Effect of Illuminance and Colour of Light Source on Assessing Tooth Whiteness

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ABSTRACT

The aim of this work is to investigate whether light source illuminance and colour affects the rank order of tooth-coloured samples assessed for whiteness. Four different light sources varying in colour temperature (CCT) and illuminance (Lux) have been used: 3000K/700Lux, 6500K/700Lux, 6500K/350Lux and 8500K/700Lux. A total of 30 observers ranked the Vita Toothguide 3D-Master with Bleached shade guide (29 artificial tooth tabs) in terms of whiteness under each of the four illumination conditions. The rank data were used to generate interval-scale perceptual whiteness values. Instrument whiteness results were obtained from CIE XYZ tristimulus values that were calculated under each of the illumination conditions. The WIO whiteness index that was especially developed for use in dentistry was explored and the importance of using the correct white point in this equation was investigated. Performance of the instrumental results was assessed by correlation (using coefficient of determination) and an empirical test using a wrong decisions criterion. Results indicate that the rank order of visual whiteness for tooth-coloured samples is invariant to changes in the colour and intensity of the viewing illumination. Variation in the white point of the WIO equation does not affect agreement with interval-scale visual whiteness values because changing the white point is simply an affine transform.

KEYWORDS: whiteness, light source, dentistry

INTRODUCTION

Tooth colour is one of the key aesthetic factors in oral health and in fabrication of ceramic restorations. Colour of teeth can be visually assessed using traditional shade guides. There are a number of commonly used shade guides including Vitapan Classical, Toothguide 3D-Master and Linearguide 3D-Master [1]. One of the most important factors in shade-matching is the light source. The recommended standard for dental shade-matching is a colour temperature of 5500K and a colour rendering index of 93 or above [2-3]. However, visual assessment is considered to be subjective. The instrumental approach for measuring the colour of teeth uses colorimeters, spectrophotometers [4], spectroradiometers and digital imaging systems [5].

The whiteness of teeth assessed instrumentally is generally quantified by whiteness indices [6]. Whiteness indices are used for evaluation and prediction of the whiteness of teeth and assessment of changes in tooth whiteness [7-8]. One particular whiteness metric, the WIO [9], was derived from the CIE whiteness metric and is based on the CIE XYZ system; it was developed and optimized specifically for evaluation of tooth whiteness. It has been proven to be robust and adequate for tooth whitening research. In recent years, however, a new whiteness index WI_D was optimized in CIELAB colour space based on correlations with visual perception of tooth shaped shade tabs and dental materials [10].

The most common light sources used in dental studios are incandescent and fluorescent. The incandescent light bulb emits relatively higher amounts of long wavelengths whilst the fluorescent light bulb emits relatively more of the shorter wavelengths. Tooth colour assessment is normally performed under D50 (5500K) illuminants, which provide the closest colour rendition to natural sunlight in order for the clinicians to see and select the correct shade [11]. Meanwhile, the WIO equation was developed using visual assessments that were made under D65 and the equation has been published using the D65 white point. Although some research has been carried out on the effect of light conditions on tooth colour assessment [12-14] there is still uncertainty about the robustness of, for example, the perceptual rank order of tooth samples when viewed under different lighting conditions. It is also not clear whether the white point in the WIO equation should be modified depending upon the colour of the light under which it is intended to predict whiteness. In this study, we explored the effect of illuminance and colour of light source on assessing tooth whiteness and robustness of WIO under different lighting conditions with different white points.

EXPERIMENTAL

The experiment was conducted in a dark room only illuminated by four spectral-tuneable LED light cubes (THOUSLITE) installed on the ceiling. Four different lighting conditions (Table 1) were prepared and each lighting condition was applied to all four LED cubes at any one time.

Table 1. The four different light settings used in the experiment

Lighting	Correlated Colour Temperature (K)	Illuminance (Lux)	Luminance (cd/m^2)	x_n	y_n
Illuminant 1	3000	700	224	0.4378	0.4062
Illuminant 2	6500	350	114	0.3124	0.3287
Illuminant 3	6500	700	228	0.3144	0.3207
Illuminant 4	8500	700	227	0.2889	0.3050

The Vita Toothguide 3D-Master with Bleached Shade Guide (29 tabs) was used in this study. The colours of the shade tabs were measured by a spectrophotometer (Konica Minolta CM-2600d) which recorded spectral reflectance, CIELAB and CIE XYZ values. The colours of the tabs were plotted in CIELAB colour space (Figure 1.). A total of 30 observers were asked to rank the shade tabs in terms of whiteness under each lighting condition. There was a 2-minute adaptation to the new lighting condition after each light has been changed before the start of each ranking task. The rank-order data were used to calculate interval scale perceptual whiteness values for each tab under each lighting condition.

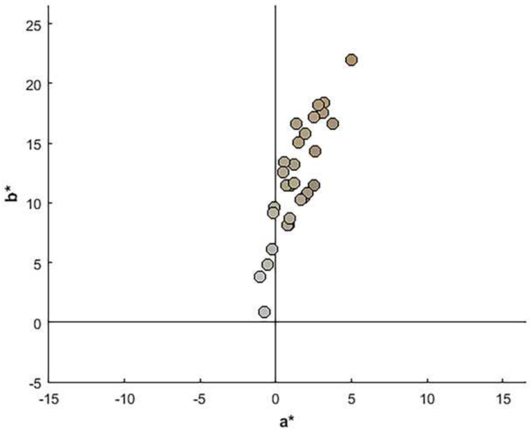

Figure 1: Colours of the 29 shade tabs measured with a spectrophotometer plotted in CIELAB colour space.

It is not clear from the literature whether WIO is defined by Equation 1 or by Equation 2.

$$WIO = Y + 1075.012\times(x_n - x) + 145.516\times(y_n - y) \quad (1)$$

where x_n *and* y_n are the chromaticity coordinates of the white point (for D65 this is x_n is 0.3138 and y_n *is* 0.3310).

$$WIO = Y + 1075.012\times(0.3138 - x) + 145.516\times(0.3310 - y) \quad (2)$$

In this work, the metric in Equation 2 is defined as WIO (where the white point is fixed) and the metric in Equation 1 will be referred to as a modified WIO (where the white point is changed according to the viewing conditions). When the modified WIO was calculated the values of x_n and y_n were taken from Table 1 depending upon the lighting condition.

Performance of WIO methods was assessed by comparing the values with the visual whiteness values and calculating the correlation (expressed by the coefficient of determination r^2) and the wrong decisions criterion. For wrong decisions, the samples are considered pairwise pair (there are 406 possible pairwise comparisons) and for each the instrumental result (obtained using either Equation 1 or Equation 2) is deemed to be correct if it places the pair in the same whiteness order as the visual result (obtained from the interval scale values that result from the observations made by 30 observers under the test light source). If the per cent of wrong decisions is zero then the instrumental pairwise whiteness decisions would be identical to the visual decisions.

RESULTS AND DISCUSSION

It may be that the colour appearance of the tabs varied under different lighting conditions but we did not assess this. Our interest is whether the relative colour appearance (specifically, whiteness) of the tabs stays the same (so, for example, they all may look a little redder under one light source rather than another but they would still be placed in the same rank order in terms of perceptual whiteness if evaluated by an observer).

Figure 2 shows the perceptual whiteness interval scale values obtained for the tabs under different conditions. In Figure 2 (left) the whiteness values obtained from the observations under light at 3000K are plotted against those obtained under light at 8500K (r^2 = 0.996). In Figure 2 (right) the whiteness values obtained from the observations under 6500K light at 700 lux are plotted against those obtained under 6500K light at 350 lux (r^2 = 0.996).

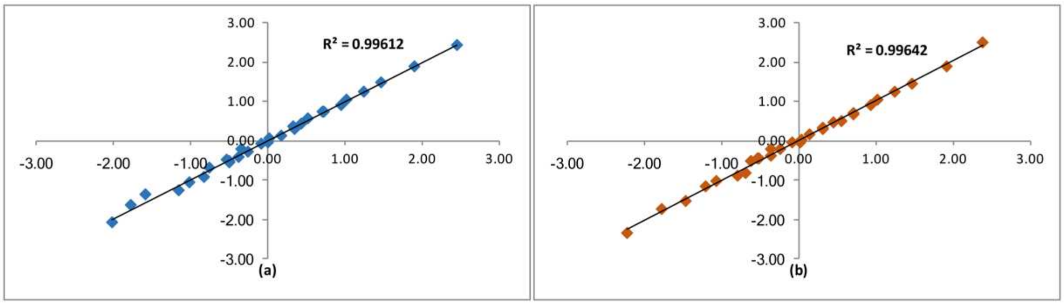

Figure 2: (a) Correlation between perceptual whiteness when viewed under 3000K and 8500K illumination; (b) Correlation between perceptual whiteness when viewed under 700 lux and 350 illumination at 6500K.

From Figure 2 it is evident that relative assessment of whiteness for teeth samples is invariant to changes in the colour and intensity of the illuminant within the ranges that were included in this study (illuminance between 350 and 700 lux and between 3000K and 8500K). Table 2 shows the variability between observers and it is evident that this is very similar under all four lighting conditions.

Table 2. Observer variability was obtained by calculating the average per cent wrong decisions when each observer is compared with the average visual rank order (the maximum per cent wrong decisions is given in parentheses)

	Illuminant 1	Illuminant 2	Illuminant 3	Illuminant 4
Observer variability	4.2 (9.4)	3.8 (7.6)	4.3 (7.4)	4.2 (6.9)

In order to compare the visual results with the instrumental results, the XYZ values were calculated for the samples using the spectral power distribution of the light source used in the visual observations. However, the WIO values were calculated using either the fixed D65 white point (denoted WIO) or using the white point of the illumination under which the samples were viewed.

Table 3. Correlations (r2) between perceptual whiteness and whiteness indices

	Illuminant 1	Illuminant 2	Illuminant 3	Illuminant 4
r^2 (WIO)	0.91	0.88	0.89	0.89
r^2 (modified WIO)	0.91	0.88	0.89	0.89

Table 4. Agreement between visual assessment and instrumental measurement (Wrong Decisions)

	Illuminant 1	Illuminant 2	Illuminant 3	Illuminant 4
%WD (WIO)	6.65	8.62	8.37	9.85
%WD (modified WIO)	6.65	8.62	8.37	9.85

There is some evidence that the instrumental results agree best with the visual results under illuminant 1 (3000K at 700 lux) and agree least with the visual results under illuminant (8500K at 700 lux). There is no effect of changing the values of x_n and y_n in the WIO equations on the agreement between visual and instrumental results.

CONCLUSION

The primary finding from this work is that the average visual rank order (in terms of whiteness) of a series of tooth-colour tabs is unchanged by the colour temperature and the intensity of the illumination. In other words visual assessments of tooth whiteness are relatively robust to moderate changes to the colour and intensity of the viewing illumination. There is also no evidence that participants' inter-observer variability is affected by the colour or intensity of the light source.

It was found that a WIO index calculated using a fixed white point (Equation 2) or under the white point that matches the viewing illumination (Equation 1) produced identical correlation (measured either using coefficient of determination or per cent wrong decisions) with the visual scale values. This is because the visual scale values are interval data (not ratio data) and changing the white point in Equation 1 (for example) is an affine transformation (interval scale data are invariant to affine transformations). It is interesting, however, that there was some evidence that the instrumental-visual results agreed best under 3000K and agreed least under 8500K and further work may be needed to confirm this.

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