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Is blue light solely detrimental for human eyes? A concise overview of the current knowledge on how blue light affects eye health.

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Abstract

It has long been assumed that blue light is solely detrimental to the eyes and that it is a serious risk factor for a number of ocular diseases. In order to gain a more nuanced comprehension of the impact of blue light on the eye and to ascertain whether there are any beneficial aspects to this influence, this article presents a synthesis of the relevant research and offers updates on the current understanding of the subject matter. The review encompasses the environmental and societal changes that result in increased light exposure, the working principle and reasons for the prevalence of light-emitting diodes, and the safety classification of artificial light sources. Subsequently, we present the impact of blue light on ocular growth and the known mechanisms by which blue light affects different areas of the eye, including the cornea, conjunctiva, lens and retina. Finally, we discuss the validity of blue-blocking lenses and review other recommended strategies aimed at minimising the negative effects of blue light exposure.

Keywords: blue-blocking lenses; blue light; light-emitting diodes; ocular growth; oxidative stress; phototoxicity

Aim of this study: The objective of this study is to investigate the ambiguous effects of blue light on eye health to provide an updated account of the current state of knowledge on the subject.

Material and methods: The review of the available scientific and medical literature from PubMed, Google Scholar and the Cochrane Library was conducted. The search was performed using keywords: age-related macular degeneration; blue-blocking; blue-filtering; blue light; blue-light-hazard; circadian; cataract; correlated colour temperature; dry eye disease; light emitting diodes; oxidative stress; phototoxicity; retinal ganglion photoreceptor; retinal phototoxicity, with the following analysis of the gathered information.

Introduction

The increase in the use of electronic devices is one of the dominant features of the 21st century. Adequate indoor and outdoor lighting is a prerequisite for the rapid technological and industrial development. Conventional light sources such as incandescent and fluorescent lamps were found unsatisfactory in the changing scene. Consequently, an increase in the use of economical light-emitting diodes (LEDs) has been observed. Widespread use of cheap, efficient and durable light sources makes it possible to engage in activities requiring proper illumination regardless of the time of day and absolves humanity of its dependence upon daylight. Still, gradually widening adoption of artificial light sources and the associated light pollution by artificial light at night (ALAN) is becoming an increasingly recognised problem in the scientific community. The term ALAN refers to the light displaying characteristics deviating from those of the natural night lighting with adverse effects on living organisms.[1,2] With the increasing recognition of the environmental impact on human well-being, the topic of blue light is emerging as a subject of interest. These novel challenges have yet to be fully evaluated in terms of their long-term impact on human health.

As the scientific community continues to debate the impact of artificial blue light on human physiology, the aim of our study is to compare the positive and negative effects of blue light on eye health.

LEDs

While LEDs are not the only sources of blue light in the environment, their working principle and pervasiveness in everyday life make them an essential part of this discussion. In the process of electroluminescence, most commonly used white LEDs emit seemingly white light with peak emission in the blue light spectrum – roughly between wavelengths of 400 to 500 nm.[3] Its photon energy is the largest of the visible light spectrum as it is inversely proportional to the wavelength. Consequently, it poses the greatest risk for eye tissues damage, which is commonly referred to as the blue light hazard.[4] It is envisioned that by 2030, LEDs will become the primary light source for both indoor and outdoor applications. This shift is expected to be evident in public venues and households, as well as in streets, roadways, parking lots, and buildings exteriors.[5] Aside from general illumination, LEDs are commonly used in appliances such as smartphones, tablets, e-readers and television sets. The trend is towards an increase in the use of this type of devices in both work (in offices and while working from home or attending online meetings and classes) as well as leisure environments which results in longer periods of exposure to blue light, and at very close range. Notably significant escalation in screen time has been observed during COVID-19 pandemic, especially among children.[6,7]

Two methods exist for the production of white light from LEDs: by combining an ultraviolet (approximately 390 nm) or blue (approximately 450 nm) LED with a yellow phosphor (emission peak around 580 nm) or by combining red, green and blue (RGB) LEDs.[5,8,9] However, the amount of blue light emitted by a source does not depend on its type or technology but on the colour of the light itself.[10,11] In light of aforementioned considerations, digital devices may emit radiation with characteristics varying between appliances of the same model, depending on the user's settings. The correlated colour temperature (CCT) of a "white" LED may be significantly influenced by the design of the LED, too. The parameter is used to measure the quality of white light and employed to describe the perceived temperature of colour, in relation to Planckian thermal radiator, expressed in units of Kelvin. Higher CCT is associated with more blue emission spectrum, while lower CCT relates to more red emission spectrum. The CCT adjustment represents a fundamental aspect of the "human centric lighting". The concept entails the modification of colour and intensity of LED lighting throughout the day in order to sustain natural circadian rhythms in humans.[5,12]

Safety

Safe exposure limits and guidelines regarding blue light hazard and artificial light sources have been issued by institutions such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the International Electrotechnical Commission (IEC), the Illuminating Engineering Society (IESNA) and the American Conference of Governmental Industrial Hygienists (ACGIH).[4,5] In *Photobiological safety of lamps and lamp systems* (IEC 62471:2006) IEC proposed a classification of lamps into risk groups: RG0, RG1, RG2 and RG3, based on exposure limits. The exposure risk grows progressively from RG0 (exempt category, no photobiological hazard) to RG3 (hazardous even for swift exposure). It has been established that the majority of LEDs used for general lighting can be classified as RG0, and thus associated with no hazard and within safe viewing boundaries for most of healthy adult individuals during average usage.[5,13] Similarly, blue light emission from digital devices estimates do not exceed harmless range and are not considered to cause immediate adverse impact. Nevertheless, the long-term effects of prolonged exposure remain uncertain, and the emergence of new trends and risks continues to challenge existing knowledge.[4]

Eye role

The eye is an organ responsible for visual perception. As such, it is particularly susceptible to damage caused by light. The term "visual perception" encompasses four forms of vision: photopic vision, colour vision, scotopic vision and mesopic vision. In a healthy eye, light enters the eye through the cornea, passes through the lens and vitreous body and reaches the retina. The retina is composed of photoreceptor cells called rods and cones. These two type of cells differ distinctively in their morphology, function and number. The process of phototransduction begins with the activation of photosensitive proteins, which are responsible for converting light into electrical signals. These proteins, which include rhodopsin in the rods and opsin in the cones, initiate the conversion of light into nerve impulses that are transmitted to the brain, where they are used to construct an image.[8]

Natural conditions

While artificial lighting is ubiquitous in present-time society, it is crucial to recognise that natural sunlight, the primary source of outdoor illumination, is considerably brighter than human-made light. The radiation from the sun encompasses all visible light wavelengths, and is especially rich in blue light. Such light has accompanied vertebrates throughout their evolution and plays an important role in regulating their biological rhythms.[14] The literature contains reports of eye injuries resulting from intentional sungazing, with a particularly high incidence of solar retinitis following solar eclipses. Particularly bright conditions produce discomfort glare so the act of direct gaze at luminous sources would be perceived to be an unusual behavioural pattern. The human body has developed a series of reflexes that protect the eyes from excessive light. These include blinking, closing the eyes, and moving the head away from the light source. Consequently, the occurrence of eye damage due to sunlight is relatively uncommon in the absence of extreme conditions.[15,16]

Ocular growth

A considerable body of research indicates that engagement in outdoor activities may mitigate the occurrence and progression of myopia. Conversely, scarce exposure to daylight, prolonged periods spent indoors and near work have been identified as risk factors for myopia.[17–20] While there is strong evidence for time spent outdoors and light intensity, the spectral composition of light is one of the possible environmental factors influencing myopia.[20] In animal models, short wavelengths proved protective against experimental myopia in chick, mouse and guinea pig[21–23,23–26], whereas longer wavelengths have been shown protective in tree shrew and some primates[27–29]. Multiple factors, including differences in the structure and sensitivity of retinal photoreceptors and variations in experimental protocols, such as the duration and intensity of light exposure, may account for this variation in spectral response between species.[20] A study conducted by Thakur et al. revealed that blue light (with a wavelength of 460 nm) had an inhibitory effect on axial elongation. In contrast, red light (with a wavelength of 623 nm) and green light (with a wavelength of 521 nm) both demonstrated a promoting effect on this process in a group of young adults.[30] The precise impact of short wavelengths on eye growth remains unclear. However, some theories suggest that it may involve changes in ocular neurotransmitters and signalling molecules, particularly dopamine

(DA). DA is released by dopaminergic amacrine cells that are connected via synaptic pathways with the intrinsically photosensitive retinal ganglion cells (ipRGCs). The stimulation of melanopsin in the ipRGCs by blue light results in a subsequent modulation of dopamine release.[31–33] Other potential factors include the impact of longitudinal chromatic aberrations (LCAs), which prompt the eye to elongate in response to hyperopic defocus of long wavelengths, and to shorten in response to myopic defocus of short ones.[30,34] With the growing evidence of the protective function of short wavelength light exposure on myopia in experimental studies, there is a pressing need to examine the potential impact of such wavelength exposure on children and its viability for myopia control.

Cornea, conjunctiva and tear film

The cornea, conjunctiva and tear film collectively represent the initial barrier between light and the visual system. Additionally, the cornea constitutes a component of the eye refractory system, which plays a pivotal role in maintaining visual acuity. Given their extensive exposure to the external environment, the cornea and conjunctiva are the most vulnerable to the damaging effects of blue light. A comprehensive body of research has demonstrated that the mechanism of blue light overexposure hazard on the ocular surface is associated with oxidative stress-induced damage, ocular surface inflammation and cell apoptosis. It has been demonstrated that excessive reactive oxygen species (ROS) in the corneal and conjunctival epithelial cells can lead to mitochondrial dysfunction. Furthermore, ROS have been found to induce the production of inflammatory cytokines and the recruitment of macrophages. Consequently, the release of inflammatory factors elicits reduction in the secretion of tears and mucin, which destabilises the tear film, promotes tear evaporation and ultimately leads to the hyperosmotic ocular surface, loss of cell viability and dry eye disease.[15,35]

In the context of clinical practice, it is well documented that exposure to certain environmental factors, such as light, can result in damage to the ocular surface and the exacerbation of symptoms associated with dry eye.[35] According to the Tear Film & Ocular Surface Society Dry Eye Workshop II (TFOS DEWS II) report: “Dry eye is a multifactorial disease of the ocular surface characterized by a loss of homeostasis of the tear film, and accompanied by ocular symptoms, in which tear film instability and hyperosmolarity, ocular surface inflammation and damage, and neurosensory abnormalities play etiological roles.”.[36] Dry eye syndrome is symptomatically connected to computer vision syndrome (CVS), which is also known as digital eye strain (DES) or visual fatigue (VF). It has been suggested that blue light emitted by digital devices may also be a contributing factor in the development of CVS.[37]

In consideration of this finding, a number of proposed protective measures have been formulated with the aim of reducing the adverse effects of blue light on digital equipment users. These measures will be discussed in greater detail subsequently.

Lens

Following its passage through the ocular surface, incoming light reaches the aqueous humour and crystalline lens. In addition to its role in the eye's refractive system, the crystalline lens exhibits a high degree of absorptive capacity for ultraviolet (UV) -A and UV-B light, as well as a moderate capacity for visible blue light.[4,8] Some scientific data indicates that crystalline lens transparency diminishes with increasing age, resulting in a progressive increase in light absorbance within the blue light spectrum and decrease in retinal light damage occurrence.[15] Further investigation is necessary to determine whether visible blue light has a unique and significant impact on the formation of cataracts, in addition to that proposed for ultraviolet light.[4] In a manner analogous to that observed in the corneal epithelial cells and conjunctival epithelial cells, lens epithelial cells that have been exposed to blue light radiation have been found to exhibit a reduced viability, an elevated production of reactive oxygen species in mitochondria and an inflammatory response. Recent studies have demonstrated that oxidative stress plays a significant role in the development of cataracts. Furthermore, the importance of antioxidants in preventing this process has been emphasised.[38–40]

Retina

The retina is the innermost layer of the eye, comprising light-sensitive tissue. The refractive system of the eye creates an image on the retina, which is then processed and transmitted along the optic nerve to the visual cortex, where visual perception is created. The neural retina is constituted by a number of distinct layers of neurons linked by synapses, and is supported by the presence of a layer of pigmented epithelial cells located on its external surface. Rods are primarily responsible for vision in low-light conditions, providing monochromatic vision. Conversely, cones are responsible for the perception of colour in bright conditions, utilising a range of opsins. Additionally, they are involved in tasks requiring high acuity vision, such as reading. The third category of light-sensitive cells is the intrinsically photosensitive ganglion cell. These cells possess melanopsin, which exhibits peak absorption at 480 nm (blue light). ipRGCs represent a component of the non-image visual response system, and their function is essential for regulating circadian rhythms.[41,42]

Given that blue light has the highest photon energy of any wavelength in the visible light spectrum, there is a continued concern regarding its potential to cause photochemical damage to the retina and retinal pigment epithelium (RPE). A substantial body of research has consistently demonstrated that the blue light emitted by smartphones, tablets, and personal computers consistently falls below the published exposure limits for this type of light set by ICNIRP. This information leads to the conclusion that the blue light emitted by these devices poses no acute risk to the retina. The potential long-term effects of repeated exposure to low-illuminance blue light remain a subject of contention in the research community.[4,16,43]

The application of blue light-emitting diodes has been demonstrated to result in a reduction in cell viability and an increase in the production of reactive oxygen species in both photoreceptor cells and RPE cells. Nevertheless, a significant proportion of research into the potential ocular photodamage associated with blue light has been carried out using in vitro and animal models. This is particularly pertinent to models based on nocturnal animals and on mice and rats, which do not possess melanosomes, the organelles that facilitate light absorption and free radical removal in human RPE. In addition to the previously mentioned conditions, other unusual circumstances have been observed in these studies. These include the use of high colour temperature (CCT) LEDs, exposures that substantially exceed the ICNIRP exposure limits, a fixation on the light source, and long-term exposure. Consequently, it is not feasible to extrapolate these findings to the potential impact of blue light emitted from digital devices in domestic use (falling within established safety limits) on the retina and RPE in humans.[3,4,8,44–46]

The precise role of visible light, particularly blue light, in the aetiology of age-related macular degeneration (AMD) remains uncertain. The hypothesis that blue light is phototoxic, and that cumulative retinal damage from repetitive acute phototoxicity may increase the risk of AMD, remains to be proven. There is currently no supporting evidence for this hypothesis. As with other hypotheses in this field, the evidence base for this one also suffers from similar limitations, as described in the previous paragraph. Furthermore, given the multiplicity of factors involved in the pathogenesis of AMD and the variability in individual susceptibility to blue light damage, it is challenging to establish a causal relationship between blue light exposure and the development of AMD.[3,4,8,44,45,47–50]

Blue light is a component of the visible spectrum and plays a role in the formation of images. It is evident that modifications to the lighting environment can have a considerable effect on visual performance. The impact of blue light on visual performance is a subject that is commonly debated in relation to blue blocking lenses, particularly in the context of scotopic and mesopic conditions, which primarily concern rod-mediated vision.[51–55] The subject of blue blocking lenses will be addressed subsequently.

It has been demonstrated that blue light stimulates melanopsin, a photopigment expressed by ipRGCs. As has been previously discussed in this text, ipRGCs constitute a part of the non-image visual response system, which has a profound influence on mental and physical health. The ipRGCs send projections to the circadian clock in the suprachiasmatic nuclei, thus ensuring entrainment of the 24-hour daily cycle to the natural light-dark rhythm. Additionally, the ipRGCs extend their projections to the perihabenular nucleus and adjacent brain regions, which regulate mood, stress, and learning. Furthermore, the activation of ipRGCs results in a change in retinal dopamine levels in response to blue light. Dopamine is involved in a number of retinal processes, including light adaptation, retinal development and eye growth, which were previously discussed.[4,12,42,44,48]

Blue-blocking lenses

A number of means have been proposed to mitigate the negative effects of blue light radiation associated with the use of digital devices. The most popular of these are blue-blocking (yellow-tinted) lenses, which claim to filter out short-wave light. Lens manufacturers market them as relieving CVS symptoms, improving sleep quality and preventing retinal phototoxicity. However, recent studies have shown that these claims are highly controversial.[9] Firstly, most displays are within the standard safe range of blue light emissions under normal viewing conditions, as we have already established.[4,5] Secondly, recent studies have shown that there is no high quality evidence for the use of blue-light blocking lenses in the general population for improving visual performance, promoting sleep or attenuating symptoms of digital strain.[9,54,55] Whether or not blue light blocking lenses impair contrast perception under scotopic or photopic conditions, particularly in the elderly, is another controversial issue. Some authors argue that the hypothesis is true and emphasise the importance of blue light for scotopic photoreception in preventing night falls and related injuries[45,53,56], while others point out that the decrease in transmittance is not sufficient to cause a significant reduction in visual performance.[51,52,57,58] The matter in question must be investigated further. It is noteworthy that in the past, the utilisation of yellow-tinted intraocular lenses (IOLs) implanted during cataract surgery gave rise to a further concern, namely the potential adverse impact of the removal of blue light on the regulation of circadian rhythms, sleep and cognitive function. Consequently, the utilisation of these IOLs was terminated.[59]

Other protective measures

It can be argued that the less popular methods contemplated as protection against the adverse impact of blue light can be divided into two groups. The first of these comprises methods that modify the exposure to the light, while the second group includes those that modulate the photobiological processes following the irradiation with blue light. Modifying exposure can take form of: using software to limit high-energy visible light transmission, adjusting the CCT of the screen or light source depending on the time of day and adhering to the "20-20-20" rule recommended by the American Academy of Ophthalmologists (AAO).[8,37,39] The fundamental premise of this rule is that, for a minimum duration of 20 seconds, one should direct their gaze away from the screen and towards an object situated 20 feet away at least every 20 minutes.[60] The hypothesis that modulating the photobiological reaction may offer protection against blue light hazard is based upon the pivotal role oxidative stress plays in this process. Some studies indicate that antioxidant compounds, including lutein, zeaxanthin, and vitamin E, may be beneficial in limiting the accumulation of oxidative stressors, thereby offering protection. However, specific guidelines, drugs, and prognoses still require further development.[8,15]

Conclusions

Given the growing amount of time spent exposed to artificial light sources and digital devices, it is necessary to gain a deeper understanding of the potential effects of blue light emissions on human health and wellbeing. Although our research hypothesises that low-illuminance blue light from electronic devices does not have an immediate detrimental impact on the eye, there is still a lack of high-quality studies that have considered the relevant parameters and exposure durations in order to ascertain the long-term effects of this blue light on human eyesight. The cumulative effect of light, which is influenced by a number of characteristics, including wavelength, intensity, duration of exposure, and time of day, necessitates an assessment of the spectral output of artificial light sources to mitigate the potential risks associated with blue light exposure.[4,44]

Although retinal complications from blue light exposure appear to be the most serious concern, it is notable that natural ambient light exposure in everyday environments does not cause acute retinal phototoxicity. Similarly, the research to date has not provided definitive evidence of its role in the incidence or progression of AMD. Nevertheless, there is a pervasive tendency to misrepresent the hazards associated with blue light. The blue light hazard is employed as a marketing tactic to induce consumers to utilise spectacles and intraocular lenses that restrict blue light. However, the available data suggests these lenses do not provide clinical protection. In contrast, an increasing number of scientific studies have indicated the pivotal role of blue light in maintaining mental and physical well-being. Furthermore, it has been shown that blue light plays an essential function in achieving optimal scotopic and mesopic vision.[9,45,48,53–56]

While it is premature to provide definitive answers at this stage, the encouraging outcomes observed in animal models, coupled with the limited number of human studies, have facilitated a more comprehensive understanding of the impact of blue light on the axial length of the eye. This understanding could potentially pave the way for the development of an anti-myopia tactic that incorporates blue light exposure. Nevertheless, further investigation is needed to confirm and explore these findings and do gain a full understanding of the underlying mechanisms.[20,30]

It must be acknowledged that the adverse effects of blue light on the body, in association with oxidative stress, remain a valid phenomenon. Furthermore, there is a growing body of scientific evidence to suggest a causal relationship between blue light exposure and the development of diseases such as dry eye syndrome. However, in order to avoid the pitfalls of oversimplification, it is essential to recognise that blue light is but one contributing factor in the complex web of oxidative stress in our bodies.[35,36,40]

Scientists worldwide are engaged in the endeavour of elucidating the effects of blue light on humans, the mechanisms by which it acts and the long-term implications, employing novel technology and research tools. In order to form and publish comprehensive, evidence-based guidelines, it is imperative that more data be obtained. It would be advantageous to conduct longitudinal observational studies with the objective of quantifying light exposure and measuring key indicators of eye health, circadian rhythm function, and other potential areas of interest. At this time, it is of the utmost importance to distinguish between information presented in media reports and the actual findings derived from scientific research, thereby preventing the perpetuation of misinformation and the repetition of previous erroneous assumptions. Furthermore, it is essential to adopt a reasonable approach to our exposure to blue light from artificial sources, with a bias towards caution.

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Conflicts of interest

The authors declare no conflict of interest.

Data availability

Not applicable.

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