

Sleep Hygiene in the Digital Age: Impact of Screen Exposure on Sleep Quality

Dr. Hitansh Kotadiya¹; Dr. Maan Patel¹; Dr. Dinesh Mewara²; Payal Prasad²

¹Doctor of Pharmacy; ²Assistant Professor Department of Pharmacy Practice, A-One Pharmacy College, Ahmedabad, Gujarat, India

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Abstract: Background: Sleep hygiene has evolved from simple environmental sanitation to broader behavioral practices. In the digital era, widespread nighttime use of smartphones, tablets, computers, and televisions has become an important concern for sleep health. **Objective:** This narrative review synthesizes evidence on how digital screen exposure affects sleep across age groups and examines the biological, behavioral, and cognitive mechanisms involved. **Methods:** A narrative review of open-access peer-reviewed studies indexed in PubMed, Embase, and Scopus was conducted, focusing on experimental studies, cohort studies, systematic reviews, and meta-analyses published between 2015 and 2025. **Key Findings:** Evidence shows a clear negative association between late-night screen use and sleep quality. Screen exposure disrupts sleep mainly through melatonin suppression by blue light and increased cognitive arousal from digital content. Although blue-light filters and night mode may offer limited benefit, reducing screen use before bedtime remains the most effective strategy. **Conclusion:** Pre-sleep screen exposure is a modifiable contributor to poor sleep. Effective digital sleep hygiene should address both light exposure and content-related psychological stimulation.

Keywords: Sleep Hygiene; Screen Exposure; Blue Light; Circadian Rhythm; Melatonin Suppression; Digital Media Use; Sleep Quality; Bedtime Screen Use.

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I. INTRODUCTION

Adequate, restorative sleep is a fundamental biological necessity, serving as a critical pillar for maintaining physical health, cognitive function, immune resilience, metabolic homeostasis, and emotional regulation. Despite its physiological imperative, modern industrialized societies are witnessing a pervasive and alarming decline in both the duration and quality of sleep across all age demographics. While numerous socioeconomic and environmental factors contribute to this phenomenon, one of the most profound environmental shifts of the 21st century is the ubiquitous integration of light-emitting digital screens into daily life, particularly during the vulnerable hours immediately preceding sleep [1,2].

The concept of "sleep hygiene" has undergone a profound transformation since its inception. Historically, the terminology was rooted in literal environmental sanitation. In the 19th century, medical professionals such as Paolo Mantegazza (1864) and later Nathaniel Kleitman (1939) discussed the "hygiene of sleep," referring to the cleanliness of the sleeping environment, adequate ventilation, and the avoidance of pests or disruptive physical elements. The modern conceptualization of sleep hygiene emerged in 1977 when psychologist Peter

Hauri introduced a formalized set of behavioral and environmental rules designed to promote improved sleep quantity and quality for patients suffering from insomnia. Hauri's original directives focused on regulating time spent in bed, establishing consistent sleep-wake schedules, exercising regularly, and avoiding stimulants such as caffeine or alcohol prior to sleep onset [3,4,5].

However, the rapid technological advancements of the past two decades have necessitated a critical paradigm shift in how sleep hygiene is defined, practiced, and prescribed. The traditional rules of sleep hygiene did not account for the continuous physical proximity of interactive, light-emitting devices in the modern bedroom. Today, epidemiological data indicates that up to 90% of adults and adolescents report using an electronic device within one hour of their intended bedtime. This behavioral shift has introduced novel chronobiological and psychological disruptors, primarily in the form of artificial light at night (ALAN) and continuous cognitive stimulation [6,7].

The scientific consensus increasingly recognizes that the unmitigated use of digital devices at night directly antagonizes the physiological processes required for sleep initiation.

Consequently, the objective of this narrative review is to synthesize the current scientific understanding of how digital screen exposure impacts sleep quality. By examining the interplay between human circadian biology and modern technology, this report untangles the complex biological and psychological mechanisms linking screen use to sleep disruption, evaluates the controversies surrounding technological countermeasures, and offers actionable, evidence-based strategies for navigating sleep health in the digital age [6,8].

II. LITERATURE SEARCH STRATEGY

To investigate the multi-dimensional impact of screen exposure on sleep quality, a rigorous narrative synthesis approach was utilized to evaluate existing peer-reviewed literature. The synthesis drew upon original research articles, systematic reviews, meta-analyses, and epidemiological cohort studies indexed in major scientific databases, including PubMed, Embase, the Cochrane Library, and Scopus.

The search strategy utilized a combination of Medical Subject Headings (MeSH) and free-text keywords, including but not limited to: "blue light," "screen exposure," "sleep quality," "melatonin suppression," "circadian rhythm disruption," "digital sleep hygiene," "binge-watching," and "social media sleep".

Inclusion criteria were strictly defined to encompass open-access, English-language, peer-reviewed publications

that directly assessed the relationship between digital screen exposure and sleep parameters. Priority was given to studies published within the last decade (2015–2025) to ensure the data reflected contemporary device usage patterns (e.g., modern smartphone and tablet displays). The synthesis included diverse study designs, ranging from highly controlled laboratory experiments measuring salivary melatonin concentrations to massive cross-sectional and longitudinal epidemiological surveys.

Exclusion criteria eliminated non-peer-reviewed literature, opinion pieces, purely animal-model studies lacking direct human translational value, and studies where sleep disruption was primarily attributed to severe underlying psychiatric or neurological pathologies rather than environmental digital exposure. The resulting narrative synthesis integrates findings across pediatric, adolescent, and adult populations to provide a comprehensive, balanced, and nuanced overview of the current scientific landscape.

III. PHYSIOLOGY OF SLEEP AND CIRCADIAN RHYTHM

To fully comprehend how digital devices disrupt rest, it is essential to first delineate the intrinsic physiological mechanisms that govern human sleep. The sleep-wake cycle is primarily regulated by the intricate interaction of two distinct biological systems (Fig.1): the homeostatic sleep drive (often referred to as Process S) and the circadian rhythm (Process C) [10,11].

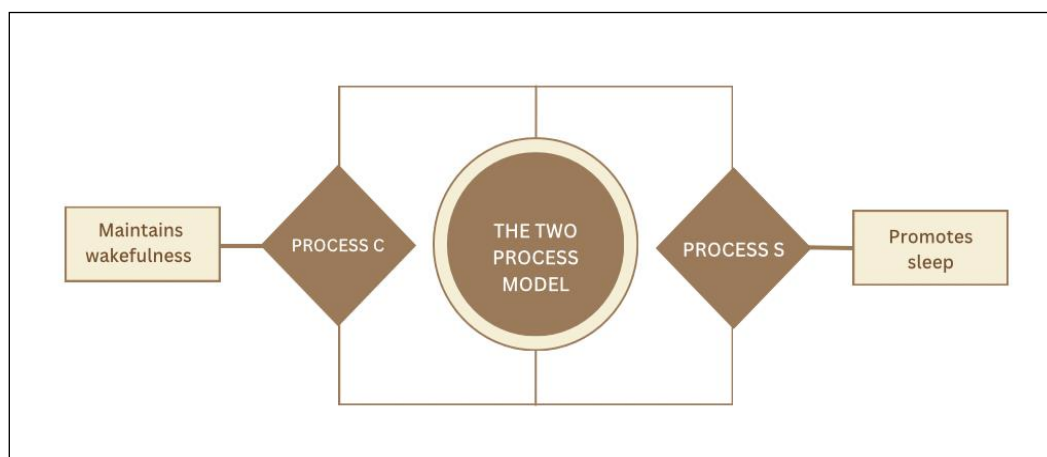


Fig. 1 The Two Process Model of Sleep Regulation

Process S represents the gradual accumulation of "sleep pressure" during wakefulness. The longer an individual remains awake, the stronger the biological drive to sleep becomes, driven largely by the accumulation of neuromodulators, such as adenosine, in the basal forebrain. Upon sleep initiation, this homeostatic pressure dissipates. Process C, conversely, is the body's internal 24-hour biological clock, which dictates the precise timing of sleepiness and wakefulness independently of how long one has been awake [10,11].

The master pacemaker of the human circadian rhythm is the suprachiasmatic nucleus (SCN), a bilateral cluster of approximately 20,000 neurons located in the anterior hypothalamus, directly above the optic chiasm. While the SCN operates autonomously, generating a rhythm of approximately

24.2 hours, it relies heavily on external environmental cues—known scientifically as zeitgebers (German for "time-givers")—to synchronize the internal biological clock with the exact 24-hour solar day. Of all potential environmental cues, including temperature and food intake, light is by far the most powerful synchronizing agent [12,13].

When environmental light diminishes in the evening, the SCN signals the pineal gland, a small endocrine gland situated in the brain, to begin synthesizing and secreting melatonin. Often colloquially termed the "hormone of darkness," melatonin plays a pivotal role in sleep architecture. It facilitates the transition into sleep by lowering core body temperature, reducing central nervous system arousal, and promoting a profound state of physiological drowsiness. The onset of melatonin secretion, known as Dim Light Melatonin Onset

(DLMO), typically occurs two to three hours before habitual bedtime and is a critical biological marker of circadian timing. Artificial disruption of this delicate neuroendocrine cascade represents the primary biological mechanism by which modern digital environments impair sleep [14,15].

IV. DIGITAL SCREENS AND BLUE LIGHT EXPOSURE

To understand the specific danger posed by digital screens, one must examine the physics of light and ocular anatomy. Not all light impacts the human circadian system equally. For decades, it was believed that the retina contained only two types of photoreceptors: rods (for low-light vision) and cones (for color vision). However, in the early 2000s, researchers discovered a third, highly specialized class of photoreceptors known as intrinsically photosensitive retinal ganglion cells (ipRGCs) [12,16,17,18].

Unlike rods and cones, which are responsible for image-forming vision, ipRGCs are non-image-forming. Instead, they project directly via the retinohypothalamic tract to the SCN to regulate the circadian clock. These ipRGCs contain a unique photopigment called melanopsin, which is exquisitely sensitive to short-wavelength light—specifically light in the blue spectrum, peaking at approximately 450 to 480 nanometers (nm). During the day, exposure to the blue-enriched light of the sun is physiologically vital; it suppresses daytime melatonin, boosts cognitive alertness, elevates mood, and aligns the circadian rhythm to the active phase [16,17,18].

However, the advent of energy-efficient lighting and digital displays has artificially extended daylight into the nocturnal environment. The backlights of most modern smartphones, tablets, laptops, and LED televisions are primarily composed of white light-emitting diodes (LEDs). To produce bright white light, these displays utilize a blue LED coated with a yellow phosphor, resulting in a profound and unnatural spike in the short-wavelength blue spectrum [19,20].

Because electronic screens are typically held in close proximity to the face (often within 30 centimeters), the retinal illuminance of this blue light is highly concentrated. This provides a potent biological signal to the SCN that it is still daytime, thereby deceiving the brain's internal clock and derailing the biological preparations for sleep [19,21].

V. MECHANISMS LINKING SCREEN EXPOSURE TO SLEEP DISTURBANCE

The adverse impact of evening screen exposure on sleep quality is multifaceted, operating through a combination of direct neurophysiological interference and psychological disruption. Current scientific literature highlights three primary mechanisms driving this relationship: melatonin suppression, circadian phase shifting, and cognitive arousal [15,19,22].

A. Melatonin Suppression

Exposure to blue light from digital screens in the hours leading up to bedtime directly inhibits the synthesis and release of melatonin from the pineal gland. Experimental studies have demonstrated the profound efficacy of this suppression. For instance, exposure to a short-wavelength-emitting electronic reader for just two hours before bed can reduce melatonin

secretion by over 50% compared to reading a printed book under dim ambient light [19,22].

The wavelength dependency of this effect is highly specific. Controlled studies exposing healthy participants to blue LED light (peaking at 464 nm) versus red light revealed stark differences: after two hours of exposure, melatonin concentrations under blue light were suppressed to a mere 7.5 pg/mL, whereas under red light, melatonin levels were permitted to rise to 26.0 pg/mL, yielding a statistically significant biological difference ($p = 0.019$). Without the natural evening rise in melatonin, the physiological signals that promote sleepiness are severely blunted, resulting in prolonged wakefulness [19,22].

B. Delayed Sleep Onset and Circadian Phase Shift

Because blue light acts as a powerful zeitgeber, nighttime exposure not only suppresses melatonin in the immediate term but also shifts the entire circadian phase backward. A phase delay means the body's natural biological window for sleep is pushed later into the night [23,15].

When the circadian rhythm is delayed, an individual will not feel naturally tired until much later than their desired bedtime. If that individual must then wake up at a set time the following morning for school or work, this delayed sleep onset directly compresses the total sleep window. This phenomenon leads to chronic partial sleep deprivation and "social jetlag"—a state wherein an individual's biological time is chronically misaligned with their social and professional obligations, leading to severe downstream metabolic and cognitive consequences [24,25].

C. Cognitive Stimulation and Psychological Arousal (The Content Effect)

Beyond the optical properties of the screen's hardware, the psychological nature of the software and the content being consumed plays a profound, independent role in sleep disruption. Digital activities such as engaging in fast-paced multiplayer video games, navigating socially fraught social media feeds, or consuming distressing news fundamentally activate the central nervous system [6,26].

This psychological engagement induces a state of "cognitive pre-sleep arousal". Instead of the parasympathetic nervous system taking dominance to initiate relaxation and lower the heart rate, the sympathetic nervous system remains highly active. This state triggers the release of stress hormones such as cortisol and adrenaline, elevating the heart rate and sustaining cognitive hypervigilance. Therefore, even if the screen's blue light is perfectly filtered, the psychological arousal generated by interactive digital tasks can independently delay sleep onset, increase sleep fragmentation, and degrade overall sleep architecture [6,26].

VI. EVIDENCE FROM RESEARCH STUDIES

The relationship between screen exposure and sleep disruption has been extensively documented across various robust methodologies and diverse demographic populations. The findings demonstrate a consistent and alarming narrative: increased screen time correlates directly with diminished sleep health [27,9,28].

A. Experimental Studies

Highly controlled experimental laboratory designs provide the most definitive evidence for the physiological impact of screens. A landmark study by Chang et al. (2015) utilized a randomized crossover design, requiring participants to read from either a light-emitting e-reader or a physical printed book for four hours before bed for five consecutive nights. The results definitively revealed that using the e-reader significantly suppressed evening melatonin secretion, delayed the circadian clock by over an hour and a half, lengthened the time it took to fall asleep, reduced the amount of restorative Rapid Eye Movement (REM) sleep, and significantly impaired next-morning cognitive alertness [22].

B. Observational and Cross-Sectional Studies

Large-scale observational data corroborate these controlled laboratory findings on a broad population level. An exhaustive cross-sectional analysis of 122,058 adults in the American Cancer Society Cancer Prevention Study–3 (CPS-3) revealed that participants who reported daily electronic screen use in the hour before bed experienced significantly higher rates of poor sleep quality and shorter sleep durations compared to those who abstained from screens [7].

Notably, the CPS-3 study demonstrated that this impact was highly dependent on an individual's inherent chronotype. Individuals identifying with an "evening chronotype" (night owls) who used screens daily lost an average of 8.36 minutes of sleep per workday (95% CI, 4.94-11.78 minutes), compared to morning chronotypes who lost roughly 5.64 minutes. Over the course of a standard week, this cumulative sleep debt amounted to approximately 50 minutes of lost sleep specifically attributable to evening screen users. Furthermore, daily screen use was associated with 5.04 fewer minutes of sleep on nonworkdays. Overall, screen users demonstrated a 33% higher prevalence of self-reported poor sleep quality (Prevalence Ratio, 1.33; 95% CI, 1.27-1.39) [7].

C. Pediatric and Adolescent Populations

Children and adolescents represent the most biologically and behaviorally vulnerable demographic regarding digital sleep disruption. Physiologically, children possess clearer ocular lenses and larger pupillary diameters than adults,

allowing a significantly greater transmission of short-wavelength light directly to the retina. Consequently, light-induced melatonin suppression is reported to be nearly twice as strong in children compared to adults under the exact same lighting conditions [29,8].

Systematic reviews and comprehensive meta-analyses have repeatedly confirmed this vulnerability. A major meta-analysis synthesizing 21 distinct cohort studies involving 548,338 participants confirmed a robust association. It verified that each additional hour of daily screen time was linked to an average 13.2-minute delay in bedtime and a heightened risk of clinically short sleep duration (Odds Ratio = 1.25). The authors noted that over 90% of published studies reported statistically significant adverse associations between pediatric screen use and at least one negative sleep outcome, leading to public health recommendations advocating for the total elimination of screen use at least one hour before pediatric bedtimes [27,9].

D. Adult Populations

While much public health focus is understandably directed at youth, adult populations suffer similarly profound effects. In university and young professional populations, excessive screen time and measurable smartphone addiction have been strongly correlated with poor sleep quality. [30,8]

In a representative cross-sectional study of university students, researchers found a moderate positive correlation (r = 0.60) between smartphone addiction scales and sleep quality indices. Nearly 70% of those in the highest quartile of smartphone usage reported demonstrably poor sleep quality, alongside elevated levels of excessive daytime sleepiness. Furthermore, adults engaging in high nighttime screen time are statistically more likely to report chronic fatigue, reduced workplace productivity, and elevated symptoms of clinical insomnia [30].

VII. IMPACT ON SPECIFIC SLEEP PARAMETERS

The integration of digital devices into the bedroom environment degrades various specific parameters of sleep architecture, which can be categorized as in "Table 1".

Table 1 Impact of Digital Devices on Sleep Parameters

Sleep Parameter	Clinical Definition	Impact of Evening Screen Exposure
Sleep Onset Latency (SOL)	The time required to transition from full wakefulness to sleep.	Significantly prolonged, driven by both the delayed onset of melatonin and sustained cognitive arousal preventing parasympathetic relaxation [19,22].
Total Sleep Time (TST)	The total amount of time spent in actual sleep during the night.	Dose-dependent reduction, as screen time directly displaces sleep time, and delayed sleep onset compresses the sleep window prior to morning alarms [27,22].
Sleep Efficiency (SE)	The percentage of time spent asleep while in bed.	Noticeably reduced, since pre-sleep short-wavelength light exposure decreases initial slow wave activity, leading to shallower sleep and increased nighttime awakenings [19,22].
Insomnia Risk	Chronic difficulty falling or staying asleep.	Highly elevated, making excessive screen time a primary risk factor for behavioral insomnia, exacerbated by the psychological stress of "bedtime procrastination" [6,30].
Daytime Functioning	Cognitive, emotional, and physical performance during waking hours.	Severely impaired, as degraded nocturnal rest leads to excessive daytime sleepiness, reduced executive function,

Sleep Parameter	Clinical Definition	Impact of Evening Screen Exposure
		impaired sustained attention, and negative mood alterations [1,27].

VIII. BEHAVIORAL AND LIFESTYLE FACTORS IN THE DIGITAL ENVIRONMENT

To fully understand sleep hygiene in the digital age, one must evaluate not just the hardware of the screen, but the nature of the software and the specific behaviors of the user. Different forms of digital media exert distinct psychological pressures that inhibit the transition to sleep [6,26].

A. Binge-Watching and Television Consumption

The advent of on-demand streaming platforms has revolutionized media consumption, popularizing "binge-watching"—the viewing of multiple episodes of a television series in a single, uninterrupted sitting. Observational studies have established that frequent binge-watchers report significantly poorer sleep quality, higher daytime fatigue, and more insomnia symptoms than those who adhere to traditional, episodic viewing habits [6,26].

Crucially, psychological researchers have identified that cognitive pre-sleep arousal fully mediates the relationship between binge viewing and daytime fatigue as well as insomnia symptoms. Viewers become highly immersed in complex narrative plotlines, experience heightened emotional involvement with characters, and find it exceedingly difficult to disengage. This leaves the brain in an active, anticipatory state that is fundamentally incompatible with the neurological de-escalation required for sleep initiation [6,26].

B. Social Media Engagement and Bedtime Procrastination

Social media platforms are meticulously engineered to capture and sustain human attention through variable reward schedules. Use of these platforms before bed triggers cognitive arousal through several potent psychological mechanisms: negative social comparison, the fear of missing out (FoMO), and deep emotional investment in peer feedback [26].

Studies tracking emotional responses to social media note that the psychological distress, anxiety, and rumination generated by online interactions directly correlate with increased sleep latency and fragmented sleep. Furthermore, the passive, "infinite scrolling" architecture of these applications effectively bypasses the brain's natural "stopping cues," making it exceedingly easy for users to unknowingly sacrifice intended sleep time—a behavioral phenomenon frequently termed "bedtime procrastination" [26].

C. Interactive Gaming

Interactive digital media, such as high-stakes multiplayer video games, demand intense levels of visuospatial attention, rapid decision-making, and motor coordination. The physiological arousal associated with gaming—marked by significant adrenaline and dopamine release—can dramatically delay sleep onset, shorten overall sleep duration, and reduce sleep efficiency entirely independent of the screen's light emissions. Studies reveal that internet gaming

disorder severity is strongly associated with psychological distress measures like depression and anxiety, which further degrades sleep [25,26].

IX. CONTROVERSIES AND CONFLICTING EVIDENCE: LIGHT VS CONTENT

As the mechanisms of blue-light-induced sleep disruption became widely disseminated in public health spheres, technology companies responded by introducing software solutions. Features such as Apple's "Night Shift," Windows' "Night Light," and various Android blue light filters shift the color temperature of the display toward the warmer, amber spectrum, theoretically mitigating melatonin suppression. Concurrently, the consumer market for physical blue-light-blocking glasses expanded rapidly [21,31].

However, the empirical evidence regarding the actual clinical efficacy of these interventions is highly mixed, sparking a rigorous scientific debate over whether the light or the content is the primary driver of digital sleep disruption [21,31].

A. The Inefficacy of Software Filters

Recent rigorous experimental studies evaluating smartphone "night mode" functions have challenged their protective claims. A notable study published in Sleep Health by researchers from Brigham Young University divided 167 young adults into three groups: those using a phone with "night mode" on, those using a phone with "night mode" off, and those who abstained from phone use entirely for the hour before bed. The study split 167 young participants into three groups for seven nights, revealing that abstinence yielded the best results. The group that abstained from phone use entirely experienced the best sleep outcomes by a wide margin, while the participants using "night mode" fared no better than those using a standard, unfiltered screen [21,31].

Other physiological investigations comparing tablet usage with and without the "Night Shift" feature found negligible differences in subjective sleep quality or leptin suppression between the two screen-use conditions. The primary limitation of software filters is that while they reduce the proportion of blue light emission, they do not eliminate it entirely. If the overall screen brightness remains high, the total retinal illuminance is still biologically sufficient to disrupt circadian rhythms, regardless of the warmer hue [21,31].

B. The Debate on Blue-Light Blocking Glasses

Physical interventions, such as amber-tinted blue-light-blocking glasses, have demonstrated slightly more promise, particularly in specific clinical settings such as protecting night-shift workers. Some randomized controlled trials have shown that wearing these glasses in the hours prior to sleep can advance the sleep phase and reduce sleep onset latency [21].

Nevertheless, a comprehensive 2023 Cochrane Systematic Review assessing 17 randomized controlled trials concluded that there is a lack of high-quality, long-term evidence to support the widespread use of blue-light-filtering lenses for the general population. The review noted only minimal short-term advantages for broad sleep quality or visual fatigue [21,31].

C. *The Supremacy of Psychological Engagement*

The failure of night modes and blue-blocking glasses to consistently rescue sleep quality underscores a vital scientific insight: addressing the optical wavelength of a device solves only half the problem. The psychological engagement and cognitive arousal generated by using a smartphone acts as a powerful, independent biological barrier to sleep [6,26].

Relying solely on blue light filters can create a dangerous false sense of security, encouraging individuals to engage in highly stimulating digital activities late into the night under the mistaken belief that their sleep physiology is protected. Ultimately, screen brightness and psychological content frequently override color temperature. A warm-toned but intensely bright screen displaying highly exciting or stressful content will invariably disrupt sleep architecture more severely than a dim, cool-toned screen displaying passive, unengaging content [6,21].

X. PRACTICAL IMPLICATIONS FOR DIGITAL SLEEP HYGIENE

Given the compelling epidemiological and physiological evidence linking screen exposure to sleep degradation, updating traditional sleep hygiene guidelines for the digital age is an urgent public health priority. Effective digital sleep hygiene cannot rely on technological band-aids alone; it requires a multimodal approach that comprehensively addresses environmental light, behavioral routines, and psychological arousal [1,2].

➤ *Establish a "Digital Curfew"*

The most universally supported, evidence-based recommendation across sleep science literature is the complete cessation of screen use 60 to 90 minutes prior to intended bedtime. This physical and temporal separation allows for natural melatonin onset and provides the nervous system time to de-escalate from pre-sleep cognitive arousal [8,22].

➤ *Remove Devices from the Sleeping Environment*

The mere physical presence of an interactive device in the bedroom is independently associated with poor sleep outcomes. This is driven by the temptation of bedtime procrastination, the psychological anticipation of messages, and physical sleep interruptions from audible or vibrational notifications. Bedrooms should be strictly maintained as tech-free environments to strengthen the psychological association between the bed and sleep [27,7].

➤ *Manage Screen Brightness and Utilize Ambient Lighting*

For individuals who absolutely must use screens in the evening for occupational or academic reasons, mitigating

harm is key. While "night mode" software and blue-blocking glasses are not a panacea, utilizing them in conjunction with drastically lowering the overall screen brightness to its minimum setting can somewhat reduce the biological alerting signal sent to the SCN. Furthermore, viewing screens in completely dark rooms increases contrast and pupil dilation, maximizing light intake; thus, maintaining soft, warm ambient room lighting is recommended to reduce eye strain and photic signaling [21,31].

➤ *Curate Evening Content*

If digital media must be consumed before bed, the psychological nature of the content should be tightly regulated. Users should deliberately substitute highly arousing activities (e.g., competitive multiplayer gaming, engaging with anxiety-inducing news feeds, active social media posting) with passive, low-stakes consumption (e.g., listening to a familiar podcast, reading non-stimulating digital text on an e-ink display) [6,26].

➤ *Optimize Daytime Light Exposure*

Circadian health is dictated by the contrast between day and night. Ensuring robust exposure to bright, natural sunlight—especially during the morning and early midday hours—strengthens the amplitude of the circadian rhythm. A highly stimulated daytime clock makes the biological pacemaker slightly more resilient to minor artificial light exposures in the evening [12,13,15].

XI. FUTURE RESEARCH DIRECTIONS

While the relationship between screen exposure and sleep quality is robustly established in the literature, significant gaps in the current scientific understanding remain.

First, the vast majority of existing evidence is derived from cross-sectional or observational epidemiological designs, which fundamentally struggle to definitively prove causality or eliminate bidirectional effects. For instance, it remains partially unclear whether adolescents sleep poorly strictly because they use screens excessively, or whether they use screens excessively as a coping mechanism because underlying anxiety prevents them from sleeping. Future research must prioritize robust, long-term longitudinal cohorts and randomized controlled intervention trials (e.g., mandated "digital detox" protocols) to isolate these variables and establish definitive causal pathways.

Second, there is a distinct and pressing need for greater objective measurement in future studies. Many current epidemiological studies rely heavily on self-reported estimates of screen time and subjective sleep questionnaires, both of which are highly prone to recall bias and underestimation. The integration of device-logged application data, wearable actigraphy, and home-based electroencephalography (EEG) will provide more accurate, granular, and physiological insights into how specific application usage alters actual sleep architecture.

Finally, research must continue to disentangle the complex "content versus light" paradigm. Future laboratory investigations should aim to isolate the physiological effects

of specific light wavelengths from the dopaminergic and sympathetic nervous system responses triggered by various forms of interactive media. Understanding these independent mechanisms will be essential for developing more sophisticated, targeted digital health interventions and nuanced public health policies.

XII. CONCLUSION

The evolution of modern technology has vastly outpaced human chronobiology. The comprehensive evidence synthesized in this review confirms that evening exposure to digital screens exerts a profoundly disruptive influence on sleep quality, duration, latency, and efficiency across all age demographics. This disruption is mechanistically driven by two parallel, compounding forces: the biological suppression of the sleep-promoting hormone melatonin by short-wavelength blue light, and the induction of deep physiological and cognitive arousal by engaging, interactive digital content.

While technological countermeasures such as blue light software filters and specialized eyewear offer an intuitive, frictionless solution, rigorous scientific scrutiny reveals they are insufficient on their own. By failing to address the fundamental psychological arousal that delays sleep onset, these tools often provide a false sense of security. Consequently, mitigating the immense public health burden of modern sleep deprivation requires a return to foundational behavioral boundaries.

Updating traditional sleep hygiene to include strict "digital sanitation"—primarily through establishing tech-free temporal buffer zones before sleep and removing interactive devices from the bedroom entirely—remains the most evidence-based strategy for protecting the integrity of human sleep in an increasingly connected world. Public health initiatives, clinical guidance, and individual daily habits must adapt to recognize a fundamental physiological reality: in the digital age, a restorative night's sleep begins long before the bedroom lights are turned out, it begins the moment the screen is turned off.

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