BLUE LIGHT: WHAT ARE THE RISKS TO OUR EYES?

The potential dangers of blue light on the human eye are a subject of increasing debate, notably since the widespread use of LED lamps. This review addresses what blue light is, demonstrates where it is found, and explains why it can be harmful and under what conditions, and concludes with some recommendations for reducing associated risks.



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lue light is everywhere, originally mainly in sunlight. This is nothing new. What has changed is our way of life. In short, we have gone from darkness to light within a few decades. Consider the changes to our habitat, where living spaces are now facing south and have large windows, whereas our elders tended to protect themselves from the sun; then there is extensive exposure of our bodies to sunlight in Western countries where garments are lighter and leisure is geared toward the sun (sea, mountains, ski, etc.). But that's not all. Two major technologies have emerged in recent years that have contributed to blue light over-exposure: LED lamps and the last generations of screens. At the same time, the elderly are now suffering from age-related macular degeneration (AMD) on a large scale, and the use of screens by all of us, especially the younger generations, is literally exploding. These changes are now giving rise to fears of potentially associated health dangers, and an increasing number of questions.

What is blue light?

Most of the time, blue light cannot be "seen" as such. It is just one of the different spectral components of any given light. This is true for both sunlight and for artificial lights.

The human eye is a highly selective receptor of electromagnetic waves, being sensitive to only a very small

KEYWORDS

Blue light, AMD, LED lamps, color temperature, color rendering index (CRI), luminance, emission spectrum, OLED/AMOLED screens, digital devices, transient unilateral blindness, retinal toxicity, oxidative stress, degeneration of photoreceptors, cumulative effect.

number of them. Its "spectrum" covers wavelengths from approximately 400 to 700 nanometers, allowing us to successively see the colors of the rainbow from the so-called "cold" hues of violet, blue, and blue-green from 400 to 500 nm, to "hot" colors: orange and red from 590 to 700 nm, through to intermediate colors: green and yellow from 500 to 590 nm. This spectrum corresponds to what we call visible light. Other animal species have receptors that are capable of perceiving other regions of the electromagnetic spectrum.

These terms of hot or cold light are related to a feature reflecting the general color sensation produced by a given light source: the color temperature. This is expressed in kelvin (K) (although kelvin degrees have not been used since 1967!), ranging from 2000 to 3000 K for a reddish light (an incandescent lamp on low power, for example) to values of 6000 to 7000 K giving the appearance of a bluish light like that of a summer sky at noon, via intermediate values in the order of 4000 to 5000 K, producing a yellowish appearance, such as that emitted by a halogen lamp (fig. 1).

In the field of lighting, another characteristic of light is also important, the color rendering index (CRI). This characteristic is of a different nature because it measures the ability of a light source to provide the eye with a rendering of colors as close to reality as possible, up to an upper limit value of 100. These lighting characteristics can sometimes be found coded on commercial artificial light sources, especially neon lights. Code 840, which is often found on basic fluorescent tubes, means that the light's CRI will be greater than 80 and its color temperature will be 4000 K. However, manufacturers prefer to give names that are more evocative than numbers. This light will bear a name such as "neutral white", "warm white", "cool white" or "daylight".

Where is blue light?

So from this it is obvious that a given light source can produce lights of different qualities, and that the colder the light, the more blue there will be in the spectrum.

In the past, when we were using good old incandescent bulbs (the famous "lightbulbs" known since Edison in 1879), we would talk about the amount of light as the power supplied by the bulb. The quality of light was not an issue, because this type of lamp only gave an orangey to yellowish light, barely clearer than 100W lamps. The CRI was really poor, and the color temperature was low. On the other hand the spectrum of these lights contained very little blue light (fig. 2). They are now something of the past, as various lobbies managed to have them phased out in Europe by 2012; this is a shame for the comfort and health of our eyes. What's more, it is astonishing that these drastic decisions were based on the poor energy



FIG. 1] The different color temperatures in K representing the color of the radiation of a black body (theoritical body heated at these temperatures) for an observer in daylight standard D65. (http://www.cie.co.at/index.php)



 $\mbox{FIG.2}|$ $\mbox{Spectrum of an incandescent lamp, which contains very little blue light.}$



FIG. 4| Spectrum of a standard fluorescent lamp, giving a light spectrum with little blue light

efficiency of incandescent lamps and the overall energy savings expected from the use of more modern lamps, without taking into account the carbon footprint of manufacturing, and especially recycling, of the latter. This is another subject, on which there is much to say.

As far as incandescent lamps go, the halogen variety are still available. They appeared much later (the last quarter of the twentieth century, they were invented in 1959 by Zubler and Mosby) and retain the advantage of a spectrum that is poor in blue light (fig. 3), but with a higher color temperature. Their CRI remains low because we are still far from the solar spectrum. European authorities have also decided to ban them and they should be phased out by 2018.

Fluorescent lamps have been around for some time (Germer 1926) in their long tube form known as "neon". In fact, there has not been any neon in these lamps for a



FIG. 3



FIG. 5] Spectrum of a «full spectrum" fluorescent light which is closer to the solar spectrum and contains a lot of blue light.

long time; their light production system results in a very different spectrum from the aforementioned since it is a line spectrum (fig. 4).

As we have seen, this spectrum can vary according to the desired light characteristics (fig. 5).

Modern development of this type of lamp (in the early 80s) is epitomized by "compact fluorescent" lamps said to be "low energy". Their spectrum is similar, they are of the same type and their small size makes them practical. Fluorescent lamps containing little blue in their spectrum are now easy to find.

Finally, LED lamps have ruthlessly invaded the market in only the last few years (1990s), but with lightning speed. The leaders of the lighting industry estimate that over 90% of all global light sources will be based on solidstate and LED lighting products by 2020. «The danger comes not from the total amount of light emitted (luminous flux) but from the twofold risk of closeness and length of time. Watching movies on a smartphone with an AMOLED screen can therefore be very dangerous.»

Manufacturers attribute these lamps with all kinds of qualities: long-life, consistency of light emitted, relative insensitivity to the number of ignitions and to shock, cold light and especially the significant energy savings due to their exceptional energy efficiency. Unfortunately, this is far from proven, starting with lifespan that is only theoretical and which depends heavily on the manufacturing quality and the lamp's ability to cool; the light might be cold, but the lamp is not! However, most disturbing to ophthalmologists is these lamps' double disadvantage of their significant emission of blue light (most LED lights today) and their tremendous luminance of about 1,000 times that of a conventional lamp, due to the extremely concentrated beam.

LED lamps are discharge lamps in solid phase using semiconductors so that they can only issue one peak light (i.e. only one "color"). So, white LEDs do not exist. For white light, one must either: combine multiple colored LEDs (three primary colors), but this is very expensive; add a phosphor to the outer surface of the diode (making a daylight white LED) (fig. 6), or deceive the user's eye through blue LEDs with a very high luminance that produces a feeling of "white" light. This is currently the case for the majority of commercially available LEDs, especially for cheap lamps and flashlights. Their spectrum is devastating for the eye with a single peak that is more toxic the higher it is (fig.7). Fortunately, warm white LED lamps are now available where the proportion of blue is much lower thanks to a technology that uses two phosphors. But this means costs are high and energy efficiency is much lower (fig. 8).

And the sun in all this? It remains by far the first producer of blue light. The solar spectrum depends heavily on the time of day, the observation latitude, the altitude, the season and the atmosphere (presence of clouds). The reference spectrum of daylight said to be natural is that of a sky observed to the North, in the Northern Hemisphere, at noon. This spectrum is fairly balanced which allows us to consider that this light is "white" in appearance (fig. 9).

It contains a significant portion of blue light that we need to be wary of.

According to standards (ASTM G173-03 and D65), blue light represents 24%-30% of daylight. When we know that the luminance of a sunny sky is at least $5,000 \text{ cd/m}^2$ and that of a computer screen 250 to 300 cd/m², it makes you think.

Blue light and screens

Apart from LED lamps, the increasingly protracted use of screens is also a major cause for concern. Sixty percent of the population spends more than six hours a day in front of a digital device (Study "Blue in light"). ^[1]

We have seen that the luminance of screens is small compared to that of sunlight. Nevertheless, not only do we use screens for hours a day, but we do not think of protecting ourselves like we do from sunlight. Televisions may be viewed at a safe distance, but that is not the case for computer screens, and even less so for tablets and mobile phones used especially by young people, sometimes for hours and hours a day.

The proportion of blue light emitted by screens basically depends on the technology used.

In conventional LCD screens, the panel is backlit by fluorescent tubes. The perception of blue light by the user is very small, and there is very little risk.

In LCD-LED screens, LEDs either backlight the panel or are located on the sides to reduce the thickness of the screen. The fact that the light passes through the LCD panel greatly diminishes the risk.

However, OLED or AMOLED (Active Matrix Organic Light Emitting Diode) screens produce their own light, directly visible to the user. These are said to be emissive in contrast with LCD screens that are said to be transmissive. Very thin, they are increasingly used in smartphones and tablets. The blue light emitted is directly collected by the retina at a very short distance. The danger comes not from the total amount of light emitted (luminous flux) but from the twofold risk of closeness and duration of exposure. Watching movies on a smartphone with an AMOLED screen can therefore be very dangerous. Recently, there

Cool White LED



 $\mathsf{FIG.6}|$ Spectrum of a cold white LED lamp, containing a lot of blue light (35%) and in its most toxic location.



 ${\rm FIG.8}|$ Spectrum of warm white LED lamps using two additional phosphors (figure from the ANSES report)

have been reports of transient unilateral blindness in young women who had watched their smartphone in the dark for extended periods of time lying on their side. ^[2] These are only the immediate risks. Our troubles are only just beginning. The simple, straightforward comparative view of an AMOLED smartphone screen and an LCD-LED screen shows anyone who wants to see that it is not the same category of brightness. The skill of the salesman is to make it appear an advantage where in fact there is only discomfort and danger. The same goes for desktop monitors. Even the CEO of the French Agency for Lighting has harsh words about such marketing trends: "the market has been corrupted by opportunistic manufacturers selling products of very poor quality". ^[3]

What are the ocular risks of blue light?

It is clear that we all receiving more and more blue light. So is this famous "blue light" really harmful and should we be afraid?

First of all, why would blue be more dangerous than red or green?

The answer is a simple formula from 1900 by Max Planck: W = hv, showing that the energy of an oscillator (the concept of photon emerged in 1926 after the work of Einstein and Compton) is directly proportional to its



FIG.7| Spectrum of blue LED lamps with an average peak around 440-450 nm, close to the most toxic color (figure from the ANSES report).



FIG. 9] Spectrum of sunlight (CIE illuminant D65) which includes a lot of blue light (24% to 30%) and balance of the various components.

frequency, the inverse of its length wave (h is Planck's constant). The shorter the light's wavelength, the more energy it carries.

Blue is therefore on the front line for this. However, this does not explain the retinal toxicity of blue

light.

It seems that the first study of the phototoxicity of blue light (on rat optical rods illuminated by fluorescent lights) dates from half a century ago (Noell 1966). ^[4]

It is however the important work of John Marshall that clarified the issue. In 1972, he started to show the toxicity of short wavelength light on pigeon cones. ^[5] It was followed by very important studies showing the mechanisms of destruction of photoreceptors by blue lights *in vitro* in AMD.

It has been shown that the photo-activation of the retinal all-trans by blue-violet light can cause oxidative stress in the outer segments of the photoreceptors. More specifically, it is A2E, the lipofuscin photosensitive component which can be triggered by the radiation of blue light of 440 nm, eventually resulting in the degeneration of the photoreceptor and of the retinal pigment epithelium cells. «So we should reduce the retinal risks of blue light, but keep the essential function of the circadian clock. Blue light should therefore be avoided up to about 455 nm, but not filtered beyond 465 nm»

It would nevertheless be unwise to completely banish blue light; even if its wavelengths are barely above 480 nm, there is a real benefit to receiving this light because it corresponds to the peak sensitivity of melanopsin ganglion cells that are directly involved in the synchronization of the circadian clock (study by Provencio in 1998, ^[6] and Brainard in 2001 ^[7]).

The line is very thin between the "good blue" that is beneficial for our circadian cycle whose effects on the general economy of human physiology are considerable, and the "bad blue" capable of destroying our precious visual receptors.

So we should limit the retinal risks of blue light, but preserve the essential function of the circadian clock. Blue light should therefore be avoided up to about 455 nm, but not filtered beyond 465 nm. This means that the room to maneuver is very small. (Fig. 10).

The appearance of LEDs after 1990 led researchers to look directly at the associated risks.

In 2001, Dawson and colleagues used monkey retinas to show that LED lamps emitting blue light were as toxic as a blue laser with equal exposure. ^[8]

In 2010, ANSES, the French national agency for the safety of food, the environment and labor, published a key report under the direction of Professor Béhar-Cohen on the "health effects of lighting systems using LEDs". ^[9] The report was followed by two French publications in 2011 ^[10] and 2013 ^[11] and cautions about the risks of LED lamps in direct relation with the spectral imbalance of these lamps, in favor of low wavelengths whose *in vitro* toxicity has been thoroughly demonstrated and with the very high brightness of these lamps, finding in particular that the photochemical risk was related to the cumulative dose of blue light to which the person was exposed.

The report made recommendations, including the need to restrict the release of LED lighting systems on "mainstream" markets, as well as to adapt standards and to enforce them. It also considered it necessary to inform the consumer (informative labeling of lighting systems). To date, these recommendations are far from being implemented and it is not clear that they will be. There is no awareness yet of the risk of LEDs on public health and one can only wonder why and be concerned that the precautionary principle is not yet applied, while a few unfortunate events on the subject in recent decades should encourage reflection and prudence.

It is clear that there are not enough studies with conclusive *in vitro* findings on the macular toxicity of short wavelength light to transpose them *in vivo*. Few long-term studies are available to allow us to clearly establish a relationship between the prolonged exposure to blue light and ARMD (Beaver Dam Eye Study^[12], Eureye Study^[13]). It is, after all, only a question of means and methodology. Research teams need to agree to undertake long and difficult studies to take into account new lifestyle parameters which will change in years to come (screens, LED lamps). Otherwise the voice of caution will be silenced because economic stakes are too high.

Conclusion

We cannot seriously deny the potential ocular risks from overexposure to blue light.

In order to remain level-headed but lucid before this much debated issue, we must remember the main producers of this high-energy light capable of destroying macular cells *in vitro*. First there is the sun, then there are artificial lights with cold white LEDs and AMOLED screens.

BLUE LIGHT



FIG. 10 The dilemma of blue light

«It is important not to forget that it is the cumulative effect that is dangerous and must be avoided. Precautions should be taken early, and taken over time.»

Permanent eye protection against solar radiation using good quality tinted glasses is above all necessary to guard against all harmful effects. Precaution against screens that have a high emission of blue light: avoiding close, long-term exposure and using protection against toxic blue light as far as possible. These processes already exist and will only improve and become increasingly widespread. It is more difficult to protect oneself against bad light LED lamps that are becoming the norm, except at least by using them sparingly at home. The awareness of public authorities themselves could be effective in this regard.

It is important not to forget that it is the cumulative effect over time that is dangerous and must be fought. Precautions should be taken early and should be longterm. Particularly close attention must be paid to children whose ocular media allow these high-energy lights pass in large volumes, and to young people, prone to long exposure to the sun and screens.

Finally, emphasis should be placed on the need for increased protection for older groups at risk: people who have had cataract surgery, especially if they have not received yellow implants and those affected by age-related maculopathies.

Let us not deprive ourselves of light that is so basic but let us, as we do for so many natural elements, better understand it in order to better reap its benefits without its risks. \bullet



- Blue light is not visible as such. It is a spectral component of visible light corresponding to wavelengths of approximately 400 to 500 nm.
- The main producers of high-energy blue light capable of destroying macular cells *in vitro* are, primarily, the sun, and secondly, artificial lights with cold white LEDs, and AMOLED screens.
- The recent emergence of LED lamps and the latest generations of screens contribute to over-exposure to blue light.
- Blue light of a wavelength of 440 nm can induce oxidative stress in the outer segments of photoreceptors, which can ultimately lead to their degeneration as well as of the cells of the pigment epithelium.
- Increased caution should be taken especially for children, people undergoing cataract surgery, and individuals with age-related maculopathies.
- Not all blue light should be avoided wavelengths of just over 480 nm are beneficial as they are directly involved in the synchronization of the circadian clock.

REFERENCES

- 1.Campagne Bleu en Lumière : http://www.bleuenlumiere.com/#bleuenlumiere
- 2.Transient Smartphone "Blindness" N Engl J Med 2016; 374:2502-2504June 23, 2016DOI: 10.1056/ NEJMc1514294
- 3.Les Brèves de l'AFE n° 64, mars 2011. http://www.afe-eclairage.fr/docs/10267-ext.pdf
- 4.Noell WK, Walker VS, Kang BS, Berman S. Retinal damage by light in rats. Invest Ophthalmol. 1966;5:450– 473
- 5.Marshall J, Mellerio J, Palmer DA. Damage to pigeon retinae by moderate illumination from fluorescent lamps. Exp Eye Res 1972;14:164—9.

6.Provencio I, Jiang G, De Grip WJ, Hayes WP, Rollag MD. Melanopsin: an opsin in melanophores, brain, and eye. Proc Natl Acad Sci USA. 1998;95:340–5.

7.Brainard GC, Hanifin JP, Greeson JM, Byrne B, Glickman G, Gerner E, Rollag MD. Action spectrum for melatonin regulation in humans : evidence for a novel circadian photoreceptor. J Neurosci 2001;21:6405–6412. [PubMed: 11487664]

- 8.Dawson W, Nakanishi-Ueda T, Armstrong D, Reitze D, Samuelson D, Hope M, et al. Local fundus response to blue (LED and laser) and infrared (LED and laser) sources. Exp Eye Res 2001;73:137—47 9.ANSES. Effets sanitaires des systèmes d'éclairage utilisant des diodes électroluminescentes (LED); 2010 [Disponible sur le site www.anses.fr].
- [Disponible sur le site www.anses.fr]. 10.Behar-Cohen F, Martinsons C, Viénot F, Zissis G, Barlier-Salsi A, Cesarini JP, et al. Light-emitting diodes (LED) for domestic lighting: any risks for the eye? Prog Retin Eye Res 2011;30:239—57, http://dx.doi.org/10.1016/j. preteyeres.2011.04.002 (Epub 2011 May 14).

^{11.}Arnault E, Barrau C, Nanteau C, Gondouin P, Bigot K, Viénot F, et al. Phototoxic action spectrum on a retinal pigment epithelium model of age-related macular degeneration exposed to sunlight normalized conditions. PLoS One 2013;8:e71398, http://dx.doi.org/10.1371/journal.pone.0071398 [eCollection 2013]

^{12.} Cruickshanks KJ, Klein R, Klein BE, et al. Sunlight and age-related macular degeneration the Beaver Dam Eye Study. Arch Ophthalmol 1993;111:514–18.

^{13.} Fletcher AE, Bentham GC, Agnew M, et al. Sunlight exposure, antioxidants, and age-related macular degeneration. Arch Ophthalmol 2008;126:1396–403.