Current Trends in Ophthalmology and Visual Sciences
Gagné V and Turgeon R. Curr Trends Ophthalmol and Vis Sci 2: 109.
www.doi.org/10.29011/CTOVS-109.100009
www.gavinpublishers.com

Review Article

LED Lighting and Retinal Toxicity: A Clearer Picture: LED Lighting and the Reality of Retinal Safety

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Citation: Gagné V, Turgeon R (2023) LED Lighting and Retinal Toxicity: A Clearer Picture: LED Lighting and the Reality of Retinal Safety. Curr Trends Ophthalmol and Vis Sci 2: 109. DOI: https://doi.org/10.29011/CTOVS-109.100009

Received Date: 05 October, 2023; **Accepted Date:** 16 October, 2023; **Published Date:** 20 October, 2023

Abstract

Numerous studies have analyzed the potential for retinal toxicity caused by light, especially in the short-wavelength spectrum, which necessitates the use of additional protective measures during exposure. This is the case for high light intensities like sunlight and welding arcs. Nevertheless, it appears less reasonable that multiple other studies have arrived at comparable conclusions concerning light given off by Light-Emitting Diodes (LEDs). It is worth noting that certain companies have utilized these findings to promote the sale of eyewear or intraocular lenses that could filter out the blue wavelengths of light. This study aims to determine the stance taken by various international committees concerning the Blue Light Hazard (BLH). Additionally, it delves into the comparative harm caused by LEDs when compared to other forms of light, such as sunlight. Lastly, this study aims to establish the effectiveness of blue light filtering lenses in reducing retinal degeneration and supporting the BLH theory. Of the 727 studies investigating the relationship between polychromatic light and retinal toxicity, only 19 studies have identified LED lights as a source of potential harm with no confirmed retinal toxicity. Despite these findings, it appears that no organization is warning about the hazardous effects of the blue component of LED light. Furthermore, this light source appears to be no more dangerous than other light sources, and blue-light-filtering intraocular lenses do not provide significant preservation of retinal health compared to conventional lenses.

Keywords: LED; Retinal damage; Phototoxicity; Blue light hazard

Introduction

Humans have always been exposed to blue light through sunlight. With advancements, the replication of this accessibility led to the invention of artificial lights, which allow controlling the duration of light exposure independently of sunlight. As humans adapted to an era of efficiency, energy-efficient light sources such as Compact Fluorescent Lamps (CFLs) and Light-Emitting Diodes (LEDs) were invented. LEDs have gained popularity and are used in almost all electronic technologies, including LED-backlit displays. They provide lighting that reduces carbon dioxide emissions [1] while offering a cost-effective long-term option [2]. An interesting aspect of LED lights is that they offer a light spectrum with a peak around 460 nm, produced by a diode surrounded by a phosphor that absorbs some of these short-wavelength photons and converts them into longer wavelengths. This combination of short and long wavelengths allows for more natural lighting [3,4].

The blue portion of light has shown several beneficial effects by synchronizing our circadian clock to the 24-hour period of the day [5,6]. It notably suppresses melatonin secretion

[7,8], optimizing neurocognitive function, increasing vigilance, and regulating hormones [9-13]. It can also be used in therapies to treat emotional disorders such as seasonal depression [14]. These effects can be attributed to stimulating a specific type of photoreceptor called intrinsically photosensitive Retinal Ganglion Cells (ipRGCs) which due to its melanopsin photopigment, is activated by a light spectrum with a peak at 480 nm [10,15].

Although these effects are essential for human functioning, some studies have focused on their potentially harmful effects. Specifically, the spectrum between 415-455 nm (appearing as blue-violet) has been found to be more toxic [16]. Exposure to intense light for a few minutes, such as sunlight [17,18] or welding arcs [19], can cause retinal degeneration known as photoretinitis. This condition led to the term Blue-light Hazard (BLH), which represents the risk of photochemical damage to the retina, photoretinitis, or photopic maculopathy. In 1966, it was suggested that long-term exposure to short-wavelength sources such as LED lamps could also cause retinal degeneration [20]. Currently, this photodegeneration is explained by a loss of synergy between the retinal pigment epithelium (RPE) and photoreceptors. The RPE is responsible for regenerating cones and rods by phagocytosing their outer segments, producing lipofuscin, an undigested disc. This lipofuscin contains a chromophore, N-retinylidene-N-retinylethanolamine (A2E), as well as other oxidation products [21]. When exposed to blue light, RPE cells containing A2E die [22,23]. Retinal damage caused by blue light has been found to involve an inflammatory response [24,25], DNA damage [23,26], mitochondrial damage [27,28], and lysosomal damage [29], all of which are related to lipofuscin. Other mechanisms are also involved, such as growth factor secretion and damage to the blood-retinal barrier, as explained in detail in a recent literature review [30]. The sensitivity function of BLH follows the weighted spectrum $B(\lambda)$ defined by the visible wavelength range of the human eye (300-700 nm). All wavelengths in the visible spectrum have the potential to be toxic to the retina. However, the region with the highest potential for damage is in the short-wavelength portion, with a sensitivity peak around 440nm [31]. It should be noted that BLH should not be confused with a visual response, as the spectra are not entirely identical.

These findings have led to the establishment of safety standards by ICNIRP [32,33] to limit BLH during the production of lighting technologies such as LEDs. These standards set maximum radiance and irradiance levels below which adverse effects from lighting are unlikely. Professions such as welders, spotlight installers, and dentists, where exposure to blue light exceeds physiological standards established by ICNIRP and CIE, require protective measures such as glasses that filter out this toxic portion of light [30]. It is important to note that attention should be given to radiance emitted by the light source, rather than irradiance perceived by the cornea. Conversely, several studies have applied these results to LED lights to which we are exposed almost daily when using screens [34], justifying the use of blue light-filtering lenses to protect against retinal degeneration such as Age-related Macular Degeneration (AMD) [35]. LED lights are particularly targeted in these studies because, although perceived as white, they emit a light spectrum with a peak close to BLH (around 460 nm). However, it is relevant to review these studies before classifying screen blue light as a "blue-light hazard." These studies have been criticized by CIE and ICNIRP for not representing the actual conditions to which we are exposed. They usually involve exposure to excessively high doses, direct and prolonged exposure times, in animals with different eye geometry than humans and dilated pupils. The extrapolation of results seems to be flawed, and more recent studies have reevaluated these risks.

This literature review offers a comprehensive synthesis of research studies confirming the absence of a retinal damage risk associated with LED lights. The central focus of this review is to investigate various aspects related to LED light safety and its potential impact on retinal health. Key questions explored within this review include the position of different international committees on the "Blue-light Hazard," whether LED lights present a greater risk to the retina compared to other light sources like sunlight, and the effectiveness of blue light-filtering lenses in mitigating retinal degeneration while supporting the Blue-light Hazard theory.

Methodology

This literature review focuses solely on studies concerning LED lights and the position of retinal non-toxicity in humans. The keywords used in the PubMed library were ((LED) AND (Retinal Damage) OR (Blue light hazard) OR (Phototoxicity)). Exclusion criteria were studies involving only light sources other than LEDs, phototoxicity on the anterior part of the eye or any other organ, and circadian impacts of blue light exposure. Finally, as it has been demonstrated that screens do not emit UV rays, this article will not cover phototoxicity caused by these wavelengths. Of these keywords, 1048 articles were imported, of which 321 duplicates were removed. Of the 727 studies analyzed, only 19 met the inclusion criteria's. These articles were then separated into 3 main categories: the position of international committees, the comparison of different light sources to put the risks into perspective, and the effectiveness of blue-light filtering lenses in limiting age-related macular degeneration.

Position of International Committees

Since retinal toxicity induced by blue light has been known for several years, international committees have established safety standards for the manufacture of technologies involving any form of lighting. These committees regularly review these standards to keep up with technological advancements. The International

Commission on Non-Ionizing Radiation Protection (ICNIRP) has established standards based on distance and duration of exposure to certain light sources through calculations. For long-term exposure (over 10,000 seconds), the radiance limit for lighting to avoid adverse retinal effects is 100Wm-2sr-1 [33].

All these organizations and committees position themselves against the retinal toxicity risk posed by LED lights. ICNIRP and the International Commission on Illumination (CIE) state that white light enriched with blue light is not sufficient to present such a danger, as it emits radiance below the limit set by ICNIRP. The opposite would result in a glare effect perceived by the eye, preventing fixation on such a source [31,32].

As mentioned, these committees argue that studies showing a link between AMD and blue light cannot be extrapolated to the human eye because they do not consider the geometry and function of the human eye. The studies report effects when the retina is directly and continuously stimulated with high intensities, which does not represent our reality [31,36]. The Royal Australian and New Zealand College of Ophthalmologists (RANZCO) supports this conclusion, explaining that the human eye uses multiple mechanisms to protect against BLH. The cornea, lens, and macular pigments absorb a significant portion of short-wavelength light, protecting the retina from the toxicity risk posed by A2E [36,37].

Furthermore, the American Academy of Ophthalmology (AAO) suggests that the discomfort experienced when observing a screen is likely due to decreased blinking, leading to dry eyes. It is not caused by excessive radiance effects [38]. They do not recommend using blue light-filtering lenses to protect the retina because the literature does not provide concrete evidence that this light is genuinely harmful to the eye [39]. The part of the light that should be avoided is the ultraviolet portion, which is not emitted by screens [40].

Comparison of Different Light Sources

Considering these safety standards and the position of these committees regarding the risks of LED lights on screens, several studies have chosen to compare different light sources to determine whether the criticism leveled against LED lighting in recent years is justified. The main criticism is that LED lights emit a light spectrum with a peak (460 nm) close to the peak sensitivity of BLH (around 440 nm). However, this peak is not specific to LED lights. Fluorescent lights also emit a peak in the spectrum around 436 nm (quite closer to the BLH peak), which has not received the same level of criticism. Moreover, at equal correlated color temperature, LEDs do not emit more blue light than fluorescents. The following figure illustrates this comparison [41] (Figure 1).

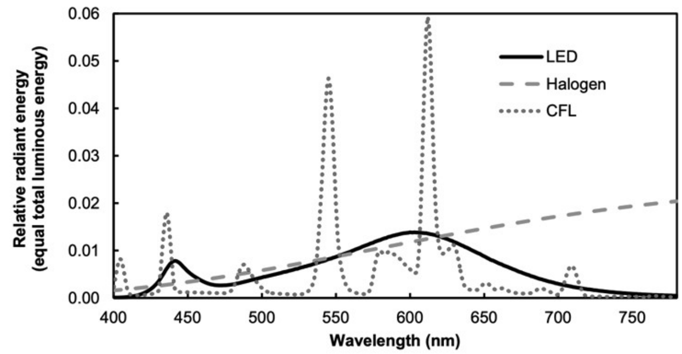

Figure 1: Compares the spectrum of a LED light with that of a halogen light and a fluorescent light (CFL). All of these lights have an equivalent correlated color temperature and equivalent radiance. The diagram is adapted from the article of Dain [41].

It should be noted that the correlated color temperature of a light source does not predict the risk of BLH; it is rather the radiance emitted by the source [37]. For instance, even though a 6000K LED light would technically present a greater BLH risk than a 3000K LED light, the permitted exposure time for these two light sources differs very little and represents much less risk than sunlight exposure [37]. AAO has adopted the position that the blue light from screens is less intense than that emitted by the sun. In other words, exposure to blue light and its risks reported in the literature when outdoors is more significant than any artificial lighting [38]. In fact, the highest intensity blue light emitted by screens is still nearly 30 times less intense than sunlight [41,42]. Even when screens are at their maximum intensity and projecting a white screen (corresponding to the highest potential radiance), no light source exceeds the limits set by ICNIRP [43]. In fact, O'Hagan demonstrated that screens do not emit even 1% of the allowed long-term exposure limit. Therefore, there is no justification for concerns about exposure to blue light emitted by screens as their radiance is too low [43,44].

Light sources that should be of greater concern due to their excessive radiance and high risk of retinal toxicity, even with short exposure durations (less than a minute), include sunlight, welding arcs, plasma cutting, and discharge lamp arcs [33,44]. These types of lighting are classified as high-risk groups in lighting classifications [45]. In fact, LED lights would be classified in risk group 0, corresponding to an effective blue light radiance below 100W/(m2·sr). The groups are established based on the exposure time to light required before exceeding the limit set by CIE and ICNIRP. The shorter the exposure time, the higher the risk [45,46].

Studies on Blue Light-Filtering Lenses

The concept that blue light may have adverse implications for retinal health has prompted the development and sale of blue light-filtering lenses. These lenses are intended to mitigate the potential progression of degenerative retinal diseases, such as Age-related Macular Degeneration (AMD), purportedly associated with exposure to blue light. However, as mentioned earlier, it remains controversial in the field of ophthalmology whether these lenses actually limit age-related macular degeneration. In fact, a prospective study showed that patients who underwent cataract surgery with blue light-filtering Intraocular Lens (IOL) implantation did not have fewer cases of AMD or a more favorable progression compared to those with conventional UV-only lenses [47]. Another case-control study showed that among patients with wet AMD who had cataract surgery at least three years before diagnosis, over 60% had blue light-filtering IOLs [48], raising questions about their effectiveness. Furthermore, a cohort study of over 185,000 patients in Taiwan followed for 10 years after cataract surgery with IOL implantation found that blue light-blocking IOLs offered no advantage over conventional lenses [49]. Similarly, another cohort study involving 11,397 patients, half of whom underwent cataract surgery with blue light-filtering IOLs and the other half with conventional lenses, arrived at the same conclusion, indicating that blue light-filtering lenses did not reduce the incidence or progression of neovascular AMD or the appearance of variables related to its severity [50].

Regardless of the type of analysis, studies on blue light-filtering IOLs do not support the decision to implant these lenses to preserve macular health. A Cochrane systematic review reached the same conclusion after examining 51 randomized controlled trials evaluating the effects of IOLs [51].

Discussion

Regarding the retinal toxicity that can be caused by short wavelengths, LED lights do not appear to warrant more attention than other types of lighting. In fact, no artificial lighting should be a concern for macular health according to the standards established by ICNIRP and CIE. The comparison between different types of lighting and the conclusion that blue light-filtering lenses do not improve retinal health has led organizations such as CIE, ICNIRP, RANZCO, and AAO to conclude that LED light does not pose a risk of BLH. Studies supporting the idea that blue light is harmful to the retina have primarily examined sunlight exposure, which far exceeds the intensity of LEDs. Moreover, even exposure to sunlight, without direct viewing, does not necessarily cause AMD, according to a meta-analysis [52]. Thus, knowing that LED lights emit much less radiance than the sun reinforces the idea that LED lights are not harmful to the retina.

However, it is not only the toxic effects of LEDs on the retina that are criticized in the literature but also the disruption of circadian rhythm. Touitou and Point suggest being cautious about these effects [46]. For example, exposure to a screen such as an e-book within four hours before bedtime results in poorer sleep quality and decreased cognitive performance the following day [53]. Thus, exposure to blue-enriched white light in the evening can have deleterious effects on cognition, performance, and wakefulness [54]. However, it appears that this topic is also controversial in the literature. Indeed, the beneficial effects of the blue portion of light appear to have a positive impact on survival in humans. A retrospective cohort study by Griepentrog et al. [55] analyzed over 9,000 patients who underwent cataract surgery with intraocular lens implantation and observed a trend toward better survival in patients implanted with IOLs that do not filter blue light compared to those with blue light-blocking IOLs. It is suggested that preserving circadian rhythmicity through access to the full spectrum of visible light would have significant physical benefits on survival [55]. Other studies have also shown that patients wearing blue light-filtering lenses experienced more mood disorders [56], particularly depression [57]. Another study showed that conventional IOLs allowed better cognitive function and sleep quality [58]. If exposure to blue light from LED screens in the evening can cause circadian disruptions, a more economical and effective solution than using blue light-filtering lenses may be to simply limit exposure during that time of day [39]. Additionally, modern screens incorporate a feature that allows for preprogrammed reduction of blue light emissions after specific hours, resulting in a yellowish screen tint—a potential alternative worth considering.

Furthermore, it appears that blue light may also provide protection against the progression from dry AMD to wet AMD. A study on A2E-loaded RPE cells exposed to blue light (440 nm) observed a decrease in vascular endothelial growth factor (VEGF) synthesis (a factor involved in the mechanism of wet AMD) and an increase in VEGFR1 (which could act as a VEGF trap) [59]. This could explain why other retrospective studies found that the first anti-VEGF injection occurred earlier in patients who had cataract surgery with blue light-filtering IOLs (thus reducing the protective mechanism observed in this study) [48,50,60].

Limitations

While there seems to be little evidence in the literature that LED lighting poses a risk of retinal toxicity, it is important to note that these studies are primarily based on standards established by CIE and ICNIRP for a fully formed eye with intact protective mechanisms. In its guidelines, ICNIRP cautions against the potential impact of blue light on newborns and the elderly, emphasizing the vulnerability of these age groups due to potentially inadequately developed protective ocular functions [31].

Conclusion

This literature review has addressed questions regarding the blue light hazard of LED lights criticized in the literature. No organization warns the population about the toxic effects of the blue component of LED light. This light source does not pose more danger than other light sources, and certainly less so when compared to the risk presented by natural light. Furthermore, blue light-filtering intraocular lenses do not better preserve retinal health than conventional lenses, raising questions about the actual role of blue light in the retinal degeneration process. While studies have identified theoretical risks, providing a better understanding of the relevance of protecting the retina when the eye is exposed to very intense sources such as a solar eclipse, they do not support the idea that LED lights present the same risk, even with long-term exposure. In fact, it appears that the neurocognitive benefits of blue light should not be underestimated and restricting its exposure may potentially cause more risks than benefits.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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