LED's Viewed through Coloured Lenses

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ABSTRACT

The chromaticities and contrasts of a yellow LED simulating a traffic signal and of an instrument panel indicator (simulated by mixing light from two LED's) were calculated for viewing through three popular sunglare protection or driving lenses. Colour naming and quality rating of the lights confirmed the theoretical changes in chromaticity and contrast. If LED's are to be used for non-trivial indicating or signalling tasks, the likely effects of viewing through coloured lenses (sunglasses) must be considered.

1. INTRODUCTION

The availability of an increasingly large range of inexpensive, reliable LED's of differing colours and with spectral power distributions that can be narrow or wide enough to approach a full "white" spectrum [1], is to be welcomed by technologists for their many potential applications. One obvious use of LED's is for indicators and signals in equipment of all kinds. Some indicators are used to signal operational states of industrial processes and they must be clearly perceived by operatives and their meanings must be unambiguous. LED indicators are being introduced into automobile dashboards and are found in trains and aeroplanes: in these applications clarity is also essential. With the advent of high brightness LED's the range of uses has increased and they are coming into use in roadside traffic signals where viewing conditions vary much more than in the control room of a factory or power station. The visibility of such signals must be high, and remain high in all kinds of environments, e.g. full sunlight, darkness, snow and rain. These signals will be viewed by people with normal colour vision or colour vision defects, and will often be viewed through glasses which may be coloured for medical reasons or so as to offer glare protection (sunglasses). Increasingly popular are tinted glasses used to enhance the apparent contrast of the visual scene when driving, skiing, etc.

Any coloured lens may enhance, or reduce, the contrast for both colour and brightness between a signal light and its surroundings - the kind of changes that can occur were extensively described by Phillips and Kondig [2]. These must be taken into account especially when near monochromatic LED's are to be used as warning indicators. Some coloured lenses show gradual changes of transmittance across the spectrum whilst others have spectral regions of rapid change with "absorption bands". The purpose of this paper is to examine some popular lenses intended for light hazard protection, and for improving visual performance whilst driving, to see if they alter the contrast and perceived colour of LED signals. Theoretical studies are augmented with some experimental data.

2. METHODS

A number of LED's were chosen from an electronic supplier's catalogue because they had peak emissions in those areas of the spectrum that are usually employed for signals, *viz* red, yellow and green. Their relative SPD's were measured at various driving currents with a Zeiss spectroradiometer calibrated against a lamp with a spectral output traceable to NPL standards. Cross sections of the spatial distribution of the emitted beam were also measured with a suitably calibrated detector mounted behind a pin hole of known area. From a range of popular sunglare and "driving" lenses, three examples were chosen because one had deep absorbance bands in the visible (reminiscent of the absorptions bands of didymium), one was fairly neutral in appearance and one was a blue blocker. The spectral transmittances (see figure 1) of these lenses, here termed **spec 2**, **spec 3** and **spec 6**, were measured with a Perkin Elmer Lambda V spectrophotometer. The Excel spreadsheet was used to calculate the chromaticities and luminances and from these luminance differences, contrasts and chromaticity shifts introduced by the lenses were determined.

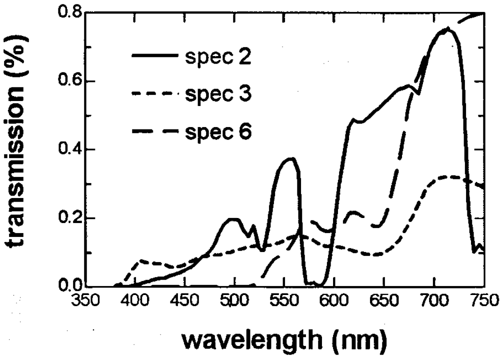

Figure 1 *Spectral transmission of the lenses*

Because the lens spec 2 had a low transmittance in the yellow region of the spectrum, it was decided to simulate, using an appropriate yellow LED as the signal source, the appearance of a yellow road traffic signal seen from 100 m against a daylight background. The simulated signal had a black "signal board" surround of the recommended dimensions and was viewed at 1 metre. It had an intensity of 0.0607 cd which was equivalent to 607 cd at 100 m. The luminance of the white background (subtended size 60 by 54 degrees) was 700 cd.m^{-2} at a colour temperature of 6000K.

A coloured indicator lamp on an instrument panel was also simulated . The panel was white with a luminance of 25 cd.m^{-2} at 2880K (tungsten), viewed at 500 mm so that its subtense was 23° high and 30° wide. The indicator was a circular opening in the panel subtending 0.5° at the eye. This aperture opened into a small integrating box painted internally with matte white titanium oxide paint. The box was internally illuminated by the light from two LED's. The chromaticity of the indicator was adjusted by changing the intensity of each LED. The relative intensities of the LED's were controlled by regulating the DC currents and by placing neutral mesh attenuators over the diodes when necessary.

Adults (20 to 60 years) with normal colour vision (D15 Test) were used and these subjects wore their (untinted) corrections if necessary. There were two experimental procedures. In the first, the subjects viewed the simulated yellow traffic signal with their naked eyes (and correction if necessary) and were told the signal had a "quality" of 100% as a traffic signal. They then viewed the signal with each of the three coloured lenses in turn and rated the quality of the signal on their own percentage scale, ascribing a score less than 100 for a degraded perception of the signal and more than 100 for an enhanced signal. They also reported whether the signal appeared brighter or dimmer and whether it had changed colour.

Table 1 *Chromaticity of simulated indicator*

condition	x	y	luminance (cd.m^{-2})
weg	0.188	0.378	60
eew	0.351	0.354	70
nw	0.445	0.439	76

For the second experiment, subjects viewed the simulated indicator with their naked eye (and correction if necessary) and then with the three coloured lenses. They were told they were viewing a control indicator that could have only one of the permitted indicator colours:

blue, green, yellow, orange, red or **white**.

The chromaticity of the indicator was set to one of three values, as shown in the Table 1, by varying the light output of each LED. Each condition was designated from its position on the chromaticity diagram, namely: white edge of green (weg), equi-energy white (eew) and near white (nw).

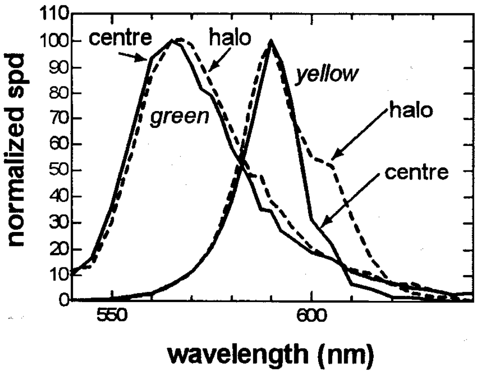

Figure 2 *Showing the spd of the central beam and of the halo for a green and a yellow LED.*

3. RESULTS

3.1 Properties of LED's

The spatial distribution of the light output from some diodes was approximately uniform within its divergent beam but for some LED's the distribution was very heterogeneous, varying markedly within each batch. For two LED types that were not used in this study, the distribution showed a central beam and a halo which had an spd different to that of the central beam. The halos contained a substantial percentage of the output of the diodes, 23% for the yellow diode shown in Figure 2. In the experiments no diode type with a halo was used.

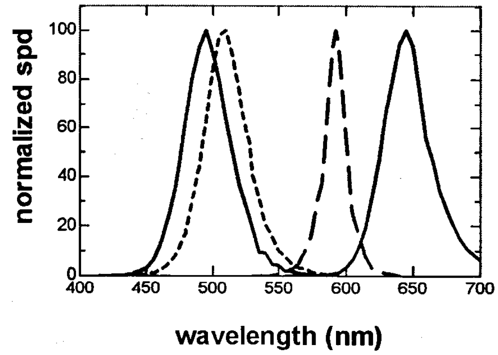

Figure 3 *Normalized spd of the diodes used: the two curves for the green LED are for different driving currents - see figure 4*

Figure 3 shows the spectral power distribution of the three LED's used in the experiments. As well as exhibiting a λ_{max} characteristic of each specific type of LED, the spd's also vary in shape and width. It also became apparent that the spd varied within a type of LED. For example, in a batch of green LED's such as that in Figure 3, the chromaticities ranged from x = 0.4085 to 0.4202 and y = 0.5767 to 0.5886. These differences could be important for precise work.

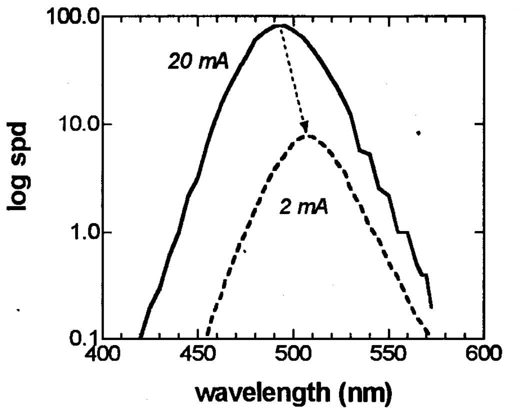

Figure 4 *The shift in the spd of the green LED when driven at the recommended 20 mA or at 2 mA.*

The LED data sheets recommend a typical drive current and state that at reduced current the light output is reduced. This is indeed so but the relationship is not necessarily linear. Also, for some, but not all, of the LED types investigated the spectral power distribution changed with current. Figure 4 shows the situation for the green LED run at the recommended 20 mA and at one tenth of this. The light output is reduced to about a tenth but the spd is shifted to longer wavelengths. Changes of spd with current were allowed for in all the experiments described here.

3.2. Yellow Traffic Signal

Table 2 shows the chromaticities of the signal when seen through the lenses and the contrast of the signal which is defined so:

$$c = \frac{L_{sig}}{L_{back}} \times 100$$

where L_{sig} is the luminance of the signal and L_{back} that of the background. All the subjects were prepared to award the simulated yellow traffic signal a "quality" score, based upon the no-lens case being 100%, when viewing through the coloured lenses. The mean score is also shown in Table 2 together with the ranking of the quality based upon the quality score assigned by each subject, shown as the number of subjects for each rank.

3.3 Colour of LED Indicator

By adjusting the light output of the two diodes into the integrating box it was possible to obtain any chromaticity for the indicator along the axis that connected the chromaticities of the green and the red LED's. Figures 5, 6 and 7 show the chosen points referred to a **weg**, **eew** and **nw**. The chromaticities of these points are given in Tables 3, 5 and 7. These Figures and Tables also show the chromaticities of the diodes and the indicator in all four viewing conditions. The shifts are more easily compared in the figures. The chromaticity of the red diode hardly changed from the no-lens condition to that with any of the lenses: for all of them it stayed within the CIE red traffic signal box. The changes for the green LED were small except for the **spec 6** lens which was the blue blocker.

Table 2 *Showing the chromaticities, contrasts, mean quality scores and the frequency of each rank of the score for the four viewing conditions*

	no lens	spec 2	spec 3	spec 6
x	0.577	0.612	0.573	0.577
y	0.422	0.388	0.426	0.422
contrast	28	9.3	27	40
mean score	--	80	87	95
rank 1	--	2	2	10
rank 2	--	4	8	0
rank 3	--	8	3	3

The changes for the **weg**, **eew** and **nw** were small for the near neutral **spec 3** lens but were all redwards along the relevant confusion axis for **spec 2** and dramatically so for **spec 6**.

Tables 4, 6 and 8 show the results of the colour naming experiment. The frequency of each named colour is also set out for each viewing condition:

Table 3 *Chromaticities for the red and green LED's and the indicator when set to the weg condition*

		no lens	spec 2	spec 3	spec 6
weg	x	0.188	0.329	0.193	0.645
	y	0.378	0.390	0.408	0.352
red	x	0.704	0.709	0.703	0.706
	y	0.296	0.291	0.296	0.294
green	x	0.083	0.081	0.083	0.254
	y	0.393	0.456	0.432	0.726

continued.....

Table 4 *Frequencies of colour naming for weg*

	no lens	spec 2	spec 3	spec 6
blue	10	3	7	0
green	3	2	6	0
yellow	0	0	0	0
orange	0	0	0	3
red	0	0	0	6
white	0	8	0	4

Table 5 *Chromaticities for the red and green LED's and the indicator when set to the eew condition*

		no lens	spec 2	spec 3	spec 6
eew	x	0.351	0.526	0.359	0.688
	y	0.354	0.339	0.372	0.311
red	chromaticities as in Table 3				
green	chromaticities as in Table 3				

Table 6 *Frequencies of colour naming for eew*

	no lens	spec 2	spec 3	spec 6
blue	3	0	4	0
green	0	0	0	0
yellow	0	0	0	0
orange	0	1	0	1
red	0	9	0	12
white	10	3	9	0

Table 7 *Chromaticities for the red and green LED's and the indicator when set to the nw condition*

		no lens	spec 2	spec 3	spec 6
nw	x	0.445	0.581	0.439	0.676
	y	0.439	0.367	0.454	0.322
red	chromaticities as in Table 3				
green	x	0.101	0.114	0.108	0.282
	y	0.629	0.644	0.650	0.702

Table 8 *Frequencies of colour naming for nw*

	no lens	spec 2	spec 3	spec 6
blue	0	0	0	0
green	1	0	4	0
yellow	0	0	0	0
orange	0	5	0	4
red	0	6	0	8
white	11	1	8	0

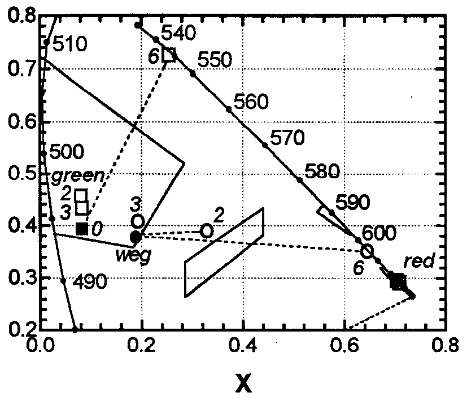

Figure 5 *Showing the shifts due to viewing with the three lenses and no lens. The red shifts are too small to be seen clearly whilst those for the green LED and the* ***weg*** *indicator are shown labelled 0, 2, 3 and 6 corresponding to the lens used. Squares = green LED, circles = weg*

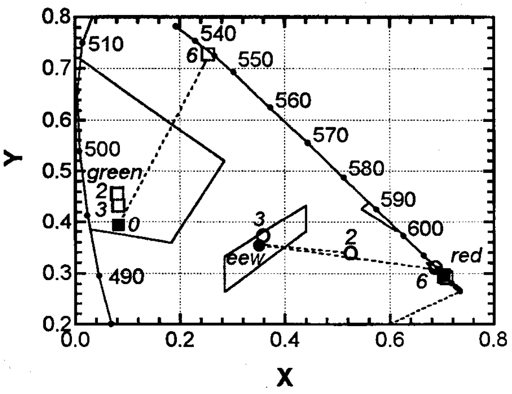

Figure 6 *As Figure 5 but for the eew indicator. Circles = eew indicator*

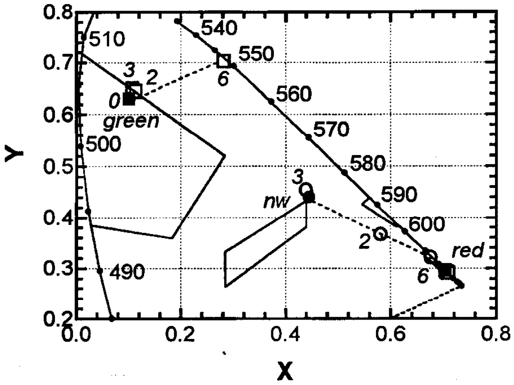

Figure 7 *As Figure 5 but for the nw indicator. Circles = nw indicator.*

4. DISCUSSION

4.1 Yellow Traffic Signal

The **spec 2** lens changed the chromaticity and contrast significantly and this is to be expected because of its prominent absorption band in the yellow part of the spectrum. Most subjects said that the light was considerably dimmed by **spec 2** and some thought it looked more orange. This is consistent with the chromaticity and contrast changes shown in Table 2. The quality scores and their ranks fit well with these observations and the reduced quality can be expected because of the reduced contrast.

Lens **spec 3** induced very little change in chromaticity and contrast but it scored less than 100. This might be explained by the overall reduction of brightness of the LED and the background. It demonstrates that conspicuity is the result of a complex relationship between contrast and brightness [3]. Lens **spec 6** showed an increase in contrast but had a mean score less than 100, a situation probably also due to the reduction in the brightness of the LED and background.

Fisher and Cole [3] give a useful relationship that links the optimum intensity of a red signal and the luminance of the background to the maximum range for safe detection of the signal so:

$$D = \sqrt{\frac{I_{sig} \cdot 10^6}{2 \cdot L_{back}}}$$

where D is the range in metres, I_{sig} the signal intensity in cd and L_{back} the background luminance in cd.m^{-2}. There is no reason to suppose that the same relation would not apply to a yellow signal and it is instructive to calculate how the safe range changes with viewing lens. For the purposes of example, it is assumed that the background luminance, L_{back}, is 1000 cd.m^{-2} and the intensity of the source is 200 cd. Table 9 shows the range for each viewing lens which correlates with the contrast. **Spec 2**, the lens which highly absorbs yellow, has the shortest range whilst **spec 6**, a blue blocker, with its enhanced contrast has a range 120% of the no lens case. These findings are in line with the expectations of spectrophotometry and colorimetry which further suggest that the advantages of the blue blocker lens would not extend to all road signal colours.

Table 9 *Showing the maximum detection range for the yellow traffic signal viewed though the lenses*

	no lens	spec 2	spec 3	spec 6
contrast	28	9.3	27	40
range (m)	316	182	310	377

4.2 The Indicator

As intended, the lens **spec 3** produced only small changes in chromaticity in all three conditions as it is an almost neutral lens. However, **spec 2** has no major absorption in the spectral regions occupied by the LED's used to simulate the indicator and it attenuates the green about twice as much as the red. Consequently, the indicator chromaticity shifts towards the orange and red for this lens. The blue blocker, **spec 6**, has a very small transmission at the green LED wavelengths so its use is expected to shift the chromaticities well towards the red. All these expectations were fulfilled and the colour naming, on the whole, followed the chromaticity shifts in a predictable manner.

However, the colour naming was not at first sight consistent. For example, Table 4 shows that for **spec 6** four people named the indicator as white when it had been shifted to the spectrum locus in the orange region. This might be explained by remembering that the chromaticity of the background will also shift red-wards and colour constancy effects can be expected to come into play. In Table 8, the red shifted indicator was called white with **spec 2** by one person. Several subjects said that in this situation the indicator appeared pink, but this was not a permitted choice so subjects had to choose between red, orange or white - the solitary subject in Table 8 is presumed to have chosen white whilst the remainder chose red or orange.

In the indicator experiments a way was sought of obtaining white from two LED's and how this was achieved using a green and a red diode is reported. Similar effects can be produced with a suitable blue and a yellow LED but these are not described here. Any practical application for obtaining three or more colours by mixing the light from two LED's could be upset if the viewers wear certain coloured glasses. Using three LED's to generate white and a wide gamut of colours, perhaps for a picture display, whilst feasible will, of course, be subject to chromatic distortion just as any trichromatic display would be, if viewed through coloured lenses. In some circumstance, the changes may not be as expected if the lenses have sharp absorption bands which coincide with the spectral output of the diodes.

5. CONCLUSION

Some commonly used coloured lenses can change the chromaticity, luminance and contrast of LED's, but the changes are often small and would not affect the indicator or warning function of these signals. However, some lenses cause significant changes which could be problematic in applications where colour appearance is important. These lenses are popular and designers of systems that employ LED's should ensure that the visual information which they hope to convey is not degraded to a dangerous extent for those who use such lenses.

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