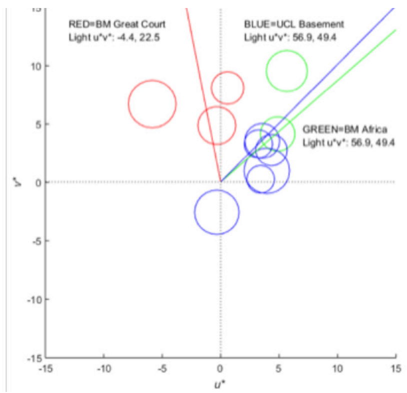

Figure 4. Chromatic adaptation results for two observers in three illumination environments.

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