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ARTICLE

Some evidences that white LEDs are toxic for human at domestic radiance?

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Abstract – Artificial lighting has been a fundamental part of social and economic development of mankind. It allows to free human activity from natural variations and conditions (weather, day/night cycle, variation of day length depending on season and latitude...). The face of this artificial lighting has changed in the last years with the emergence of white phosphor coated LEDs (Light Emitting Diodes) which offer many advantages in terms of reliability, efficiency and implementation. However, it is subject to special attention because their spectrum is typically rich in blue. Damages following exposure to high radiance blue light are well documented but some recent concerns have appeared regarding potential damages linked to white LEDs exposure at domestic radiance. Are these concerns justified? This article analyses some results of a recent study of animal retina exposure to light produced by LED technology and demonstrates that even if they are of interest in improving our understanding of the mechanisms of photochemical injury, they cannot be extrapolated to human without extreme caution and do not call into question the normative limits which are now the consensus.

Keywords: artificial lighting / LED / blue light hazard / photoretinis

1 Introduction

White LEDs have many advantages but have also shortcomings, including a blue enhanced double-peaked spectrum, which, combined with *high radiance*, can cause Ham's class damages (Ham *et al.*, 1976), *i.e.* some oxidative stress phenomena linked to the production of reactive oxygen species on retina (Césarini, 2009). But some concerns do also exist regarding *low radiance* exposure. In 2010 ANSES (ANSES, 2010) did not exclude the possibility that repeated and prolonged exposure to low radiance could potentially induce a *cumulative* risk higher than that assessed by the current Exposure Limit Values (ELV) and the French agency encouraged to make further researches on blue light hazard biological mechanisms. In 2015, the Health Council of the Netherlands also considered the lack of data on long term exposure as "an additional argument for further research into the risk of frequent exposure to the blue light emitted by white LED lighting" (HCN, 2015). In such a context, a warning has been published (Jaadane *et al.*, 2015), alerting to the fact that exposure to a LED light source could generate, on rat retina, oxidative stress phenomena responsible for retinal cells necrosis at low exposure level. The authors consequently pointed out ELV defined by ICNIRP (2013), and used in safety standard (IEC 62471-1, 2006), in these terms: "current regulation establishes that for an exposure greater than 10 000 s, ELV, expressed in term of blue light radiance, is about 100 W/m^2/sr, largely over the radiances used in this study, suggesting that these regulations should be reevaluated by transposing our results to the human eye." Such interpretation of experimental data must be discussed as it seems that at least one of the fundamental differences between rat and human eyes has not been taken into account.

2 Discussion

In 1984, Sliney enlightened the differences between human eye geometry and rat eye geometry. And he warned that "a valid calculation of retinal irradiance (...) is critically dependent upon the use of accurate values" for focal length and pupil diameter (Sliney, 1984). Consequently, we made the exercise to convert the different retinal exposure levels (in J/cm^2) calculated in Jaadane's study into corresponding source radiances (in W/m^2/sr) in the case of a human eye by using focal length value of Gullstrand eye (Gullstrand, 1909) and pupil diameter recommended in IEC 62471:2006. The corresponding radiances are then compared to ELV provided by ICNIRP.

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2.1 Method

Equation (1), extracted from ICNIRP Guidelines (ICNIRP, 2013), shows the general relationship between retinal irradiance $E_{retinal}$ and light source radiance L_s.

$$E_{retinal} = \frac{\pi.Ls.t.d^2}{4.f^2}, \quad (1)$$

where, d is the pupil diameter, f the focal length, and t the eye visible radiation transmission.

But it is fundamental to consider the blue light effective radiance noted L_b, and not the full spectrum radiance L_s in the calculation of potentially toxic retinal irradiance. Indeed, ICNIRP has defined an action spectrum Bλ describing the efficacy with which short wavelengths can affect the retina by oxidative stress. The maximum permissible exposure to wavelengths covered by this action spectrum is 10^6 J/(m^2.sr). As exposure (noted H_b) is not an intrinsic parameter of light sources, the photobiological safety standard IEC 62471-1 (2006) expresses it as the product of the blue light effective radiance L_b by the exposure time T (see Eq. (2)). It must be noted that L_b has no sense for little punctual sources. In such a case, relevant physical parameter would be blue light effective irradiance E_b.

$$H_b = L_b.T. \quad (2)$$

IEC 62471-1 (2006) defines several risk groups depending on maximum exposure time T. Limits for L_b values are made according to these exposure time values so that H_b stays below 10^6 J/(m^2.sr). Naturally, the risk group increases as the time required to exceed the permissible exposure decreases (see Tab. 1).

IEC 62471-1 (2006) describes also a complete protocol for L_b evaluation of a single non-punctual source. L_b is calculated through equation (3). An example of original measurement set-up for L_b evaluation can be found in a former study by Point (2014).

$$L_b = \int_{300\,nm}^{700\,nm} L\lambda(\lambda).B\lambda(\lambda).d\lambda \quad \left(W/m^2/sr\right), \quad (3)$$

where, Bλ is the mathematical function describing the blue light action spectrum, and Lλ is the spectral radiance measured at 200 mm from light source on the time-dependent field of view of the moving eye.

Table 1. Definition of risk groups depending on T and consequences on maximal L_b values.
Source: IEC 62471-1 (2006).

	RG0	RG1	RG2	RG3
T_{max} (s)	10 000	100	0.25	< 0.25
$L_{b\ max}$ (W/m^2/sr)	< 100	< 10 000	< 4 000 000	> 4 000 000

Table 2. Calculated exposure values and exposure time involving some retina damages on rat eye (Jaadane *et al.*, 2015) and calculated light source radiance needed to produce same exposure on human retina with $d = 3$ mm, $t = 0.9$ and $f = 17$ mm.

Calculated exposure D (J/cm^2) (Jaadane *et al.*, 2015)	Exposure time T (h) (Jaadane *et al.*, 2015)	Calculated $E_{retinal}$ (W/m^2) (this study)	Full spectrum radiance for human eye L_s (W/m^2/sr) (this study)
81	12	18.7	852
125	18	19.3	876
151	24	17.5	794
303	48	17.5	797
453	72	17.5	794

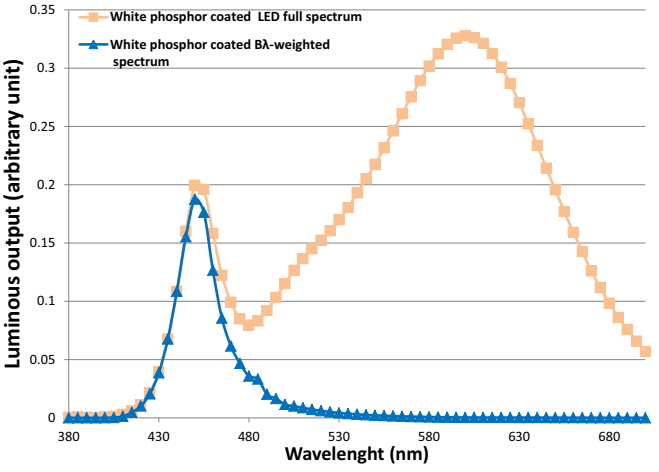

Fig. 1. Comparison of Xanlite evolution full spectrum and Bλ-weighted spectrum.

2.2 Results

$E_{retinal}$ can be written as the ratio of exposure (in J/cm^2) by exposure time (in s). We calculate it from exposure value D and duration T reported in Table 2, extracted from Jaadane *et al.* (2015). Considering $d = 3$ mm, $t = 0.9$ and $f = 17$ mm, it appears that radiance *in white light* (L_s) that could produce similar exposure on human retina is, in average, 822 W/m^2/sr, *i.e.* one hundred time higher than radiance used in Jaadane's publication to produce the exposure on rat retina (8.33 W/m^2/sr). Note that, in short wavelength range, transmission of the human adult eye is largely lower than 90%, consequently corresponding radiance values are underestimated when using 0.9 as a constant value for transmission. The corresponding radiance value could be still higher by taking into account the real wavelength-dependant transmission of the eye.

As we said previously, not L_s but L_b must be taken into account for blue light hazard evaluation. Figure 1 shows the spectrum of the white Xanlite Evolution LED used for Jaadane's experiments. Bλ-weighted luminous output is calculated by multiplying the full spectrum luminous output by Bλ. The ratio between wavelength-integrated Bλ-weighted luminous output and wavelength-integrated full spectrum luminous output appears to be 12.6%. It means we can recalculate L_b from L_s by applying the ratio as in equation (4) to obtain the Table 3.

Table 3. Calculated Bλ-weighted blue radiance from the knowledge of white light radiance.

L_s (W/m^2/sr)	L_b (W/m^2/sr)
852	107.5
876	110.5
794	100
797	100.5
794	100

$$L_b = 0.126.\, L_s. \quad (4)$$

According to our calculations, it appears that the exposure values found as hazardous for the rat retina can be generated – for given exposure times – on the human retina by effective blue radiance L_b slightly over 100 W/m^2/sr. In the standard IEC 62471-1 (2006), 100 W/m^2/sr is the limit value between RG0 and RG1. For RG1, the exposure time is limited to 100 s. For the White LED tested by Jaadane *et al.* (2015), the standard IEC 62471: 2006 *would have permitted to identify the risk* and recommended to limit the exposure time to 100 s.

It can be noted that a more recent study (Jaadane *et al.*, 2017) has confirmed deleterious action of blue light from LEDs especially on Retinal Pigment Epithelium (RPE) of rat but authors acknowledge that results obtained "cannot be directly transposed to humans" because of biological differences between rat and human eyes.

3 Conclusion

Even if all involved biological mechanisms of photochemical injury are not fully understood and are still under investigation, the demonstration that low radiance exposure can damage human retina and that current normative limits are not protective enough is not consistent today. The risk seems limited to high radiance exposure or misappropriate use of the technology, when critical parameters as exposure distance *and/or* duration are not under control, for example in professional situations where workers can be exposed to high intensity light (Salsi and Barlier-Salsi, 2013) or in pseudo-therapy practices like chromotherapy (Point, 2017).

Despite the actual lack of evidence regarding low level effect on human retina, and considering the large diffusion of the technology, we do agree that investigations have to be pursued as recommended by health agencies, but conclusions must be done with caution: other studies have been recently published regarding LED effect on rat retina (Shang *et al.*, 2014; Krigel *et al.*, 2016; Jaadane *et al.*, 2017; Shang *et al.*, 2017), and some of them also ask for regulation modification without taking into account the large difference between human eyes and rat eyes. Our work demonstrates the extreme caution that needs to be taken when trying to transpose light exposure results from rat to human.

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Conflicts of interest. The authors declare the following interests: Sébastien Point is employed by Cooper Sécurité SAS which is a lighting manufacturer.

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