Inter-observer variability of colour vision and its effect on the colour quality of modern light sources

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1 Introduction

Modern light sources, including white LED lamps, constitute promising reliable, energy efficient, long-life alternatives to conventional lighting. In their indoor applications, one aim of their spectral optimization is to ensure a good colour quality of the lit environment. Factors of colour quality include the true appearance of object colours (colour rendering), little or no distortion of colour harmonies (harmony rendering), appearance of small and large colour differences (colour discrimination capability and "visual clarity"), as well as colour preference [1]. However, perceived colour quality can be different for different observers i. e. for different users of the indoor lighting application. This is due to their different colour vision characteristics even within the group of "normal trichromatic" observers [2]. This inter-observer variability is expected to be large for modern light sources. Aim of this work is to quantify this variability in terms of a visual colour rendering index by evaluating a new experimental dataset accumulated in a viewing booth illuminated by both modern and conventional light sources.

2 Experimental method

A viewing booth was constructed (Figure 1) with two chambers of white walls (240 cd/m^2) for the test light source and the reference light source. Two types of white phosphor LEDs at 2700 K ($u' = 0.26$; $v' = 0.53$; HC3L - high CRI: $Ra = 97$; and C3L - low CRI: $Ra = 67$), an RGB-LED-cluster ($T_c = 2700$ K, $Ra = 17$), and two warm white fluorescent lamps (LL640, $Ra = 64$ and LL930, $Ra = 90$) as test light sources and a tungsten halogen reference light source approximately at the same chromaticity.

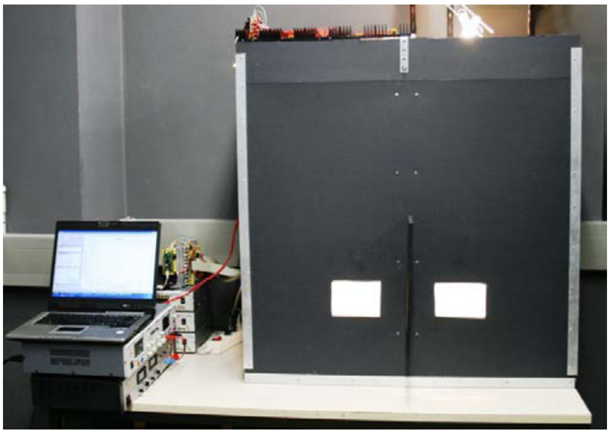

Figure 1: Viewing booth with two parts for the reference and test light sources

Two identical copies of four-degree matte colour papers of different colours were used. Twelve colours were selected (Figure 2) from the Macbeth Colour Checker Chart (Nos. 1-12) and five were taken from the NIST colour set (Nos. 13-17).

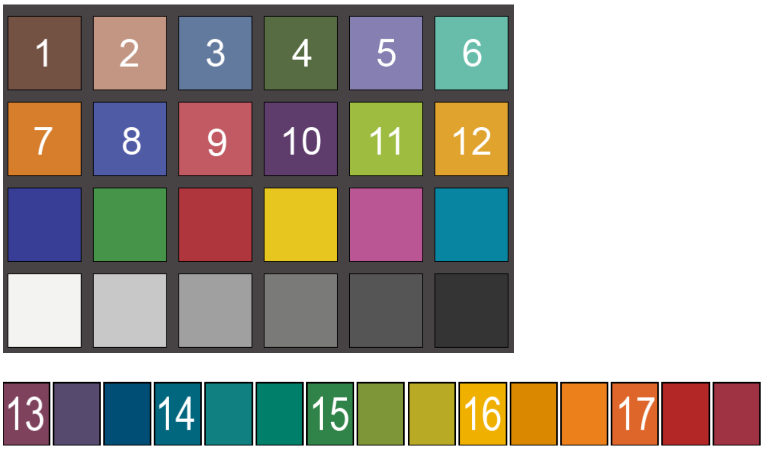

Figure 2: Colour samples: MacBeth ColorChecker Chart (1-15) and NIST colours (16-20)

These colours appeared on a grey background (59 cd/m^2). Six observers of normal colour vision scaled the perceived colour differences (ΔE_{vis}) between the test side and the reference side in the viewing booth for each of the test colours. The grey scale colour difference anchors (Figure 3) helped fix the scale of colour difference assessment.

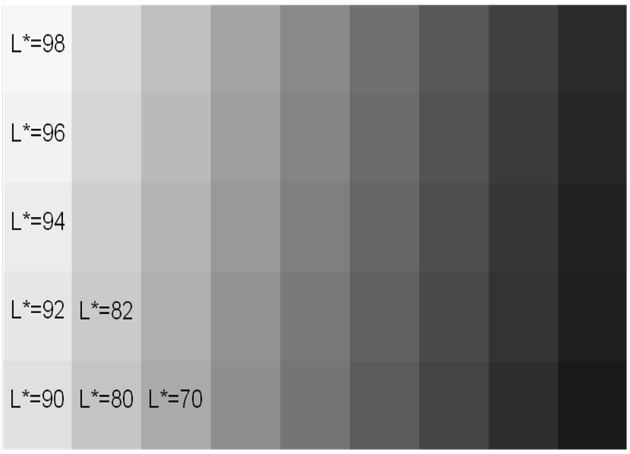

Figure 3: Grey scale to fix the scale of colour difference assessment

3 Results and discussion

From the ΔE_{vis} dataset obtained by the observers, a visual colour rendering index was calculated for each of the five test light sources in the following way:

$$R_{vis} = 100 - 0.5038\ \Sigma\langle\Delta E_{vis}\rangle \qquad (1)$$

In Equation (1), $\Sigma\langle\Delta E_{vis}\rangle$ represents the sum of the average visual colour differences computed for each of 17 test colour samples separately. Averages were computed by considering the answers of all observers. The factor 0.5038 was chosen to get $R_{vis} = R_a = 64$ for the fluorescent lamp LL640. To estimate the effect of inter-observer variability on light source colour quality, the same visual colour rendering index was also computed for each of the six observers (AG, HS, NH, PB, WK, TK) separately: $R_{vis,i}$ (i = AG-TK). Figure 4 shows the result. Note that at this stage of our research some light source data are still missing for some of the observers.

As can be seen from Figure 4, the mean visual colour rendering index is slightly higher than R_a for C3L, lower than R_a for HC3L, slightly lower for LL930 and significantly higher for RGB. Concerning the inter-observer variability of visual colour rendering, the two white phosphor LEDs produced relatively small standard deviations: STD (R_{vis}, C3L) = 7 and STD (R_{vis}, HC3L) = 5. The fluorescent lamp LL640 yielded medium inter-observer variability: STD (R_{vis}, LL640) = 9 while the RGB LED cluster produced the highest variability, STD (R_{vis}, RGB) = 13. We could not evaluate the fluorescent lamp LL930 at this point of the research but the observations are continuously underway.

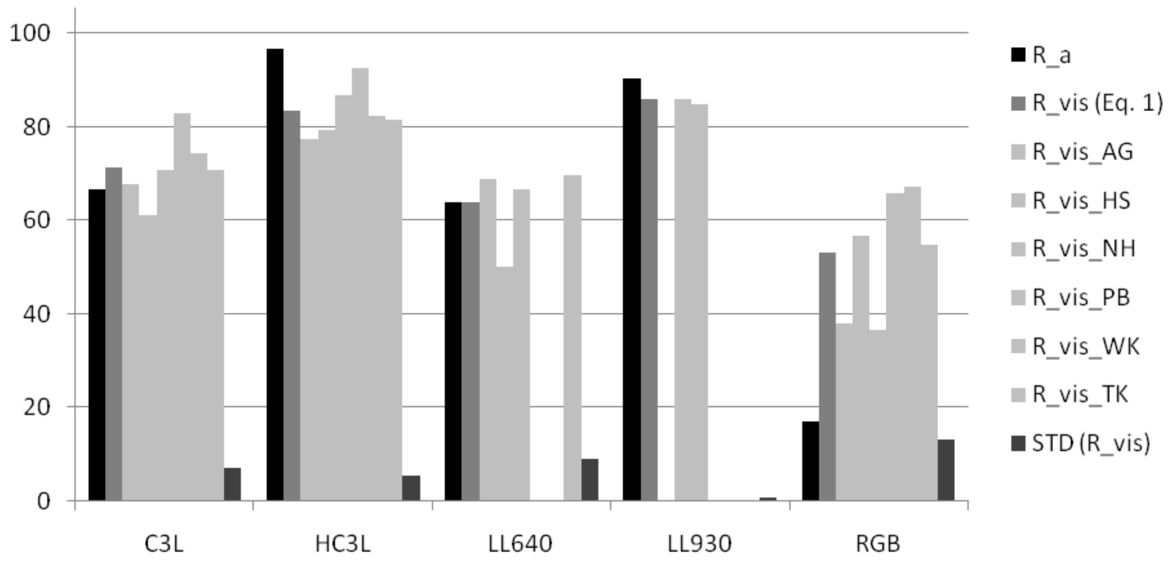

Figure 4: Values of the CIE CRI (R_a) compared with the mean visual colour rendering index (R_{vis}) from Eq. (1), with the individual visual colour rendering indices $R_{vis,i}$ (i = AG-TK) and the standard deviation (STD) of $\{R_{vis,i}\}$

Nevertheless, the current result has the following important implication. White phosphor LEDs cause less inter-observer variability of visual colour rendering than RGB LEDs and possibly also less than low-CRI fluorescent lamps. If the inter-observer variability of visual colour rendering is high then any new light source optimized for a standard observer will not be acceptable for an important subset of observers (here we talk about observers of normal colour vision only). This is why it is important to consider also the inter-observer variability of colour rendering in addition to its actual value for a standard observer.

Reasons of this inter-observer variability include the variability of the photoreceptor spectral sensitivities (colour matching functions) among observers of normal colour vision [2] as well as the variability of retinal and post-retinal (colour discrimination) mechanisms [3]. Possibilities of mathematical modelling of the former have already been considered [4] but we believe that the latter (i.e. the variability of colour discrimination mechanisms) plays a more important role. In the next future, more experimental data with further observers and further test light sources including 5000 K will be accumulated and evaluated. A mathematical modelling of the phenomenon is also foreseen to support light source designers.

4 References

1. Commission Internationale de l'Eclairage (CIE), Colour rendering of white LED light sources, CIE 177:2007.

2. Alfvin, R. L., Fairchild, M. D. (1997). Observer Variability in Metameric Color Matches using Color Reproduction Media, Color Research and Application, 22 (3), 174-188.

3. Oicherman, B., Luo, M. R., Rigg, B., Robertson, A. R. (2008). Effect of observer metamerism on colour matching of display and surface colours, Color Research and Application, 33 (5), 346-359.

4. Frohnapfel, A., Brückner, S., Bodrogi, P., Khanh, T. Q. (2009). Untersuchungen zur Farbwahrnehmung. Personenabhängige Streuungen der Farbwahrnehmungen und Konsequenzen für die Farbpraxis. FKT, die Fachzeitschrift für Fernsehen, Film und elektronische Medien, 2009 / 1-2, 19.