Computer Lenses - How Much Blue Light to Filter?

First ask: “Which threat from blue light - glare, eye damage, or sleep?” Then use the appropriate algorithm!

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Abstract.

The eyecare industry has been evolving from its selective control of the *refraction* of visible light, to now include the selective *filtration* of visible light. The filtration of UV light up to 400 nm did not present a cosmetic challenge because the adult eye does not respond to UV; however, the more recent concern about the threats posed by the exposure of the eye to the blue part of the visible spectrum presents both a cosmetic challenge: often a yellow color is imparted to the lens; and an educational challenge as certain physics issues arise. The heightened concern about “blue light” has been evident in optical trade shows over the last five to seven years, and could be articulated quickly by the re-occurring questions, “What is blue light?” and, more to the point, “How much blue light should be filtered?” This paper aims to answer both questions.

The threats posed by high energy visible (HEV) light.

High energy visible (HEV) light – what the eye associates with the colors violet and blue - is the source of three threats:

1) Loss of sleep (1),
2) Glare (2), and
3) Eye damage (3)

The eye care professionals look to sunglasses and computer glasses to filter HEV light to deal with these threats. They focus on sun lenses to filter the HEV light that leads to glare and damage to the eye; and on computer lenses – the focus of this paper - to filter the HEV light that causes a loss of sleep as well as glare.

However, there are several risks associated with the filtration of light from only one part of the color spectrum: not enough transmitted light to see well (4); and a possible loss of color perception (5).

1) Threat – Loss of Sleep.

The goal then sharpens to: “filter just what you need to minimize the threat;” that way, you will see less darkness through your lens and have a better chance of preserving the perception of color. We will start with a focus on the threat HEV light presents to sleep – and specifically, the threat to sleep from the computer monitor. The graph below shows how the nighttime production of melatonin (the body’s “sleep medicine”) is suppressed by the different wavelengths of visible light (6).

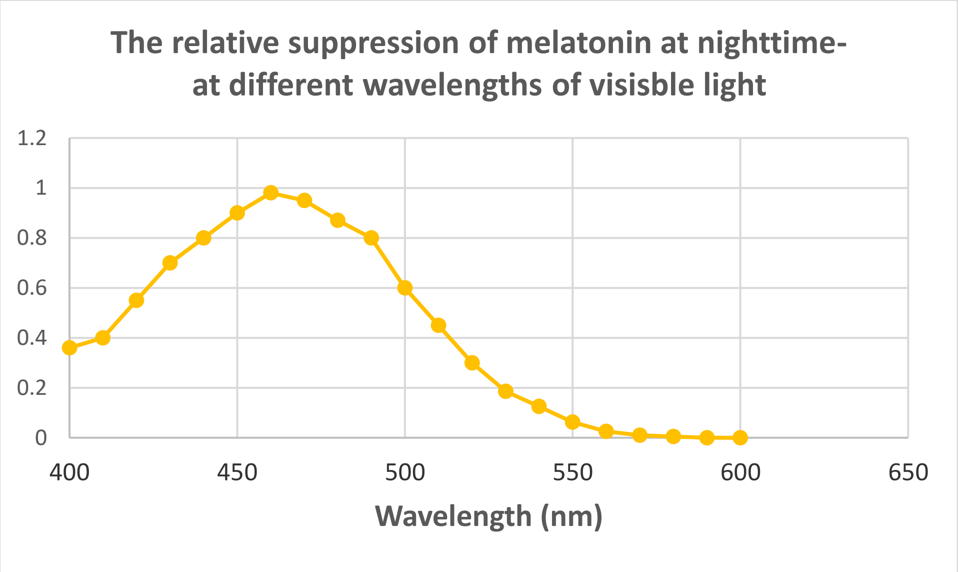

Figure 1 – the suppression of melatonin at different wavelengths[1.] of visible light. The suppression of melatonin is greatest for light at around 460 nm; and very little suppression occurs at wavelengths of 540 nm and longer.

The graphs of Figure 1. suggests that a good computer lens would transmit very little light between 400 nm and 550 nm. But 550 nm is also where the eye is most sensitive – as shown in the graph below (4):

[1.] Light is a wave; so it has a length – a “wavelength” - measured in nanometers.

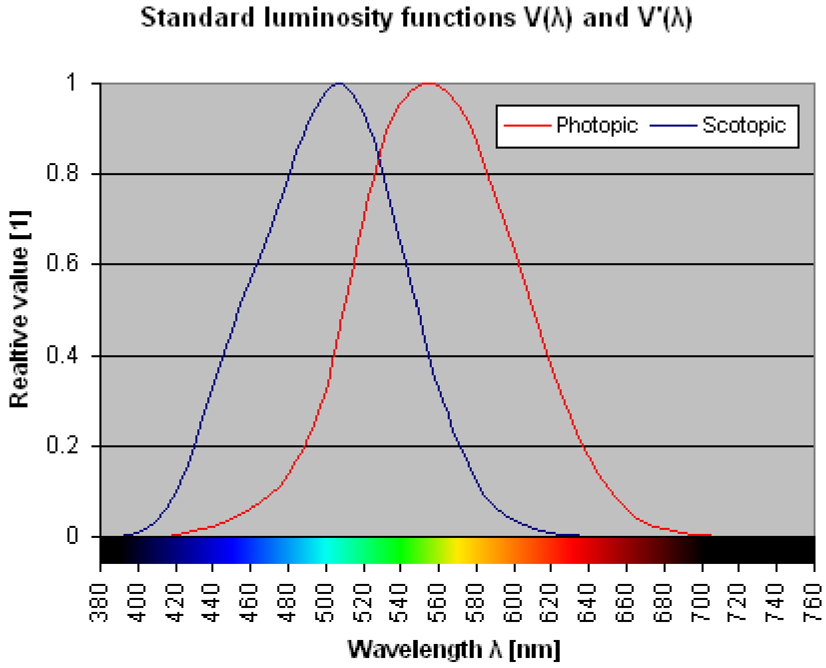

Figure 2 – The eye's sensitivity to light at different wavelengths. The photopic mode involves the cone cells and corresponds to daylight sensitivity. But photopic sensitivity shifts toward the shorter wavelengths when it's dark (Scotopic – involved the rod cells). Indoors, at night time with lights on, the eye sensitivity falls in between the two modes and is called mesopic sensitivity.

Based on Figure 2, we would want to minimize the transmission of light in and around 460 nm and have a relatively high transmission around 540 to 550 nm.

The transmission spectra of several computer lenses are shown below:

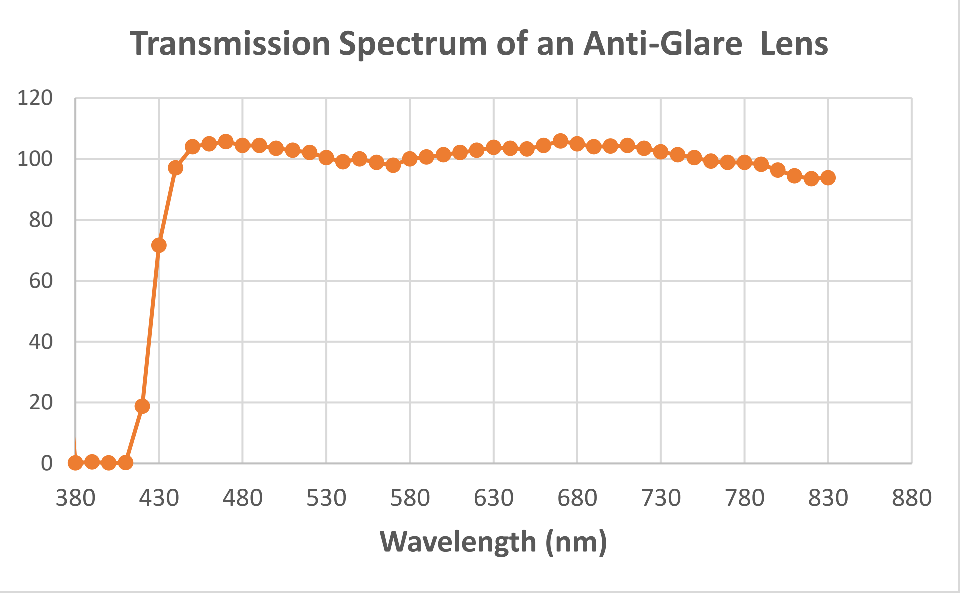

Figure 3. The transmission spectrum of an anti-glare lens.

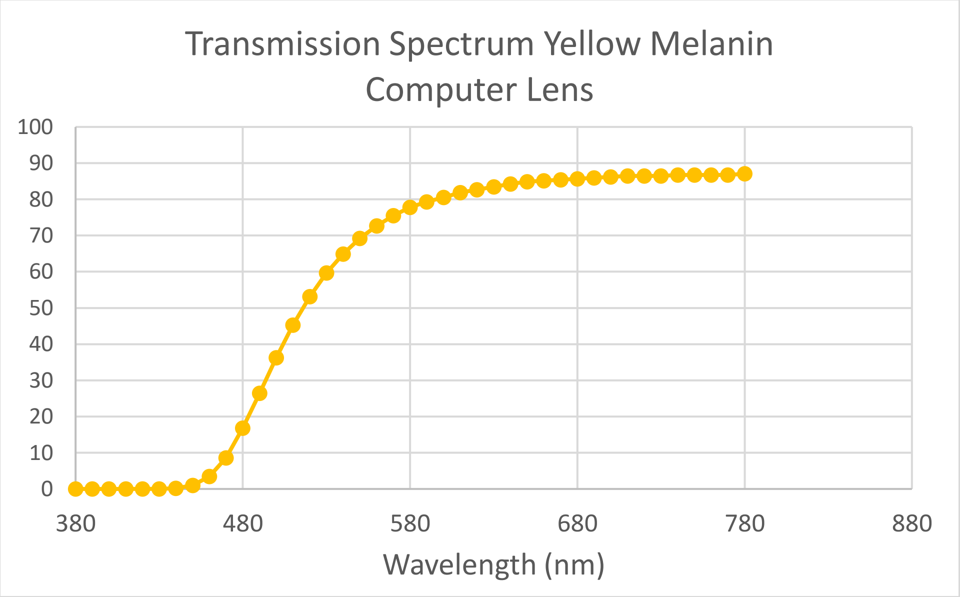

Figure 4. The Transmission Spectrum of a Yellow Melanin Computer Lens.

There are several important things to note about the transmission spectra of Figures 3 and 4:

1) The MPF value – aka, ‘The Melatonin Production Factor,’ is a measure of how well a specific computer lens preserves the night time production of melatonin (7). After 2 hours in front of the computer, the average drop in the production of melatonin in our bodies is about 22 % (8). An MPF of 7 for a computer lens means that it would take a person 7 x 2 hours = 14 hours to experience the same 22 % drop in melatonin production.
2) The Anti-glare lens of Figure 3 has a relatively high transmission of light at the wavelengths between 430 nm and 500 nm where the threat from melatonin suppression is high (see Figure 1). So, qualitatively, this lens would not be expected to reduce the threat of sleep loss.
3) The Anti-glare lens of Figure 3 does have a very low transmission between 380 nm and 420 nm which has the effect of reducing the fluorescence of the human lens which is a primary source of glare (9). It also has a high transmission of light at the wavelengths between 430 nm and 750 nm which reflects good engineering because the eye has a low sensitivity outside of this wavelength region as shown by Figure 2. Having said that, the low transmission of the anti-glare lens is only an “improvement” over UV400 filtration because fluorescence of the human lens is activated by light between 350 nm and 450 nm (9).
4) The transmission spectrum of Figure 4 offers hope of reducing the threat of sleep loss because there is significantly low transmission in and around 460 nm.

Quantifying the Threat and its mitigation by the appropriate algorithms.

There are several ways to find the average lens transmission of HEV light (assumed to be from 400 nm to 500 nm) from any given lens transmission spectrum. For example, in the case of Figure 4, there are 11 data points from 400 nm to 500 nm, and one could add these transmission values and divide by 11 to get:

$$T = [.006 + .006 + .012 + .045 + .227 + \ldots]/11 = 93\ \%$$

But intuitively, this doesn’t seem right because we noted in 4), above, that the transmission is low at the wavelengths where the threat of melatonin suppression (sleep loss) is high.

The correct way to determine the average transmission of melatonin-suppressing light is to weight the transmission spectrum of Figure 4 by the curve of Figure 1 – and also by the emission spectrum of the light source – in this case, the emission spectrum of the LCD display shown in Figure 5 below.

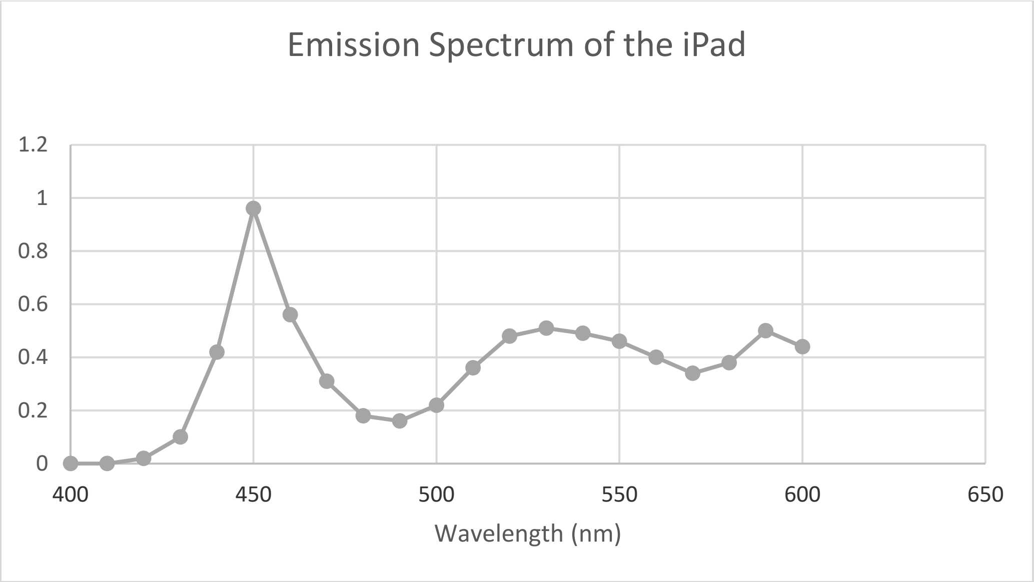

Figure 5. The emission spectrum of the iPad

The average transmission of melatonin-suppressing light by any computer lens is then given by weighting the lens transmission by the graphs of Figure 1 and 5:

$$T_{sm} = \Sigma_\lambda S_\lambda A_\lambda \tau_\lambda / \Sigma_\lambda S_\lambda A_\lambda. \qquad \text{(Equation 1)}$$

from 400 nm to 600 nm. And this time (Example 2), the average transmission is about 14.3 % instead of 93 %.

The MPF is the reciprocal of T_{sm} (7): MPF = $1/T_{sm} = 7$

For the yellow melanin of Figure 4, the MPF = 7
For the “anti-glare” lens of Figure 3, the MPF = 1.1

MPF = 1.1

2) Threat - Glare.

Glare is another threat posed by blue light.[2]

Glare is any light that competes with the light reflected off of the object that you are looking at - polarized light reflected off of a highway and into a driver’s eyes, for example. This type of glare is easily handled with polarized lenses. But there is another type of glare caused by the fluorescence of the human lens (9); it’s a glow that spreads out from the lens in all directions and generally toward the retina as shown below in Figure 6.

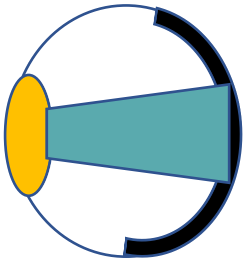

Figure 6. The blue-green fluorescence of the human lens.

Light from the computer screen at wavelengths between 400 nm and 500 nm is absorbed by the lens of our eyes and the energy is converted into a blue-green fluorescence emitted by the lens. This “glow” is a source of glare because it is light that competes with the images formed on the retina from the monitor.

We first calculate the transmission of “glare-causing HEV light” (10) It’s done the same way as with the MPF:

$$T_{gl} = \Sigma_\lambda S_\lambda A_\lambda \tau_\lambda / \Sigma_\lambda S_\lambda A_\lambda$$

$$GRF = 1/ T_{gl}.$$

S_λ is, again, the emission spectrum for the iPad; τ_λ is the transmission spectrum for the specific computer lens - Except that in this case A_λ is the action spectrum for glare sensitivity. We use the one published by Stringham et. al.(11)

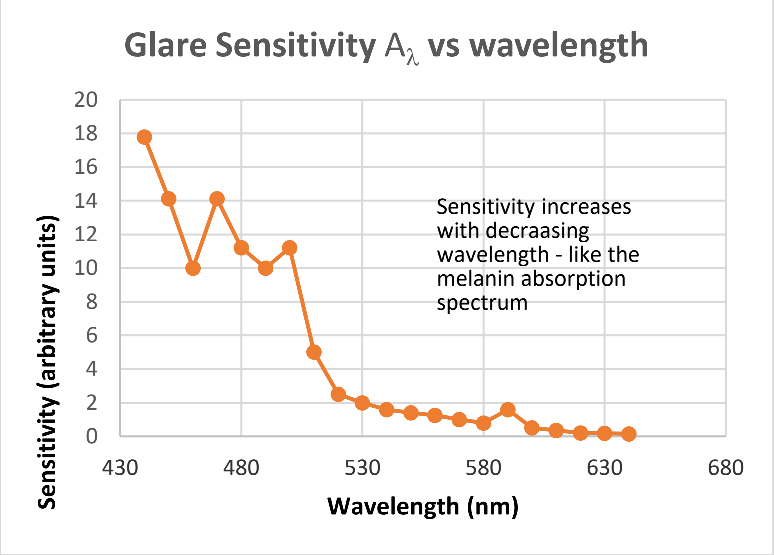

Figure 7. An action spectrum for glare sensitivity

For the yellow melanin of Figure 4, the GRF = 6.2
For the "anti-glare" lens of Figure 3, the GRF = 1.2

3) Threat – Eye Damage

At the time of this paper, there is not sufficient evidence to suggest that cell phones or computer screens cause macular degeneration(12) – an age-related damage to the central region of the retina that is used to see any type of detail. However, experts believe more studies are needed (13); and if such damage would be confirmed, it is clear that this damage would be photochemical – and not thermal; and therefore the efficacy of a specific computer lens to reduce this damage would be quantified in a manner identical to the previously described algorithms for glare and the preservation of melatonin production. The eye protection factor (EPF) was first described by Eisner (14) and was defined as:

$$EPF = 1/Tsb$$

And where

$$T_{sb} = \Sigma_\lambda S_\lambda A_\lambda \tau_\lambda / \Sigma_\lambda S_\lambda A_\lambda$$

In the Elsevier monograph, the EPF was introduced in 2001 (14) and, although epidemiological evidence for sunlight-related macular degeneration was still lacking and did not occur until 2008 (15), the emission spectrum S_λ was assumed to be that of sunlight, and the action spectrum A_λ was assumed to be the action spectrum previously determined to be that of damage to the retina shown below in Figure 8 (16). Here, the only other change to make in the EPF algorithm is in the light source, which we assume now to be that of the iPad.

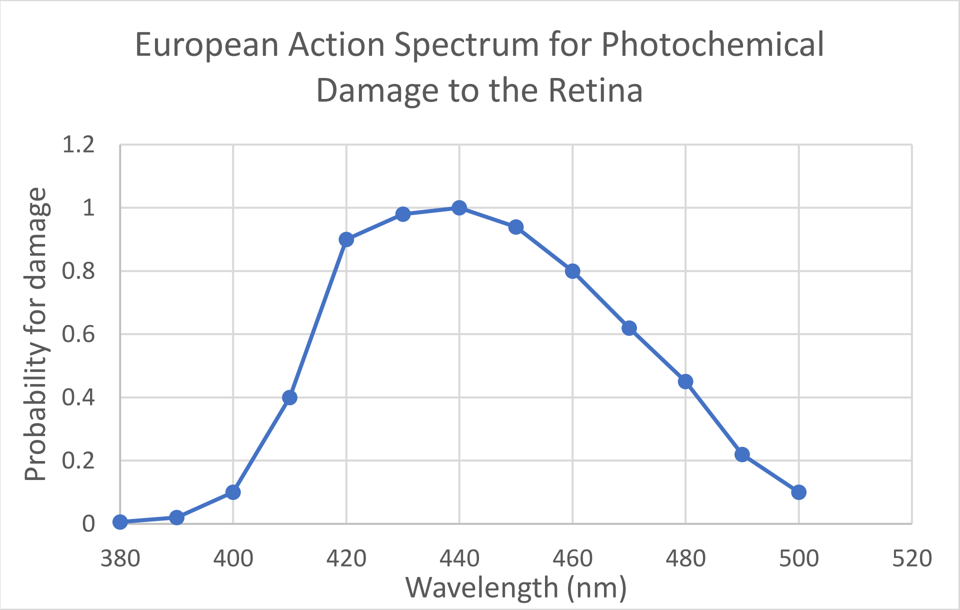

Figure 8. The action spectrum for photochemical-based damage to the retina (European standard for a person around 45 years of age). If the lens of the eyes of the tests subjects (Rhesus monkeys) are removed, then the curve - from 500 nm toward 440 nm – continues to increase even beyond 300 nm. The curve for the European spectrum

turns downward from 440 nm to 380 nm because the ocular lens pigment (OLP) strongly filters the HEV light.

For the yellow melanin of Figure 4, the EPF = 30.3
For the "anti-glare" lens of Figure 3, the EPF = 1.3

4) Color Perception

There is a 4th threat – not directly from exposure to HEV light, but rather from the measures taken to filter it with a computer or with a sun lens – the threat of compromising our perception of color because of a selective filtration of one part of the visible light spectrum. Photoprotective Technologies has used melanin and ocular lens pigment as a paradigm for developing a technology of light filtration. Because 90 percent of the light that enters the human eye is filtered by some combination of melanin and ocular lens pigment, it should be expected that some close relationship might exist between these pigments and the eye-brain system for color perception.

Feedback from people who wear lenses made with melanin has been frequently characterized by claims that these lenses preserve the perception of color. We have tested subjects used the Farnsworth-Munsell 100 color discrimination tests and preliminary results support these claims (13). Further testing is needed.

Should a relationship exist between melanin-based light filters and the perception of color, it is possible to quantify this relationship.. The absorption spectrum of both melanin and ocular lens pigment are very smooth across the visible spectrum of wavelengths – much like carbon black; however, unlike carbon black, the absorption spectrum of melanin and ocular lens pigment increases monotonically with increasing energy - or decreasing wavelength (as per the well-known Planck equation for the energy of a photon, $E = hc/\lambda$). More specifically, the absorption spectrum of melanin and ocular lens pigment consistently show an exponential dependence on the wavelength over the visible spectrum of wavelengths (17). This behavior persists for melanins and ocular lens pigments of yellow, brown or red colors. The logarithm of the absorption therefore results in a straight line with an R^2 value of 1.00 (18). Experiments are underway in PPT's lab to test an hypothesis that there is an inverse relationship between the R^2 values of computer lenses with varying absorption spectra and the errors on the FM100 tests made by subjects wearing those computer glasses.

1) The R^2 value is a measure of the degree to which a particular lens spectrum corresponds to a melanin spectrum which has a value of 1.0.

For the anti- glare lens of Figure 3, $R^2 = .09$ and MPF = 1.1

and for the yellow melanin lens of Figure 4, $R^2 = 1.0$ and MPF = 7

Discussion.

This paper addressed the topic, “How much blue light to filter?” The answer to this question is: first select which threat from blue light is to be examined. The threats are: Glare; Loss of Sleep; and Eye Damage and there is a corresponding action spectrum and an algorithm for each of these threats as summarized in Table 1 below:

Threat	Action Spectrum	Algorithm
Glare	Figure 1	GRF
Loss of Sleep	Figure 7	MPF
Eye Damage (to the retina)	Figure 8	EPF
Color Perception Index R^2		Ln(Abs); (R^2)

Table 1.

In each case the input to the algorithm is the transmission spectrum for the specific computer lens and the output is the value for the selected algorithm.

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