Research Note

A tint to reduce eye-strain from fluorescent lighting? Preliminary observations

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The rapid modulation of light from fluorescent lamps is responsible for eye-strain and headaches. The modulation is greater at certain wavelengths than at others, and it can therefore be reduced by wearing tinted spectacles. A tint was designed: (1) to minimize the luminous pulsation of light from conventional halophosphate fluorescent lamps; (2) to avoid as much as possible any concomitant increase in the pulsation from triphosphor lamps; (3) to interfere with colour perception as little as possible; and (4) to have a cosmetically acceptable colour appearance. The four design criteria conflict. A compromise design is described, together with case histories of patients who appear to have benefited from the use of the tint.

Modulation of light from fluorescent lamps

The light from fluorescent lamps is created by the discharge that occurs when an electric current is passed through gas enclosed in a tubular glass envelope. The lamps are usually controlled from the a.c. electricity supply so that the discharge occurs when the current passes in one direction and then again when the current direction is reversed, i.e. there are two discharges per cycle of the supply. The light therefore modulates in brightness at a frequency twice that of the supply (for example, in Europe, at a frequency of $2 \times 50 = 100$ Hz). The luminous modulation at this frequency depends on the type of lamp, but for a common 'cool white' halophosphate lamp is typically about 28%[1]. (Modulation is here defined as $(L_{max} - L_{min})/(L_{max} + L_{min})$, where L_{max} and L_{min} are the maximum and minimum luminances respectively.)

There is also modulation at the frequency of the electricity supply due to the dark spaces in front of the negative electrode or cathode (first described by Crookes and Faraday[2]). The electrode forming the cathode alternates between one end of the tube and the other. The dark spaces therefore also alternate, and modulation at the frequency of the electricity supply is sometimes visible at the ends of the lamp. For this reason the lamps are usually encased in luminaires that mix the light emitted from the centre of the lamp with that emitted from the ends. As a result the luminous modulation at the supply frequency is usually less than 7%[2,3].

Physiological effects of the modulation

The modulation cannot usually be perceived as flicker but it is nevertheless resolved by subcortical visual structures. There are rhythmic potentials in the human electroretinogram in response to the modulation of light from a fluorescent lamp at frequencies in excess of 100 Hz (Reference 4). Neurons in the optic tract and lateral geniculate nucleus of the cat give a response that is phase-locked to the modulation[5]. Not only is the response phase-locked, but the mean firing rate is also increased: the neurons fire at a rate about twice the rate observed in response to daylight or incandescent light. The unnatural subcortical activity may affect the control of human eye movements: there are small effects of the light modulation on the size of saccades across text[6].

Lamps can now be controlled by high-frequency (> 30 kHz) circuits which remove most of the modulation at the frequency of the supply and at twice this frequency. In offices lit by the high-frequency lighting, the incidence of eye-strain and headaches is less than half that in offices lit by conventional (50 Hz) circuitry[3]. The light modulation may be responsible not only for headaches but also for anxiety. In a double-blind study, people with agoraphobia showed a slightly higher heart rate under fluorescent lighting when the lamp was controlled by conventional circuitry than when the circuitry was high frequency[7].

Taken together, these findings suggest that the removal of light modulation might be beneficial for persons suffering from headaches and eye-strain, and for those complaining of fluorescent light. The modulation can best be reduced by high-frequency circuitry and a change to

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such circuitry is known to be beneficial. Although the change is economic in the long term because high-frequency lighting is more efficient to run, it will be some time before installations can be changed. The light from warm white halophosphate lamps modulates considerably less than that from lamps of other types, and so a change of lamp type can sometimes reduce modulation[1], although it is not known whether any such reduction is sufficient to be beneficial. Individual sufferers are usually unable to institute a change in circuitry or lamp type, and for this reason a further paper[8] describes the reduction of modulation that can be afforded by spectacle tints.

Halophosphate and triphosphor lamps

The modulation of light differs from one type of fluorescent lamp to another because of differences in the persistence or afterglow of the phosphors. The modulation of light is spectrally complex owing to the varying contribution of light from the different phosphors and the phase-lag introduced by phosphors with long persistence. For halophosphate lamps (so-called 'white', 'warm white' and 'cool white') the greatest variation with time occurs for wavelengths shorter than 550 nm. The spectral power distribution of a cool white lamp is shown as a function of time in *Figure 1(a)*[1]. The orange–red phosphor retains the light from one gas discharge to the next. A tint that removes most of the light from the short wavelength end of the spectrum can therefore provide for a more stable light.

For comparison, the spectral power distribution of a typical triphosphor lamp is shown as a function of time in *Figure 1(b)*. Triphosphor lamps (e.g. Philips Colour 84, Thorn polylux) are more expensive but are used when an efficient light source with a good colour rendering index is required. The variation at the long wavelength end of the spectrum is greater than for halophosphate lamps because of the use of a short-persistence red phosphor with a spectral peak at 610 nm. Any filter that reduces modulation from halophosphate lamps may therefore increase the modulation from triphosphor lamps. To minimize this increase it is useful to absorb some of the light with wavelengths close to 610 nm where the modulation is greatest.

Other lamps

Halophosphate and triphosphor lamps are the most common. There are many other varieties of fluorescent lamp but they are used mainly for specialist purposes. For example, hospitals are sometimes lit with deluxe lamps with good colour rendering so that diagnostic cues from skin colour are not lost. The deluxe lamps usually have only short-persistence phosphors. It is not therefore possible to reduce the modulation from these lamps with coloured filters.

Selection of a tint

Initially an attempt was made to derive a spectral transmission analytically, using optimization procedures to search for a transmission that minimized luminous pulsation, had colour coordinates within a limited range deemed to be cosmetic, and did not require rapid transitions in transmission as a function of wavelength, since these are difficult and expensive to obtain. This approach proved insufficiently specific to be tractable. Instead, readily available dyes were used to tint a series of CR39 lenses. The transmission of each trial tint was measured and from the transmission the reduction in light pulsation afforded by the tint was calculated. The extent to which the tint interfered with the perception of colour was assessed subjectively by the two authors (both of whom have normal colour vision on the Ishihara and City University tests) when viewing a typical office scene. A tint that eliminated all light with a wavelength less than 550 nm was judged to interfere with colour perception, giving objects an unpleasant orange hue. When a little light with wavelengths less than 550 nm was transmitted so that the short-wavelength photoreceptors received more stimulation, the distortion was much less marked. It was found that the distortion of colour perception could be further reduced by a gradual transition from low to high transmittance.

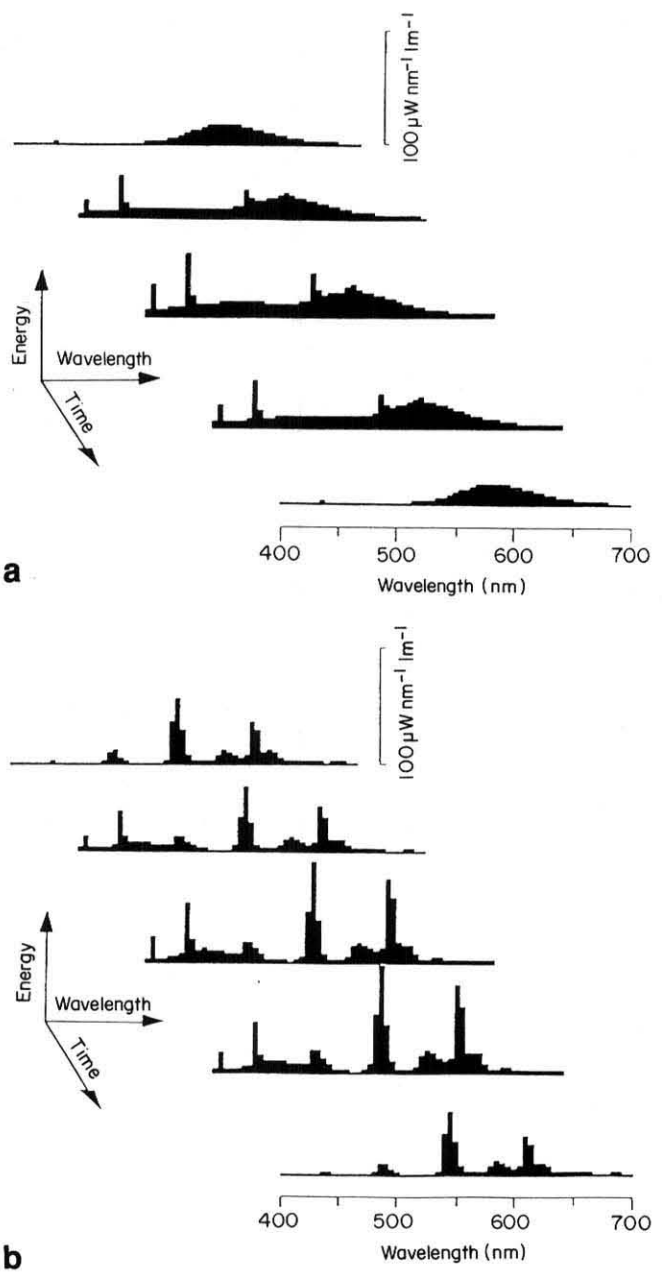

Figure 1 Spectral power distributions for two fluorescent lamps shown as a function of time over half of one cycle of a 50 Hz a.c. electricity supply: (*a*) cool white halophosphate lamp (CIE type F2); (*b*) triphosphor lamp (CIE type F11) (After Reference 1.)

FL41 tint

A filter with the transmission shown in *Figure 2* was eventually selected. Two naïve observers who suffered eye-strain from fluorescent lighting confirmed that it was the most comfortable from amongst a wide range of alternatives. The tint has been dubbed the FL41 tint, and it has a cosmetic brown–red appearance similar to that of sun-glasses. A 10% transmission is maintained between 400 and 550 nm, and the transition to high transmission at long wavelengths is gradual. Within the limits of simple dyeing techniques, the ascent to high transmittance is curtailed in the range 610–630 nm in an attempt to reduce the effects of modulation from triphosphor lamps at wavelengths where the modulation from triphosphor lamps is high.

Effects of the FL41 tint on fluorescent illumination

The FL41 tint reduces the mean luminance of any visual scene. If the scene is lit with light from a halophosphate fluorescent lamp, the tint will also reduce the modulation from the lighting. The extent of reduction depends on the spectral reflectance of the objects observed, the lamp type and its correlated colour temperature.

Figure 3 shows the effect of the filter on a variety of measures of light pulsation when white objects with spectrally uniform reflectance are lit with flourescent light from three common lamps, two halophosphate and one triphosphor. Consider *Figure 3(a)*. The first two bars show, respectively, the photopic luminance with and without the FL41 filter. In both cases the luminance is expressed as a percentage of the time-averaged mean without the filter, and the hatched section is bounded by the upper and lower limits of luminance over time. As can be seen the filter reduces the luminance by about 50%. It also reduces the proportionate variation in luminance: note the reduction in the height of the hatched section relative to the height of the bar. The reduction in modulation is close to one-third. *Figure 3(a)* also shows the corresponding values for the energy captured by the long-, medium- and short-wavelength photoreceptors, and the energy in the colour-opponent channels. The tint reduces the light energy captured by the long-wavelength photoreceptors by 60% and reduces the modulation by 26%. The corresponding figures for the middle-wavelength photoreceptors are 66% and 24%, and for the short-wavelength photoreceptors 90%

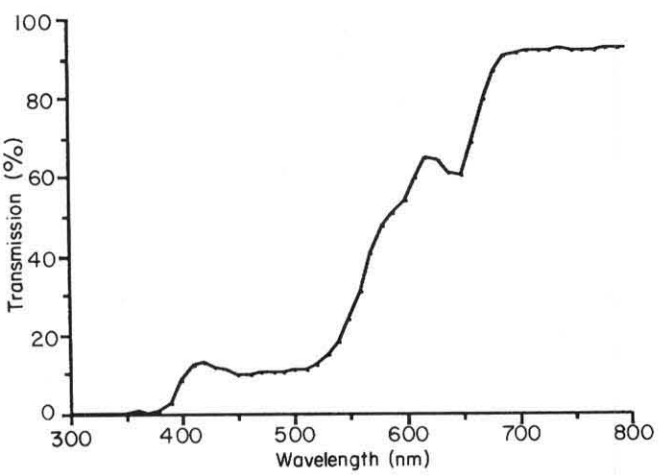

Figure 2 Transmission of the FL41 (Cambridge Optical) tint

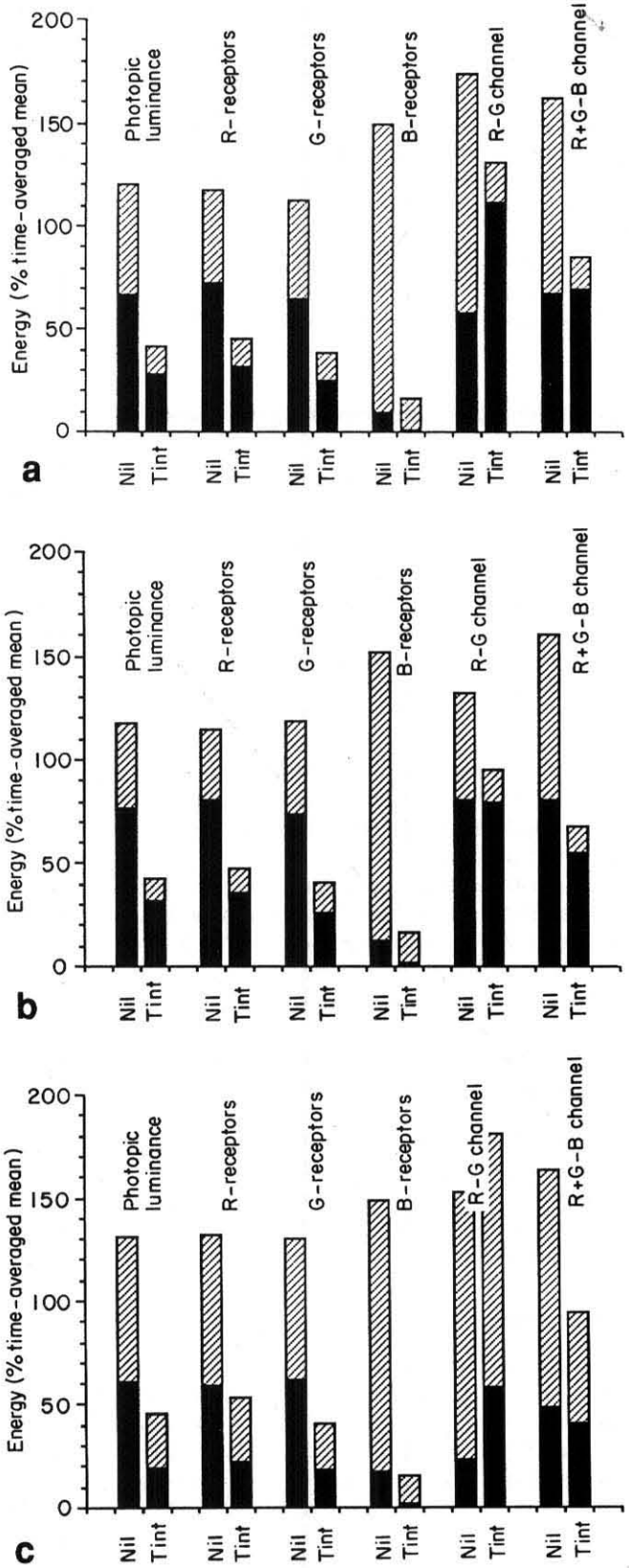

Figure 3 Effect of the FL41 tint on the modulation of light energy from (*a*) cool white and (*b*) white halophosphate fluorescent lamps and (*c*) triphosphor fluorescent lamps. The bars are grouped in pairs, the first bar in each pair referring to the modulation in energy without the tint and the second with. The first pair of bars in each graph refers to the photopic luminance, and the hatched section is bounded by the maximum and minimum luminance over time. The luminance of both bars in each pair is expressed as a percentage of the time-averaged luminance without the tint. The remaining pairs refer to the energy captured by the long-, medium- and short-wavelength photoreceptors (R-, G- and B-receptors), and to the colour-opponent channels (Hunt[9]). Based on measurements made by Wilkins and Clark[1]. ▨ = Variable; ■ = steady

and 1%. There is little effect on the modulation of light captured by short-wavelength receptors because most of the short-wavelength light is generated by the mercury discharge, or by short-persistence phosphors. *Figure 3(b)* shows the effect of the tint on light from another common halophosphate lamp. As can be judged from *Figure 3(c)*, the tint increases the modulation in luminance from triphosphor lamps (CIE type F11) from 32% to 39%, but reduces the mean luminance by 34%.

The above calculations are based on the measurements made by Wilkins and Clark[1] using the model by Hunt[9].

Acceptability of the colour

Experience with the FL41 tint suggests that there are considerable differences between individuals as regards the acceptability of the colour. It is not yet known what proportion of the population is likely to find it acceptable.

Clinical effects of the FL41 tint

As a prelude to extensive double-blind studies we offer the following observations.

Visual discomfort – A 67-year-old lady had been 'driven mad' by fluorescent lighting all her life. When exposed for more than about 20 minutes she suffered dizziness and nausea 'similar to motion sickness'. She had had to leave jobs because of her sensitivity. She suffered from common migraine, as had her mother. The tint enabled her to remain in rooms lit with fluorescent lighting for several hours without any symptoms. She had previously worn dark-grey sun-glasses but had found these to be of relatively little help.

Agoraphobia. – A 42-year-old lady had suffered agoraphobia for 12 years following treatment with librium. She reported that the tint reliably prevented the feelings of disorientation, dreaminess and dizziness that occurred on entering large stores.

Photosensitive epilepsy – A 32-year-old lady suffered from photosensitive epilepsy. Her major seizures were controlled by carbamazepine but she continued to suffer frequent absence seizures. The tint reduced the frequency of the absences to the extent that during telephone conversations members of her family could tell whether or not she was wearing the filter.

Post-traumatic light sensitivity (cerebral asthenopia) – A 52-year-old lady suffered a severe road traffic accident which left her with photosensitive epilepsy. She was nauseated by patterns and flashing light. She had tunnel vision in the right eye, a hemianopic field loss in the left and she was unable to read. The tint 'dulled things down but did not reduce the brightness or the colours'. It eliminated her sensitivity to patterns, and enabled her to read with the aid of a typoscope.

Reading difficulties – The spectral transmission of the FL41 tint is similar to the transmissions of many of the 'Irlen lenses' used to treat problems of visual distortion and eye-strain referred to as 'scotopic sensitivity' by Irlen[10]. The similarity may be more than coincidental (Wilkins and Neary, unpublished observations).

Caveat

The FL41 tint has been designed to reduce the luminous modulation of light from fluorescent lamps on the assumption that it is this modulation that is responsible for adverse symptoms. The light does not only vary in luminance, however; it also varies in colour. The colour opponency of neurons in the retina and lateral geniculate is such that the variation in colour may perhaps also contribute to the interference with subcortical nervous activity. The colour variation can be greatly reduced by a tint, but the choice of tint is not as critical as it is for the reduction of luminance. It is therefore possible, in principle that persons who find the FL41 tint unacceptable may nevertheless benefit from spectacles with lenses of a different spectral transmission. The benefit may extend beyond the reduction of symptoms from fluorescent lighting[7,10]. As has been noted recently, those who wear tinted spectacles tend to have problems of a psychological nature in addition to any that may be visual in origin[11]. Some of these 'psychological problems' may perhaps be attributable to physiological factors[6,7], but by no means all. It remains to be seen whether the FL41 will prove to be widely acceptable; and if so, whether it will be effective.

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