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Chromatic Adaptation in an Immersive Viewing Environment

Lindsay MACDONALD and Tania ROQUE
University College London

ABSTRACT

A hollow fibreglass sphere of 750 mm diameter was used to create an immersive mesopic viewing environment. Light was projected through a series of 20nm-bandwidth filters to illuminate the interior of the sphere with a near-monochromatic adapting field. The task of the observer was to set a target to appear neutral grey, using two interactive slider controls. The results suggest that chromatic adaptation is continuing even after an hour, suggesting the influence of retinal mechanisms with a very long time period.

1. INTRODUCTION

Chromatic adaptation is the visual process whereby approximate compensation is made for changes in the colours of stimuli, especially in the case of changes in illuminants (Hunt, 2011). The human visual system tends to adjust colour perception on the assumption that an object of constant reflection spectrum is illuminated by a light source of varying intensity and spectrum, as is usually the case in the natural world. There are many theories about the underlying visual mechanisms of colour constancy (Smithson, 2005). Chromatic induction is the change in perceived color of a light caused by a nearby inducing stimulus (Shevell, 1998) and is at its strongest when the inducing field completely surrounds the target. It is generally assumed that under photopic conditions chromatic adaptation of the cone photoreceptors is complete within a few seconds (Pattanaik *et al*, 2000), whereas for mesopic and scotopic (low-light) conditions at least 15, preferably 25, minutes are needed before the bleached rods become fully active. In all psychophysical experiments observers are allowed an initial period in which to adapt, but then it is invariably assumed that no further changes occur and that the observer's visual operating state remains constant.

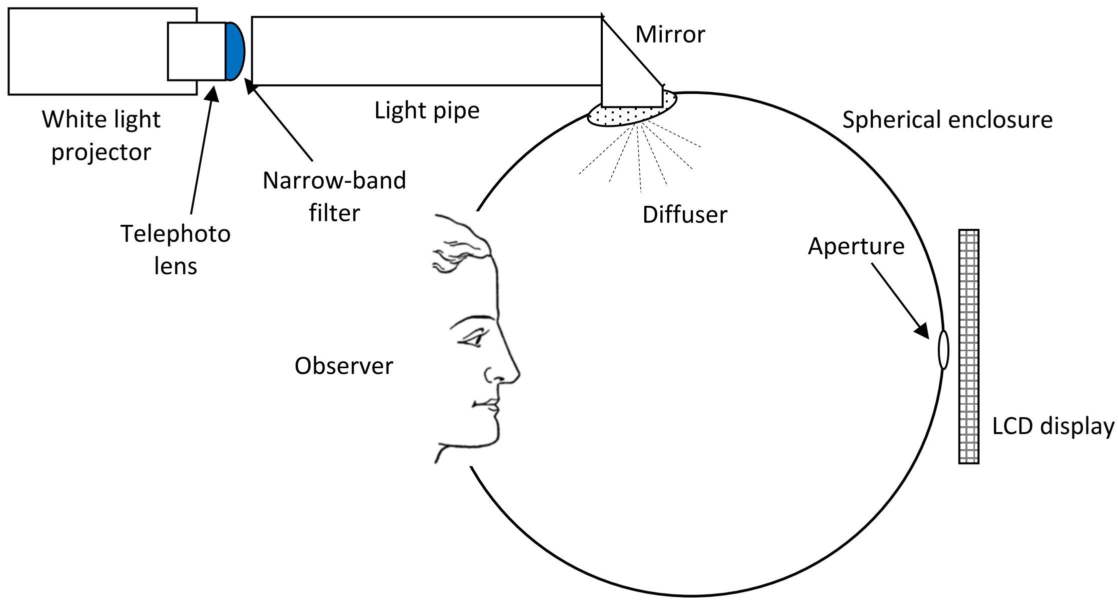

Figure 1. Schematic arrangement of apparatus for experiment

2. EXPERIMENTAL METHOD

In a novel study a hollow fibreglass sphere of 750 mm diameter was used to create an immersive viewing environment (Fig. 1). The interior surface was painted matte grey, of approx. 38% reflectance factor. The shell was cut away on one side to allow an observer's face to be inserted, from above the top of the head to below the chin and in front of the ears. On the opposite side was a circular aperture of 45 mm diameter, subtending a visual angle of 4° to the seated observer at an eye distance of ~650 mm, through which visual stimuli were presented from a flat-panel LCD display. Above the observer's head was a source of near-monochromatic illumination, passing white light from a Kodak 35mm slide projector with an open gate and 150mm telephoto lens through a single 20nm narrow-band filter. The light was conveyed through a pipe silvered on the inside and through a diffuser to produce approximately uniform illumination throughout the interior of the sphere, and therefore across the observer's entire visual field. The experiment was conducted in a completely darkened room, with the projector screened to minimise stray light. The viewing mode was binocular, without fixation or any other restrictions on eye movement.

The observer's task was to set the colour seen through the aperture to neutral, by adjusting two linear slider controls (Fig. 2) for independent red-green and yellow-blue variation. The sliders were linked through a micro-controller via a USB interface to a PC running Matlab to update the colour patch interactively on the display. No time restriction was placed on the observer while adjusting the controls, and when a satisfactory visual neutral was achieved a button was pushed to indicate completion. Each 'match' was time-stamped and the R,G,B display values saved. The starting colour for each match was randomised. The task was repeated ten times over for 16 display lightness levels (5-unit decrements of L^* from 85 down to 15) for a fixed adapting wavelength in a single session. For the 16 filter wavelengths, at 20 nm intervals from 400 to 700 nm spanning the visible spectrum, a total of 2560 judgements was recorded.

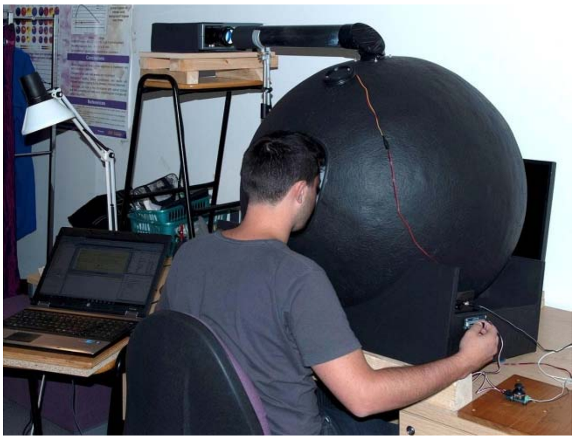

Figure 2. Experimental apparatus in use.

3. RESULTS

Two observers (LM and TR) completed the full cycle of sixteen sessions. The same procedure was used by both observers, but the white point of the display was changed from 'cool white' for LM (*XYZ*=99.04,100,151.30) to 'warm white' for TR (*XYZ*=94.97,100,98.15). Session lengths for the individual wavelengths ranged from 45 to 59 with a mean of 54 minutes (LM) and from 72 to 118 with a mean of 93 minutes (TR), corresponding to average match times of 20 seconds (LM) and 35 seconds (TR).

The spectral power distributions of both surround and display were measured with a PhotoResearch PR-650 spectroradiometer (Fig. 3). The average luminance of the surrounding chromatic adapting field ranged from a maximum of 0.75 cd/m^2 at 560 nm to less than 0.05 cd/m^2 at the ends of the spectrum, corresponding to a retinal illuminance through a pupil of diameter 8mm ranging from 38 trolands (max) to less than 2.5 trolands, meaning that the viewing environment was in the upper mesopic range.

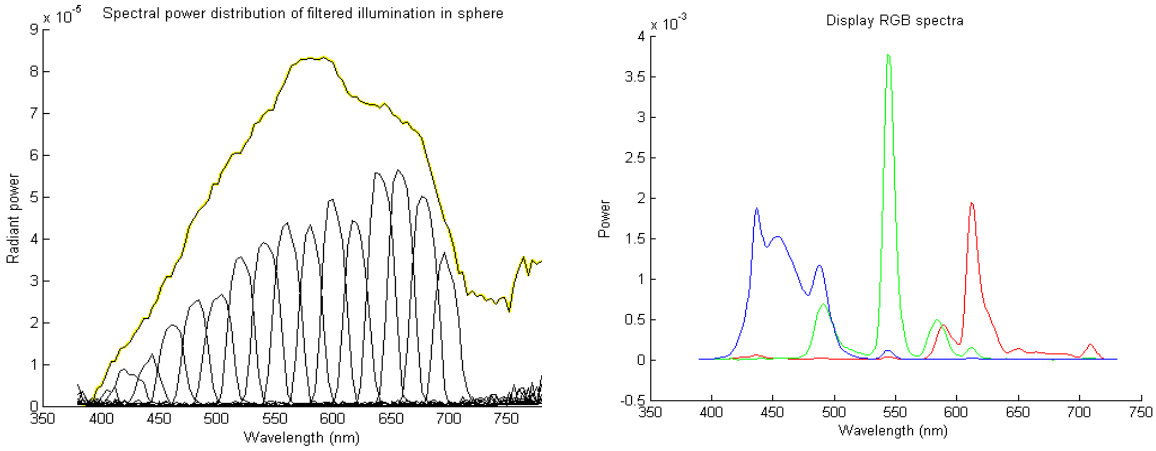

Figure 3. Spectral power distribution measured by PR-650 of: (left) projector light source unfiltered (yellow) and through each filter; and (right) LCD display primaries.

The tone reproduction curve (relationship between 8-bit signal and display luminance) for each channel was determined by interpolating the 21 measured luminance values to give a lookup table of 256 entries. For analysis, the saved display R,G,B signals for each match were converted to L,M,S cone excitations by multiplying the spectral power distribution of each display primary by the corresponding luminance factor (from the LUT), weighting by the spectral sensitivities of the 10-degree cone fundamentals (Stockman *et al*, 2000), and summing over the full spectrum at 1nm intervals. For visualisation, the data was also interpolated along the time axis to 1-minute intervals and on the wavelength axis to 5nm intervals. Colours are shown as sRGB for a D65 white reference.

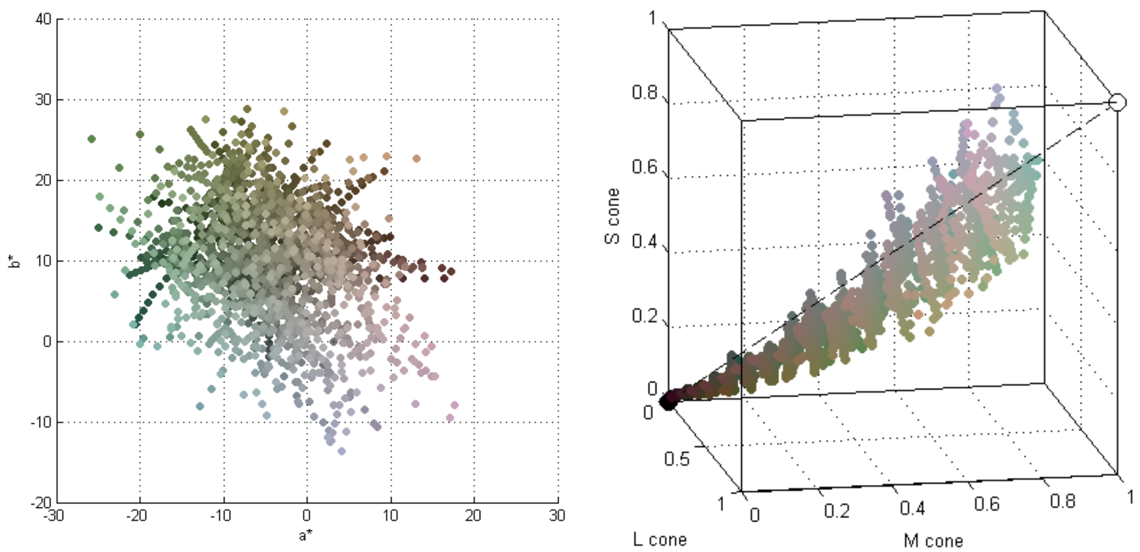

*Figure 4. Display colours selected as neutral: (left) in the CIELAB *a*b* plane; (right) in a cube of normalised L,M,S cone response signals (observer LM).*

4. DISCUSSION

The colours selected as neutral cover a remarkably large colour gamut: -25<*a**<+15 and -15<*b**<+25. Similar variability around the neutral axis is apparent when the corresponding L,M,S cone responses are plotted in a unit cube (Fig. 4). The variation of cone responses against adapting wavelength clearly shows the influence of the chromatic opponent pathways (Hurvich and Jameson, 1957). Plotting the results against time (Fig. 5) also shows the process of adaptation to the coloured surround, with the intrusion of the rods after 10-15 minutes strongly influencing L-cone and S-cone responses. What was surprising, however, was that after 30 minutes the influence of the rods diminished, as if some over-riding mechanism were restoring the chromatic balance to its cone-mediated state. Also the L-cone excitation steadily continued to diminish in the region 480-520 nm, even after 70 minutes for observer TR. To investigate this phenomenon, five consecutive sessions were conducted under the same conditions with a fixed adapting wavelength of 500 nm. The time course of the adaptation was different in every case, with the colour balance (relative output of L,M,S) continuing to fluctuate, but the trend was always downward, indicating the influence of some retinal mechanism with a time constant in excess of one hour. If it can be shown that this is true in general, the result has profound implications for the design of experiments and validity of data from all psychophysical studies where judgements of colour stimuli are made.

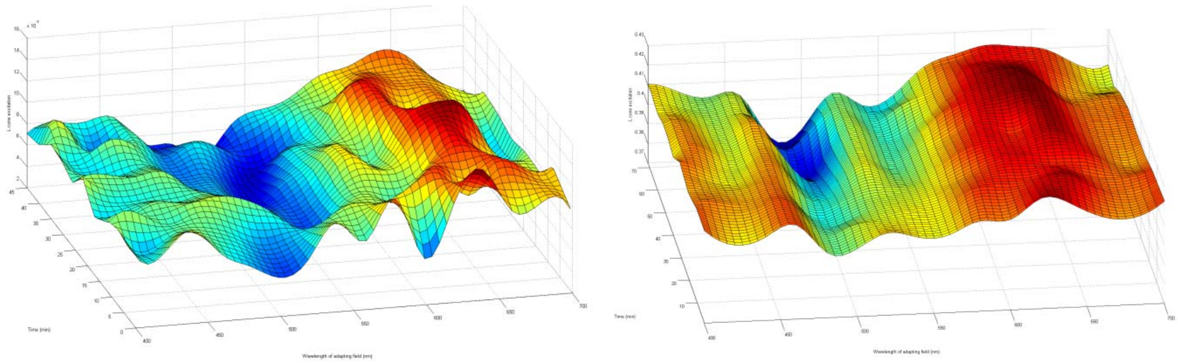

Figure 5. 3D plots of L cone excitation (Z axis) vs adapting wavelength (X axis) and time (Y axis) for two observers: (left) LM and (right) TR.

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Address: Lindsay W MacDonald, Department of Medical Physics,
University College London, Gower Street, London WC1E 6BT, UK
E-mails: ucfslwm@live.ucl.ac.uk, t.roque@ucl.ac.uk