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THE IMPACT OF BLUE LIGHT FROM ELECTRONIC DEVICES ON VISUAL FUNCTION, CIRCADIAN RHYTHM, AND WELLBEING: A SYSTEMATIC REVIEW

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ABSTRACT

Modern lifestyles involve increasing exposure to artificial light sources, particularly from electronic devices emitting blue-enriched light. Blue light, due to its short wavelength and high photon energy, may affect retinal structures and disrupt circadian regulation, leading to sleep disturbances. Additionally, recent studies suggest that blue light exposure may influence cognitive performance, alertness, and subjective wellbeing, especially in young adults and physically active populations.

The aim of this systematic review was to synthesize current evidence regarding the effects of artificial blue light on visual function, sleep quality, and human wellbeing. The review explored the underlying biological mechanisms, including the activation of melanopsin-containing intrinsically photosensitive retinal ganglion cells, and evaluated the potential risks associated with prolonged exposure to low-illuminance blue light from digital screens.

Findings indicate a consistent relationship between blue light exposure and disruptions in sleep–wake cycles, with emerging data pointing toward broader psychophysiological implications. The review highlights the need for further research to better define safe exposure thresholds, assess individual sensitivity, and evaluate protective strategies such as blue light filters.

KEYWORDS

Blue Light, Circadian Rhythm, Visual Function, Sleep, Wellbeing, Electronic Devices, Systematic Review

CITATION

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Introduction

In the digital era, electronic devices such as smartphones, tablets, laptops, and monitors have become integral to modern lifestyles. Their ubiquity in professional, educational, and recreational settings has dramatically increased daily screen time across all age groups. According to the latest WHO and OECD reports (2023), adults in high-income countries now spend an average of 7–10 hours per day using screen-based technologies, with adolescents often exceeding these values due to academic demands and social media use. This trend has led to chronic exposure to artificial light, particularly rich in the short-wavelength blue spectrum (400–500 nm) emitted by LED-based backlit displays.

Unlike natural light, which varies dynamically in intensity and spectral composition throughout the day, artificial light from screens is typically static, enriched in blue light, and used disproportionately in the evening—a biologically sensitive time period for circadian physiology. Blue light interacts with circadian photoreceptors, influencing sleep-wake regulation. These cells are responsible for synchronizing the circadian rhythm with the external light-dark cycle by projecting to the suprachiasmatic nucleus (SCN) of the hypothalamus.

Under physiological conditions, melatonin levels begin to rise 1–2 hours before habitual bedtime (dim light melatonin onset – DLMO), peaking during the night. However, exposure to blue light in the evening has been shown to delay melatonin onset, reduce its amplitude, and shift the circadian phase—leading to difficulties in falling asleep, shortened total sleep duration, and fragmentation of sleep architecture.

Beyond sleep regulation, emerging evidence suggests that blue light also influences alertness, mood, cognitive performance, and subjective wellbeing, particularly in physically active populations and adolescents with irregular sleep-wake patterns. Moreover, excessive and poorly timed blue light exposure has been linked to visual fatigue, digital eye strain, and potential phototoxic effects on retinal structures—raising public health concerns, especially with the growing popularity of evening screen use and exposure to LED-based lighting in indoor environments.

Despite these findings, blue light is not inherently harmful. When applied in a timed, controlled, and personalized manner, it can support cognitive function, improve mood, and even serve as a therapeutic tool in conditions such as Seasonal Affective Disorder (SAD) or circadian rhythm sleep disorders. This duality—where blue light can both disrupt and support human physiology depending on the context—underlines the need for a nuanced, evidence-based understanding of its effects.

Characteristics of Blue Light

Physical Properties of Blue Light

Blue light is part of the visible light spectrum, with wavelengths ranging from approximately 400 to 500 nanometers (nm). Due to its short wavelength and high energy, it can interact with ocular tissues more intensely than longer wavelengths, such as red light.

In the literature, two subtypes of blue light are often distinguished:

- **Blue-violet light** (400–450 nm), which is potentially harmful to the retina,
- **Blue-turquoise light** (450–500 nm), which plays a key role in regulating the circadian rhythm by influencing melatonin secretion.

Blue light affects specific photoreceptors in the retina, known as intrinsically photosensitive retinal ganglion cells (ipRGCs). These cells are responsible for transmitting light information to brain regions involved in controlling the biological clock.

Sources of Blue Light Emission

Blue light is emitted by both natural and artificial sources.

- **Natural source**:
  - **Sunlight** – the strongest and most significant natural source of blue light, with intensity that varies throughout the day.
- **Artificial sources**:
  - **LED lights** – commonly used in indoor and office lighting, emit a strong blue component, typically within the 450–470 nm range.
  - **LCD and OLED screens** – found in smartphones, tablets, monitors, and televisions. OLED technology tends to emit more blue light compared to LCD.
  - **Compact fluorescent lamps (CFLs) and energy-saving bulbs** – also emit visible blue light, though generally at lower intensities than screens.

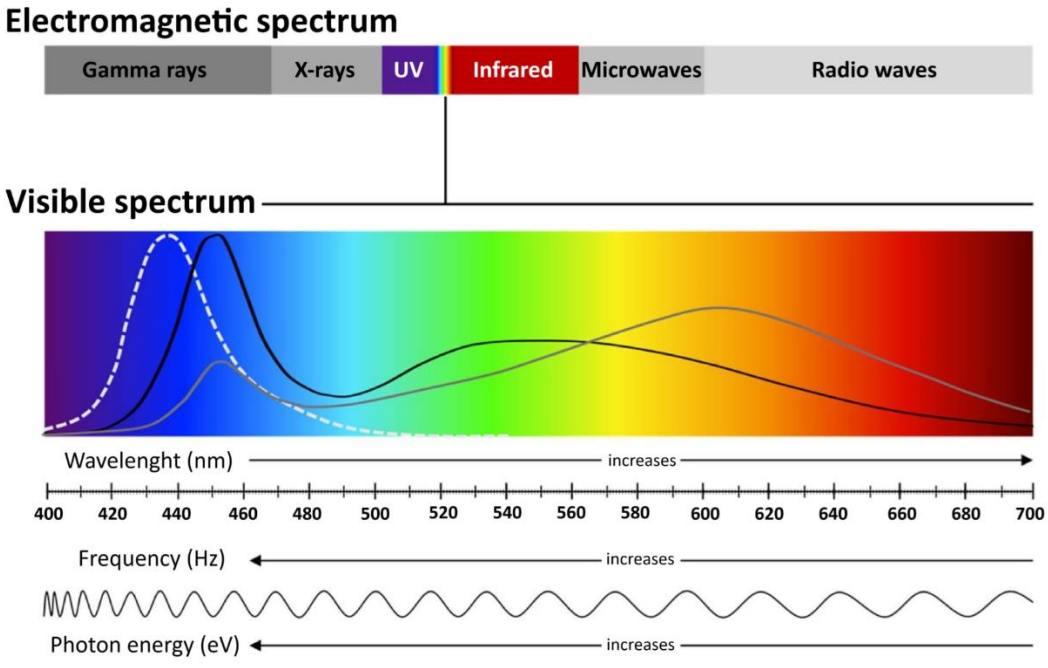

Fig. 1. *Electromagnetic spectrum and Blue Light Characteristics*

The visible portion of the electromagBluenetic spectrum spans wavelengths between approximately 400 and 700 nanometers (nm). Within this range, increasing wavelength corresponds to decreasing frequency (Hz) and photon energy (eV). The diagram illustrates key functions relevant to blue light safety: the blue light hazard function (peaking near 440 nm; represented by a dashed curve), the emission profile of a cold light-emitting diode (cold LED, peak ~455 nm for a correlated color temperature of 6000 K), and that of a warm LED (peak ~600 nm at 3000 K), shown as black and grey lines respectively. These curves demonstrate how LED light output varies with color temperature and highlight the spectral overlap with the blue light hazard function. UV = ultraviolet radiation.

The Impact of Blue Light on the Circadian Rhythm and Melatonin Secretion

The circadian rhythm is the body's internal biological clock that regulates numerous physiological processes, such as sleep, body temperature, and hormone secretion. The primary environmental synchronizer of this rhythm is light, particularly in the blue wavelength range (460–480 nm), which is detected by intrinsically photosensitive retinal ganglion cells (ipRGCs) containing melanopsin [1,9].

The light signal is transmitted to the suprachiasmatic nucleus (SCN), the central circadian pacemaker in the hypothalamus, which regulates melatonin production in the pineal gland. Under normal conditions, melatonin levels increase after sunset and peak in the middle of the night [1]. Evening exposure to blue light inhibits melatonin synthesis and shifts its secretion phase, thereby interfering with sleep onset [2,3,5].

Melatonin is essential for circadian regulation and also influences metabolism and immunity. Its synthesis requires the enzymes AA-NAT and ASMT, both of which are under SCN control. Blue light suppresses these enzymatic processes via ipRGC activation [2,9].

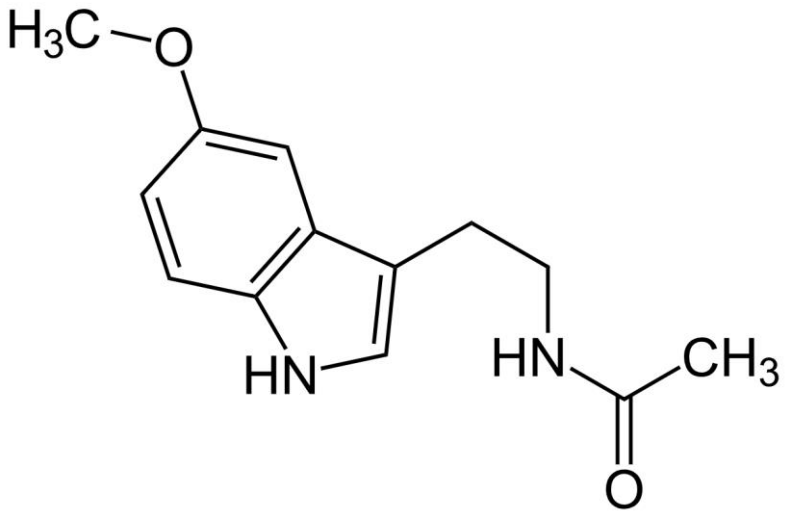

Fig. 2. *Melatonin chemical structure*

Recent studies involving adolescents and university students show that even moderate evening exposure to screen-based devices over several days can cause chronodisruption, reduce melatonin levels, impair sleep, and negatively affect perceived mental health [4,7]. Comparative studies indicate that children and adolescents are more sensitive to blue light than adults, with up to twice the melatonin suppression observed in younger individuals [5,6].

Two hours of evening tablet use reduced melatonin by over 50% and delayed its onset by ~90 minutes. [2,12,20].

There is also increasing evidence of genetic variability in sensitivity to blue light. Certain polymorphisms in circadian clock genes such as *PER3*, *BMAL1*, *CRY1*, and *NPAS2* have been associated with greater vulnerability to light-induced melatonin suppression in the evening [3,8]. While human studies are ongoing, genome-wide association studies suggest that carriers of specific variants (e.g., *PER3*) may be at higher risk for circadian misalignment when exposed to artificial evening light [8,15,19].

According to the most recent clinical data and meta-analyses (2023–2025), evening exposure to blue light remains a key factor in shifting the circadian phase, inhibiting melatonin production, and reducing sleep quality [1,4,7].

The Impact of Artificial Blue Light on the Human Eye

The human eye, as a complex optical and neural system, is continuously exposed to a wide spectrum of electromagnetic radiation. Among visible wavelengths, blue light (400–500 nm) has attracted increasing scientific interest due to its unique biophysical properties—namely, high photon energy and deep retinal penetration. Unlike ultraviolet radiation, blue light is not absorbed by the cornea or lens to a significant extent, allowing it to reach the retina with relatively little attenuation, especially in younger individuals with transparent ocular media.

Effects on the Anterior Segment: Cornea, Conjunctiva, and Tear Film

Although most discussions about blue light hazard focus on the retina, mounting evidence suggests that chronic exposure to short-wavelength light may also affect the anterior segment of the eye. The corneal epithelium and conjunctiva are directly exposed to incident light and act as the first line of defense against oxidative stress. In vitro studies have demonstrated that exposure to blue light in the 450–470 nm range can induce mitochondrial dysfunction, increase intracellular reactive oxygen species (ROS), and trigger apoptosis in human corneal epithelial cells [1,2]. These mechanisms are further amplified by desiccating stress in screen users, who often exhibit reduced blink rates and incomplete blinking during prolonged digital tasks.

In clinical settings, patients reporting digital eye strain (DES) frequently present with symptoms such as foreign body sensation, dryness, and blurred vision. While these complaints are often multifactorial, blue light exposure appears to contribute by altering the stability of the tear film and promoting low-grade surface inflammation [3]. Preliminary trials suggest that prolonged screen use under high blue light conditions may reduce tear break-up time (TBUT) and elevate levels of inflammatory cytokines in the tear film, including IL-6 and TNF-α [4]. However, further research is needed to isolate the specific contribution of blue light relative to ergonomic and environmental cofactors.

The aging lens naturally develops yellow pigmentation over time, which filters increasing amounts of short-wavelength light. In contrast, younger individuals and children—whose lenses are more transparent—may receive higher retinal doses of blue light, potentially increasing their vulnerability to phototoxicity. This physiological difference underscores the importance of age-specific exposure guidelines.

Blue Light and the Retina: Phototoxicity and Adaptation

Once blue light reaches the posterior segment of the eye, it interacts primarily with photoreceptors (rods and cones) and retinal pigment epithelial (RPE) cells, both of which exhibit high metabolic demand and vulnerability to oxidative damage. Laboratory studies using animal models and cultured RPE cells have consistently shown that blue light can induce DNA fragmentation, lipid peroxidation, and mitochondrial collapse, particularly when exposure exceeds critical irradiance thresholds or occurs in the presence of photosensitizing agents such as A2E (a component of lipofuscin) [5,6,13].

While the intensity of blue light emitted by consumer electronics is well below the threshold for acute photochemical injury, questions remain about the cumulative effect of chronic low-level exposure. Some researchers hypothesize that such exposure may accelerate retinal aging or contribute to the development of age-related macular degeneration (AMD) through oxidative stress mechanisms [7,11,23]. Nonetheless, meta-analyses to date have not established a direct causal link between blue light from screens and AMD incidence, and current international safety standards (e.g., IEC 62471) classify such devices as posing minimal retinal hazard under normal use conditions [8,18].

Importantly, blue light is not solely deleterious. The activation of melanopsin-expressing intrinsically photosensitive retinal ganglion cells (ipRGCs) by blue wavelengths is critical for regulating circadian entrainment, pupil constriction, and mood. Moreover, blue light enhances visual contrast and alertness, particularly under mesopic lighting conditions [9]. Thus, therapeutic blue light exposure during daytime hours may support cognitive function and performance in specific populations, such as shift workers and athletes.

Blue Light, Myopia, and Ocular Development

An emerging and somewhat paradoxical area of interest is the role of blue light in ocular growth regulation and myopia prevention. Animal studies, particularly in chicks and guinea pigs, have demonstrated that short-wavelength light exposure can inhibit axial elongation, possibly through retinal dopamine signaling pathways [10,25]. These findings have been partially replicated in human trials, where exposure to daylight or artificial blue-enriched lighting appears to slow myopic progression in school-aged children, although results remain inconsistent across geographic and ethnic cohorts [11].

Given that modern indoor lighting often lacks the spectral richness and intensity of natural sunlight, it has been proposed that a blue-deficient visual environment may contribute to the rising prevalence of myopia, especially in urbanized settings. Incorporating blue-enriched lighting in school or home environments—at controlled intensities and durations—may offer a novel strategy for managing refractive development during childhood.

Summary of Ocular Effects

To date, the evidence regarding blue light's impact on the human eye remains complex and context-dependent. Key factors include exposure duration, intensity, spectral composition, and individual biological sensitivity. While short-wavelength light is essential for normal visual and non-visual ocular functions, uncontrolled evening exposure and high cumulative doses may present subtle but meaningful risks, particularly for individuals with pre-existing ocular surface disorders or compromised retinal integrity.

Continued interdisciplinary research—including controlled clinical trials and longitudinal cohort studies—is essential to delineate the thresholds between physiological stimulation and phototoxic stress, and to inform the development of exposure guidelines that balance visual performance, circadian alignment, and ocular health.

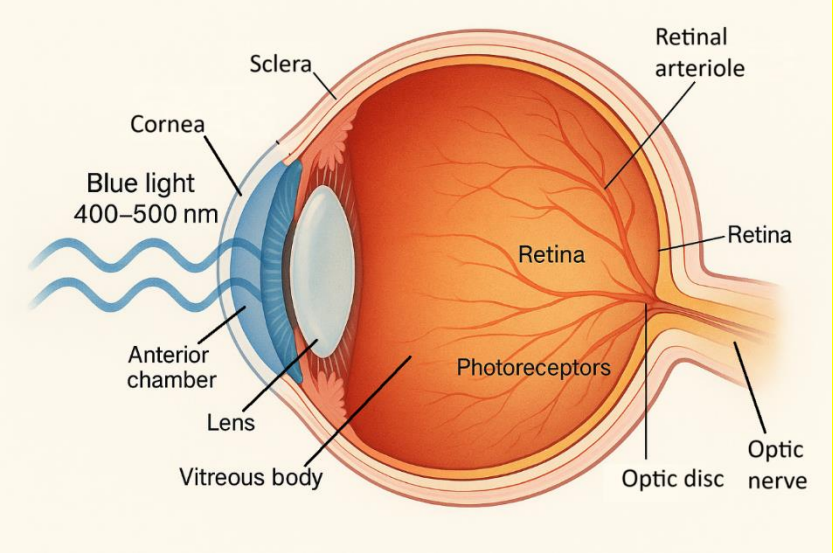

Fig. 3. *Blue light passing through the eye*

Strategies to Minimize Adverse Effects

As evidence accumulates on the physiological and behavioral consequences of blue light exposure, particularly during evening hours, strategies to mitigate its potential adverse effects have gained considerable attention in both clinical and occupational settings. While eliminating exposure altogether is neither practical nor desirable given the integral role of digital devices in modern life, several effective behavioral, technological, and environmental interventions have been proposed.

1. Blue Light Filtering Technologies

One of the most direct methods to attenuate short-wavelength light exposure is the use of optical filters, either through blue-blocking glasses or software-based display adjustments.

- **Spectral filtering lenses**, often marketed as "blue-light-blocking glasses," selectively reduce transmittance in the 400–500 nm range. Controlled studies have shown that wearing such lenses for several hours prior to bedtime can improve subjective sleep quality, reduce sleep latency, and enhance morning alertness, especially in individuals with high evening screen time [1,2,14]. These lenses vary in cut-off thresholds and filter density; orange-tinted lenses typically block a greater portion of blue light than clear lenses but may affect color perception.
- **Display-based blue light reduction modes**—available under names like *Night Shift*, *Night Light*, or *Eye Comfort Mode*—dynamically adjust the screen's color temperature to emit less blue light after sunset.

Although their impact on melatonin suppression is less potent than that of optical filters, studies suggest modest improvements in sleep parameters and eye comfort, particularly when used consistently in the evening [3,21].

- **Third-party screen protectors** and **anti-reflective coatings** for monitors can also reduce glare and filter blue wavelengths, although their efficacy varies depending on manufacturer specifications.

2. Behavioral and Environmental Modifications

Beyond device-based solutions, modifying usage patterns and ambient lighting constitutes a low-cost and effective approach to mitigating blue light exposure.

- **Limiting screen use 1–2 hours before bedtime** remains the most consistently recommended behavioral strategy. This period aligns with the natural evening rise in melatonin, and abstaining from screen exposure during this window may help restore physiological circadian timing.
- **Enhancing morning light exposure**, particularly to natural daylight, reinforces circadian entrainment and helps offset the phase-delaying effects of evening light. This is especially relevant for individuals with delayed sleep-wake phase disorder (DSWPD) or those who work night shifts [4,16,17].
- **Redesigning indoor lighting systems** to follow circadian-friendly patterns—cooler color temperatures (5000–6500 K) during the day and warmer tones (2700–3000 K) in the evening—has demonstrated positive effects on sleep onset and mood regulation. Smart lighting systems with programmable spectral outputs offer an adaptable solution for home, office, and clinical environments [5,22].
- **Implementing light hygiene protocols**, including dimming lights after sunset and avoiding overhead lighting in the late evening, further supports the natural decline in alertness and melatonin onset.

3. Personalized Interventions and Chronotype Consideration

Not all individuals respond equally to blue light exposure. Genetic polymorphisms in clock genes (e.g., PER3, CRY1, BMAL1) and individual differences in chronotype influence light sensitivity and circadian alignment. Evening types ("night owls") may be particularly susceptible to delayed sleep onset in response to artificial light, while morning types exhibit stronger entrainment to early daylight cues [6,].

Personalized interventions that account for individual light sensitivity, work schedule, and sleep timing can optimize outcomes. For example:

- **Shift workers** may benefit from timed blue light exposure at the start of their shift to promote alertness, followed by strict light avoidance protocols before intended sleep.
- **Athletes and students** facing performance tasks in the evening may strategically use short-duration blue light exposure (e.g., 15–30 minutes) to boost cognitive performance without impairing subsequent sleep—provided exposure ends at least 1–2 hours before bedtime.

4. Educational Initiatives and Public Health Policies

Despite growing awareness, many users remain unaware of the physiological implications of blue light or how to mitigate them. Therefore, educational campaigns—targeted at schools, universities, workplaces, and healthcare providers—are essential to disseminate practical knowledge about screen hygiene and circadian health.

Moreover, there is increasing interest in developing regulatory frameworks or standards for blue light emission, especially in devices marketed to children or used in educational settings. Some pediatric associations have already recommended screen curfews for children under 12 and encourage the inclusion of blue light filters in school-issued devices [7,27].

In summary, the adverse effects of blue light exposure can be significantly reduced through a combination of technological filters, behavioral modifications, environmental adjustments, and personalized interventions. As digital device usage becomes increasingly ubiquitous, such strategies represent essential tools in safeguarding both ocular health and circadian function.

Table 1. Comparison of blue light protection methods [28-36]

	Method	Mechanism of Action	Relative Effectiveness	Evidence Strength	Notes
1	Blue light filtering glasses	Blocks short-wavelength light at lens level	6	Moderate	Most effective in sensitive individuals and in evening use
2	Software night mode (e.g., Night Shift)	Reduces blue spectrum emission from screens	5	Moderate	Depends on screen brightness and user compliance
3	Screen protectors with blue light filter	Filters blue light directly from screen surface	4	Low	Physical filter; effectiveness varies with quality
4	Avoiding screens 1–2 hours before sleep	Eliminates artificial light stimulus before melatonin rise	8	High	Simple and cost-free behavioral intervention
5	Ambient lighting control (e.g., smart bulbs)	Modifies environmental light spectrum to reduce stimulation	7	Moderate	Requires smart home setup; improves both sleep and mood
6	Blue-light-blocking intraocular lenses	Physically filters incoming blue light post-cataract surgery	3	Low	Useful in ophthalmology, unclear effect on sleep
7	Exposure to natural daylight in the morning	Supports natural circadian entrainment	9	High	Strongly supported in chronobiology literature

Blue Light as a Tool to Support Cognitive and Emotional Function

Under specific conditions, blue light can enhance cognitive performance, alertness, and emotional stability. Moderate exposure in the morning or before mentally demanding tasks can improve:

- reaction time and concentration,
- working memory and cognitive flexibility,
- mood regulation and anxiety reduction via cortisol rhythm modulation [2,3,8].

In sports settings, blue light has been observed to reduce pre-competition stress and enhance mental readiness. A 2024 study found that 20-minute exposure before evening training sessions improved focus and mood in athletes, without affecting sleep quality—provided exposure ended before 8:00 p.m. [3].

Limitations and Research Needs

Despite encouraging findings, further research is needed, especially in physically active populations. Key areas include:

- **Timing of exposure** (morning vs. evening), and the role of chronotype and activity type [3,8];
- **Interactions with exercise physiology and recovery**, including effects on cortisol and melatonin secretion;
- **Long-term effects**, such as cumulative exposure, biological adaptation, and tolerance development.

Conclusions and Future Research Directions

The complex impact of blue light on human physiology—both potentially harmful and beneficial—requires in-depth investigation, measurement standardization, and interdisciplinary research.

Methodological Challenges and Standardization

The inconsistent use of light measurement units (lux, cd/m², W/m², etc.) complicates data synthesis. Longitudinal studies on daily blue light exposure under real-world conditions are lacking, limiting long-term health risk predictions [1,4].

Blue Light in Therapeutic Applications

Although blue light is often discussed in the context of potential health risks, recent research has also highlighted its therapeutic potential. When applied in a controlled, time-specific, and intensity-adjusted manner, blue light may serve as a valuable tool in managing circadian-related disorders, mood disturbances, and certain neurological conditions. These applications rely on the non-visual photobiological pathways mediated by melanopsin-containing intrinsically photosensitive retinal ganglion cells (ipRGCs), which influence the suprachiasmatic nucleus (SCN) and related neuroendocrine systems.

1. Treatment of Seasonal Affective Disorder (SAD)

One of the most extensively studied therapeutic uses of light, including blue wavelengths, is in the management of Seasonal Affective Disorder (SAD). Traditional light therapy typically employs broad-spectrum white light at intensities around 10,000 lux. However, research over the past decade has demonstrated that narrow-band blue light (~460–480 nm) can produce comparable or superior antidepressant effects even at significantly lower illuminances (e.g., 200–500 lux), due to its high efficacy in activating ipRGCs and suppressing melatonin [1,2].

In randomized controlled trials, morning exposure to blue-enriched light for 30–60 minutes daily over several weeks resulted in significant reductions in depressive symptoms, improved sleep quality, and enhanced daytime alertness. Patients reported lower fatigue and better cognitive performance during winter months. Importantly, the use of blue light in this context also aligns with the natural seasonal timing of dawn and may help realign delayed circadian rhythms [3].

2. Sleep Regulation in Neurological and Psychiatric Disorders

Patients with neurodegenerative diseases—such as Parkinson's disease, Alzheimer's disease, and multiple sclerosis—often experience circadian dysregulation, reduced melatonin secretion, and fragmented sleep-wake cycles. Emerging studies suggest that structured exposure to blue light, particularly in the morning or early afternoon, can help resynchronize circadian rhythms, improve sleep continuity, and reduce evening agitation, particularly in older adults or patients with dementia [4,26].

For instance, a recent clinical study (2023) involving Parkinson's patients reported that daily use of wearable blue-light therapy glasses for three weeks significantly improved sleep efficiency (measured via actigraphy) and reduced daytime somnolence, without worsening motor symptoms [5,24]. Similar protocols are being piloted in geriatric psychiatry wards and long-term care facilities.

In patients with bipolar disorder or major depression, blue light therapy must be used cautiously due to the potential for circadian phase advances that may trigger manic episodes. However, short-term morning light exposure under psychiatric supervision has been shown to stabilize mood and improve sleep initiation in euthymic or mildly depressed individuals [6].

3. Cognitive and Performance Enhancement

In healthy individuals, morning or task-specific exposure to blue light can enhance cognitive performance, vigilance, and working memory, primarily through effects on the noradrenergic and dopaminergic systems. Functional neuroimaging studies have demonstrated increased activity in the prefrontal cortex and thalamus following blue light exposure, suggesting an alerting effect independent of sleep loss [7,27].

This has led to the use of blue light interventions in occupational settings, such as:

- shift work,
- aviation and transport,
- high-stakes decision-making (e.g., emergency rooms),
- and athletic preparation.

For example, a crossover trial among professional esports players found that 20-minute blue light exposure sessions prior to competition improved reaction time and cognitive endurance, without negatively affecting melatonin profiles or subsequent sleep, when exposure was terminated before 8:00 p.m. [8,20].

4. Phototherapy in Dermatology and Infectious Disease

Outside the circadian realm, short-wavelength light, including blue light, has also been used in dermatological applications—notably in the treatment of acne vulgaris. Blue light exhibits antimicrobial properties, particularly against *Propionibacterium acnes*, by generating intracellular porphyrin-mediated oxidative stress, which leads to bacterial inactivation [9,17].

Furthermore, ongoing studies are exploring the use of blue LED light in wound healing, especially in chronic ulcers, and as a non-thermal antimicrobial agent in hospital settings. However, these uses fall outside the scope of circadian and ophthalmic physiology and require further validation in clinical trials.

5. Challenges and Future Directions

Despite promising findings, the clinical application of blue light therapy requires careful optimization:

- Timing is critical: benefits are typically observed with morning exposure, while evening exposure may be disruptive;
- Dosage and spectral composition vary across studies, making direct comparisons difficult;
- Individual sensitivity—related to chronotype, age, or genetic polymorphisms—may modify treatment response;
- Long-term safety data, particularly for vulnerable populations such as children, pregnant women, and psychiatric patients, remain limited.

Future research should aim to:

- Establish standardized protocols for blue light therapy in various disorders;
- Investigate portable and wearable technologies (e.g., glasses, visors, patches) for outpatient use;
- Explore combined interventions (e.g., blue light + cognitive training or exercise) to enhance resilience and recovery.

In summary, blue light, when used in a controlled and context-appropriate manner, has substantial therapeutic potential. Whether to treat circadian misalignment, enhance mood, or improve performance, its effectiveness hinges on proper timing, intensity, and individualization. Far from being a purely harmful environmental factor, blue light represents a dual-use phenomenon: one that can both impair and restore biological rhythms—depending on how, when, and to whom it is applied.

Final Conclusions

1. Evening screen exposure may impair sleep and circadian balance.
2. Controlled exposure to blue light—particularly in the morning—can have beneficial effects, including enhanced alertness, improved mental performance, and reduced fatigue.
3. Current evidence does not provide definitive proof of retinal damage from low-intensity blue light emitted by digital devices; however, long-term safety data remain limited.
4. There is a clear need for further high-quality research using standardized exposure parameters, especially in vulnerable populations such as adolescents, shift workers, and athletes.
5. It is recommended to implement good light hygiene practices, limit evening exposure to blue light, and promote the development of evidence-based technologies that reduce blue light emission.

Disclosure

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