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Biophysical Effects Of Blue Light Emitted From Digital Devices On Ocular Tissues

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Abstract

This article analyzes the biophysical effects of blue light (wavelength range 400–500 nm) emitted from digital device screens on ocular tissues, particularly the retina and retinal pigment epithelium, and discusses practical solutions aimed at preventing or reducing these effects.

Keywords: blue light, biophysical effects, retina, retinal pigment epithelium, reactive oxygen species, digital eye strain, photochemical damage, circadian rhythm.

In modern life, digital devices — smartphones, tablets, and computer monitors — have become an integral part of daily activities. Large-scale studies conducted during 2023–2024 demonstrate that the average daily screen time among the population continues to increase significantly.

According to a survey conducted in the United States by CooperVision (2023), more than 50% of respondents reported spending 6 hours or more per day in front of digital devices, while 25% reported more than 9 hours of daily screen exposure [1].

A systematic review and meta-analysis published in 2023 estimated the global prevalence of Computer Vision Syndrome (CVS) at approximately 66%; in 2024, this figure reportedly increased to 74% [2].

It should also be emphasized that the prevalence of Digital Eye Strain (DES) worldwide ranges from 8.2% to 100%, depending on study methodology and the characteristics of the investigated populations [3].

Against the background of these epidemiological indicators, an in-depth investigation of the biophysical mechanisms of blue light effects on ocular tissues and the development of scientifically grounded preventive recommendations are becoming increasingly important.

Blue light (400–500 nm wavelength range) belongs to the high-energy region of the visible light spectrum. Modern screens based on LED technology may emit peak spectral power within the 435–460 nm range, thereby increasing the potential for specific biophysical effects on ocular tissues [4].

- ***Mechanism of Photochemical Damage.*** The principal harmful property of blue light is its ability to induce the formation of reactive oxygen species (ROS) within the retinal pigment epithelium (RPE). The chromophore A2E, present in lipofuscin, absorbs blue-violet light in the 415–455 nm wavelength range and may generate reactive species such as singlet oxygen ($^1O_2$), superoxide anion (O_2^-), and hydrogen peroxide (H_2O_2). This process may lead to a decrease in mitochondrial membrane potential, activation of the caspase cascade, and ultimately apoptosis of RPE cells [5].

- ***Chronic Effects on Retinal Tissue.*** Long-term exposure to low-intensity blue light (below 100 lux) may cause structural and functional alterations in retinal tissue. Clinical observations suggest a possible reduction in photoreceptor amplitude within the macular region, while animal models have demonstrated histological changes in the retina [6].

- ***Association with Age-Related Macular Degeneration (AMD).*** RPE cells are highly sensitive to lipofuscin accumulation, and chronic photo-oxidative stress may accelerate the development of the dry form of AMD. Blue-violet light within the 415–455 nm range may induce the highest levels of ROS production and intensify mitochondrial dysfunction [7].

- ***Cornea and Lens.*** Ocular structures — including the cornea, aqueous humor, lens, and vitreous body — sequentially absorb photons of different wavelengths. Although ultraviolet radiation is largely blocked by the cornea and crystalline lens, blue light in the 400–500 nm range can penetrate these barriers and reach the retina. With aging, the lens gradually acquires a more yellowish coloration, increasing its natural protection against blue light; however, this protective mechanism may be reduced after implantation of artificial intraocular lenses [4].

- ***Effects on Circadian Rhythm.*** Blue light may activate melanopsin through intrinsically photosensitive retinal ganglion cells (ipRGCs). Evening exposure to blue light emitted from digital devices has been

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shown to suppress melatonin production, potentially resulting in sleep disturbances and disruption of the circadian cycle [8].

PREVENTIVE STRATEGIES:

- ***The 20-20-20 Rule.*** Looking at an object located approximately 6 meters (20 feet) away for 20 seconds every 20 minutes helps relax accommodative muscles and significantly reduces eye strain. Studies indicate that 51.2% of users never apply this rule [3].

- ***Blue Light Blocking Technologies.*** Blue light-blocking lenses and screen filters reduce light exposure within the 400–460 nm range. However, scientific studies confirm that these filters have minimal effects on wavelengths above 460 nm [9-31]. Therefore, filters should not be considered a standalone solution but rather used in combination with other preventive measures.

- ***Optimization of Screen Settings.*** Adjusting screen brightness according to ambient lighting conditions and using "Night Mode" or warmer color temperatures can reduce blue light emission. Since potentially harmful biophysiological effects are primarily associated with wavelengths between 400–460 nm, lowering screen color temperature to 3000–4000 K may be beneficial [4].

- ***Proper Viewing Distance and Ergonomics.*** A viewing distance of at least 50–70 cm from computer monitors and 30–40 cm from smartphones is recommended. The screen should be positioned slightly below eye level. Matching environmental lighting with screen brightness helps reduce contrast-related visual strain.

- ***Artificial Tears and Ocular Surface Hydration.*** Prolonged screen exposure decreases blink frequency (from an average of 15 blinks per minute to approximately 5–7), resulting in ocular surface dryness and discomfort. Regular use of artificial tear drops and conscious blinking help maintain adequate ocular hydration.

- ***Antioxidant-Rich Nutrition.*** Lutein and zeaxanthin — carotenoids that accumulate in the macular region — help partially filter blue light reaching the retina. These substances are abundant in carrots, spinach, corn, and green leafy vegetables. Omega-3 fatty acids contribute to strengthening RPE cell membranes
- ***Regular Ophthalmologic Examination.*** Individuals who intensively use digital devices, particularly those working in medicine, IT, and education, should undergo ophthalmologic examinations at least once per year to identify refractive

abnormalities and obtain corrective measures when necessary. Additionally, early signs of AMD should be evaluated using the Amsler grid test and fundus examination.

CONCLUSION: Based on the above-mentioned findings, it can be concluded that the biophysical effects of blue light emitted from digital devices on ocular tissues occur through complex and multifactorial mechanisms. Scientific literature indicates that blue-violet light within the 415–460 nm range emitted by LED screens may increase the production of reactive oxygen species in RPE cells; these processes may contribute to mitochondrial dysfunction, cellular apoptosis, and chronic photo-oxidative stress. Over time, such alterations may increase the risk of diseases such as AMD.

Practical management of this issue should include the following comprehensive measures:

— adherence to the 20-20-20 rule and rational screen time management;

— use of blue light-blocking filters and night-mode screen settings;

— maintenance of proper ergonomics and lighting conditions;

— a balanced diet rich in lutein, zeaxanthin, and omega-3 fatty acids;

— regular preventive ophthalmologic examinations.

This comprehensive approach may help preserve ocular health, improve visual quality, and enhance professional productivity in an era characterized by extensive use of digital technologies.

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