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EVENING BLUE LIGHT EXPOSURE AND SLEEP QUALITY: MECHANISMS, CONSEQUENCES, AND PREVENTIVE STRATEGIES — A NARRATIVE REVIEW

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ABSTRACT

Background: Blue light exposure from digital devices has become a prevalent environmental factor affecting circadian rhythms and sleep quality.
Objective: This review aims to evaluate the physiological mechanisms, sleep disturbances, and psychological consequences associated with evening blue light exposure.
Methodology: A narrative synthesis of current literature was conducted, focusing on the effects of short-wavelength light (400-500 nm) on melatonin suppression, sleep architecture, and related health outcomes.
Results: Evidence suggests that artificial blue light is an important contributing factor to delayed sleep onset, reduced sleep duration, and impaired sleep efficiency. Furthermore, growing evidence indicates that circadian disruption and evening screen exposure are associated with poorer mood outcomes and digital eye strain.
Conclusions: While blue light-filtering technologies offer limited objective benefits, behavioral and environmental interventions—such as limiting evening screen time—remain the most effective preventive strategies to mitigate the adverse effects of digital device use.

KEYWORDS

Blue Light, Sleep Quality, Sleep Disturbances

CITATION

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1.Introduction

Blue light, a high-energy visible light with wavelengths between 400-500 nanometers emitted from both natural and artificial sources, has emerged as an increasingly recognized environmental factor affecting modern human health (Grzelak, 2024). While exposure to blue light during daytime hours enhances alertness and cognitive performance by suppressing melatonin secretion, excessive evening exposure—particularly from electronic devices like smartphones, tablets, and computers—disrupts the circadian rhythm and sleep quality (Wahl et al., 2019). The widespread adoption of LED lighting and digital technologies has intensified blue light exposure, especially during evening hours when individuals should be preparing for sleep, making this an increasingly prevalent public health concern (Shu, 2026). Evidence suggests that evening blue light exposure delays sleep onset, reduces sleep duration, and impairs sleep efficiency by suppressing the production of melatonin, the hormone responsible for regulating the sleep-wake cycle (Grzelak, 2024). This phenomenon is particularly concerning for adolescents and young adults, whose heavy reliance on electronic devices compounds the problem, which may contribute to documented negative effects on academic performance, mood regulation, and broader metabolic parameters (Alam et al., 2024).

2. Physiology of Sleep

Normal sleep is a highly organized biological process comprising two distinct phases: non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep, which together constitute a cyclical pattern repeating approximately every 90 minutes in adults (Pandi-Perumal et al., 2024). NREM sleep progresses through three stages (N1, N2, N3), with N3 representing slow-wave sleep characterized by high-amplitude delta waves essential for physical restoration, growth hormone release, and metabolic recovery (Alhomrani, 2026). During this phase, the body experiences reduced metabolic demand, allowing resources to be redirected toward tissue repair and immune system consolidation (Imeri, 2026). REM sleep, which comprises approximately 20-25% of total sleep time and predominantly occurs during the latter sleep cycles, is crucial for emotional regulation, memory consolidation of procedural and emotional content, and neural plasticity (Alhomrani, 2026). The regulation of this sleep-wake cycle is governed by two complementary processes: the circadian system, controlled by the suprachiasmatic nucleus (SCN) of the hypothalamus acting as the master

biological clock, and the homeostatic sleep drive, which accumulates adenosine throughout wakefulness and promotes sleep need (Pandi-Perumal et al., 2024). The SCN synchronizes this internal timing to external environmental cues, particularly the light-dark cycle, through specialized intrinsically photosensitive retinal ganglion cells (ipRGCs) that are maximally sensitive to short-wavelength blue light (Reiter et al., 2020).

3. Characteristics of Blue Light

Blue light belongs to the high-energy segment of the visible light spectrum and is characterized by relatively short wavelengths, generally between 400 and 500 nanometers (nm). The strongest emissions generated by LED-based displays are typically concentrated within the 455–480 nm range (Grzelak, 2024). This portion of the spectrum is of particular importance due to its pronounced influence on the human circadian rhythm. Although blue light occurs naturally in visible daylight, exposure to artificial blue light emitted by electronic devices is considered an important contributing factor to disturbances in sleep regulation (Haghani et al., 2024).

The primary pathway by which blue light influences sleep involves specialized retinal neurons known as intrinsically photosensitive retinal ganglion cells (ipRGCs), which express the photopigment melanopsin (Gniedziejko et al., 2025). These cells exhibit heightened responsiveness to blue-spectrum light and play a crucial role in modulating melatonin release by the pineal gland. Melatonin is a key hormone responsible for regulating the sleep–wake cycle and maintaining circadian synchronization. Exposure to blue light during the evening hours activates these photoreceptive cells, leading to the inhibition of melatonin secretion. As a result, the brain receives signals associated with daytime conditions, which can postpone sleep initiation and alter normal circadian timing (Reiter et al., 2020; Kotadiya et al., 2026).

The predominant sources of blue light exposure in contemporary society are associated with digital technologies and artificial illumination systems (Grzelak, 2024). The most common sources include smartphones and tablets which represent some of the most prevalent contributors to evening blue light exposure, as individuals frequently engage with them for periods ranging from approximately 30 minutes to several hours before bedtime (Sobański et al., 2026). Prolonged use of desktop computers and laptops, particularly among employees and students, results in sustained exposure to blue-wavelength light emitted from screens (L & R, 2024). Contemporary LED-based lighting systems produce blue-enriched spectra, especially those engineered to enhance alertness and visibility during daytime hours (Haghani et al., 2024). The timing of blue light exposure matters substantially. Evening exposure after 9:00 PM is associated with greater sleep disruption in young athletes, leading to shorter total sleep duration and impaired cognitive performance (Souissi et al., 2025). Children are especially vulnerable; one study found that both acute (one night) and repeated (five nights) smartphone use before bed shortened total sleep time in children, with repeated exposure showing more pronounced effects (Abid et al., 2024).

4. Mechanism leading to sleep disturbances

Sleep disturbances arise from multiple interconnected biological pathways. Dysregulation of circadian clock genes may disrupt the sleep-wake cycle through impaired neurotransmitter systems (melatonin, serotonin, GABA, dopamine) and metabolic imbalance (Ren et al., 2025). The hypothalamic-pituitary-adrenal (HPA) axis may become hyperactive, leading to elevated cortisol and stress hormone dysregulation (Hyndych et al., 2025), while chronic inflammation may amplify sleep disruption through pro-inflammatory cytokine activation (Irwin & Piber, 2018). The microbiota-gut-brain axis may also contribute; gut dysbiosis reduces beneficial bacteria and metabolite production that normally promote sleep-wake homeostasis through neural, immune, endocrine, and circadian signaling (Yang et al., 2026). Sleep deprivation has been associated with impaired glymphatic function, including reduced clearance of neurotoxic proteins such as amyloid-β and tau, alongside activation of neuroinflammatory pathways including microglial activation (Keikhaei et al., 2025). Lipid metabolism abnormalities and oxidative stress may further dysregulate neuronal signaling (Li et al., 2025). Poor sleep has also been associated with disrupted emotional regulation circuits in the prefrontal-amygdala regions (Hyndych et al., 2025), creating a bidirectional loop where stress and negative emotions worsen sleep, and poor sleep amplifies emotional dysregulation (Gao et al., 2025). Genetic predisposition may play a role, with shared genetic variants affecting both circadian clock genes and depression risk pathways (Moysés-Oliveira et al., 2024). Environmental factors—artificial light exposure, circadian misalignment, and lifestyle disruptions—may exacerbate these mechanisms (Ren et al., 2025). Together, these pathways may form self-reinforcing cycles that perpetuate sleep disturbances and are associated with increased risks for metabolic, cardiovascular, and psychiatric complications.

5. Effects of blue light exposure

Table 1. Effects of blue light exposure on sleep

Sleep Parameter	Effect of Evening/Pre-Bedtime Blue Light	Key Studies
Sleep Quality	Worsens; blue light is associated with disrupted sleep architecture	The result is delayed sleep onset, shortened sleep duration, and reduced sleep efficiency (Grzelak, 2024); evening exposure impairs sleep quality through melatonin suppression (Nogueira et al., 2025)
Sleep Duration	Reduced	Smartphone use reduces total sleep time acutely and with repeated exposure (Abid et al., 2024); athletes exposed after 9 PM show significant decreases (Souissi et al., 2025)
Sleep Latency	Increased (delayed sleep onset)	5000K LED light increases latency compared to fluorescent light (Lu et al., 2025); blue light suppresses melatonin, raising sleep latency (Nogueira et al., 2025)
Deep Sleep	Reduced	Pre-bedtime blue light decreases the ratio of deep sleep (Ishizawa et al., 2021)
Sleep Efficiency	Reduced	Waking after sleep onset increases with smartphone use (Abid et al., 2024)

6. Psychological and health consequences

Growing evidence suggests that circadian disruption and evening screen exposure are associated with poorer mood outcomes and psychological consequences. A comprehensive narrative review analyzing 33 recent studies identified negative consequences including increased risk of depression and anxiety alongside impaired cognitive performance and increased daytime sleepiness (Gniedziejko et al., 2025). The relationship between circadian disruption and mental health operates through multiple interconnected pathways: altered melatonin production affects mood regulation, disrupted sleep impairs emotional processing, and circadian misalignment triggers inflammatory and neuroendocrine abnormalities that compromise psychological resilience (Walker et al., 2020).

A Polish study of university students found that those with insomnia were significantly more likely to report sadness and depression (OR = 5.6997) and difficulty with tasks (OR = 5.4723) (Gruba et al., 2021). Blue light exposure from digital devices has emerged as an important contributing factor to digital eye strain (DES), characterized by ocular discomfort, dryness, visual fatigue, and associated systemic symptoms. A clinical study of 160 patients found that those with high screen exposure (≥6 hours/day) demonstrated significantly reduced visual acuity (0.4 ± 0.3 logMAR vs. 0.1 ± 0.2 logMAR), with 65% reporting digital eye strain compared to 42% in the low-exposure group (Noor et al., 2024). Mechanistically, blue light exposure reduces blink rates and tears film stability, while the sustained accommodation required for screen viewing induces ciliary muscle fatigue (Almohammadi, 2026). A cross-sectional study of university students revealed that 80.40% experienced digital eye strain, with headache (80.62%), burning sensation (75.19%), and eye pain (71.06%) being the most common symptoms (Sengsoon et al., 2026).

Clinical evidence does not currently support that normal-use screen exposure causes long-term retinal damage in humans (Cougnard-Grégoire et al., 2023). However, animal models and in vitro studies reveal concerning mechanisms including ferroptosis (iron-dependent cell death), oxidative stress, mitochondrial dysfunction, and endoplasmic reticulum stress following intense blue light exposure (Xia et al., 2024). The retinal pigment epithelium (RPE) shows particular vulnerability in these models, with blue light exposure inducing morphological changes, impaired phagocytic activity, and compromised barrier function (Chakravarthy et al., 2024).

Beyond sleep and ocular effects, excessive screen exposure during critical developmental periods may impact cognitive development and academic performance. Excessive evening screen time is associated with impaired attention, memory consolidation, and executive function—effects potentially mediated through sleep disruption and circadian misalignment (Gniedziejko et al., 2025). Notably, a study of 186 children found that those with 70-105 hours weekly screen exposure showed significantly greater ocular surface symptoms, higher fatigue severity, and reduced hand grip strength compared to lower-exposure peers (Saleemi et al., 2025). The psychological consequences in this population warrant particular attention, as emerging data links problematic screen use patterns to increased anxiety and depressive symptoms in adolescents (Stiglic & Viner, 2019).

7. Blue light filtering and preventive strategies

Blue light-filtering interventions have gained considerable attention as potential strategies for mitigating digital eye strain (DES) and sleep disturbances associated with prolonged screen exposure. However, current evidence suggests that their effectiveness varies depending on the type of intervention employed. Blue light-filtering spectacle lenses, despite widespread commercial promotion, have shown limited clinical benefits, with a systematic review reporting little to no improvement in visual performance, eye strain, or sleep quality compared with conventional lenses (Singh et al., 2023). Although some studies have demonstrated modest improvements in accommodative function and reductions in subjective symptoms such as burning, tearing, dryness, and headache, objective measures of visual performance generally remain unchanged (Chaudhary et al., 2026; Gupta et al., 2025). In contrast, display-based interventions and software solutions that reduce blue light emission appear more promising, producing significant reductions in self-reported eye strain and improvements in perceived sleep quality, morning alertness, and productivity (Danoff-Burg et al., 2025; Danoff-Burg et al., 2026). Emerging adaptive filtering technologies, such as content-responsive blue light reduction systems, further enhance blue light attenuation while preserving visual quality (Coelho et al., 2025). Nevertheless, behavioral and environmental interventions currently demonstrate the strongest evidence base. Regular implementation of the 20-20-20 rule helps alleviate accommodative stress and supports tear film recovery, thereby reducing symptoms of DES (Więsyk et al., 2024; Manna, 2026). Similarly, limiting evening screen exposure has consistently been associated with improved sleep quality and circadian regulation (Kadiri & Tiwari, 2025; Kotadiya et al., 2026). Additional preventive measures, including optimized workstation ergonomics, appropriate viewing distances, and exposure to bright daytime light combined with reduced evening light intensity, contribute to both visual comfort and circadian health (Praksosa & Prajnaparamita, 2025; Constantino et al., 2025; Grzelak, 2024). Collectively, the available evidence indicates that while blue light-filtering technologies may provide subjective benefits, comprehensive prevention strategies integrating behavioral modifications, ergonomic adjustments, and environmental light management are likely to offer the greatest protection against the adverse effects of prolonged digital device use.

8. Conclusions

Blue light exposure has become an increasingly important public health concern due to the widespread use of digital devices and LED-based lighting in modern society. The evidence reviewed in this paper suggests that excessive evening exposure to blue light is associated with circadian rhythm disruption through the suppression of melatonin secretion, with observed outcomes including delayed sleep onset, reduced sleep duration, impaired sleep efficiency, and alterations in sleep architecture (Grzelak, 2024; Nogueira et al., 2025). These sleep disturbances extend beyond sleep itself and are associated with adverse psychological, cognitive, and ocular outcomes, including increased risks of depression, anxiety, daytime fatigue, digital eye strain, and reduced academic and occupational performance (Gniedziejko et al., 2025; Noor et al., 2024).

The physiological mechanisms underlying these effects are complex and involve interactions among the circadian system, neuroendocrine regulation, inflammatory pathways, and neural processes responsible for emotional regulation and cognitive functioning. Children, adolescents, and young adults appear particularly vulnerable due to their high levels of screen exposure and the sensitivity of developing circadian systems to environmental light stimuli (Abid et al., 2024; Souissi et al., 2025).

Current evidence suggests that while blue light-filtering technologies may provide some subjective benefits, especially in reducing visual discomfort, their effectiveness in improving objective sleep and visual outcomes remains limited and inconsistent (Singh et al., 2023). In contrast, behavioral and environmental interventions—including limiting screen use before bedtime, optimizing workplace ergonomics, following regular screen-break practices, and promoting healthy light exposure patterns throughout the day—demonstrate stronger and more consistent benefits for both sleep and visual health (Kadiri & Tiwari, 2025; Więsyk et al., 2024; Grzelak, 2024).

Future research should focus on establishing standardized exposure thresholds, identifying populations at greatest risk, and evaluating the long-term effectiveness of both technological and behavioral interventions. As digital technologies continue to play a central role in everyday life, increasing awareness of healthy screen-use habits and circadian-friendly lighting practices may represent one of the most effective strategies for reducing the negative health consequences associated with excessive evening screen exposure.

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