Review Article

Secrets Behind Scrolling: How Nighttime Screen Exposure Affects Sleep, Health, and Daily Life

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ABSTRACT

We are exposed to blue light today more than ever in history. However, little is known about the long-term impact of this societal shift. The objective of this review is to critically evaluate the health effects associated with exposure to light emitted from technological devices—particularly during the pre-sleep period—with a focus on its impact on sleep quality, overall health, daily routines, and cognitive performance. The studies in this review demonstrate that light has a negative impact; therefore, we provide advice on navigating this in the real world. To minimize blue light's effects, individuals should try restricting technology usage before bed and ensuring you have plenty of exposure to natural blue light during the day.

Keywords: Technology; Sleep; Blue light; Circadian rhythm; Obesity; Cognition; Eye; Mood

INTRODUCTION

The objective of this review is to critically evaluate the health effects associated with blue light exposure from technology—particularly during the pre-sleep period—with a focus on its impact on sleep quality, overall health, daily routines, and cognition. It is well established that exposure to blue light before bed negatively impacts sleep quality, but its effects may extend beyond sleep alone. Blue light is a short-wavelength light that is emitted by our phones and electronics. Although beneficial during the daytime, at night, it acts as a strong melatonin suppressor and disrupts the body's circadian rhythms. Melatonin is a hormone critical for initiating and maintaining deep, restorative rapid eye movement (REM) sleep, and serves as a regulator of the circadian system (1).

Sleep plays a vital role in neural health, physical recovery, cognitive performance, and overall physiological homeostasis. It helps restore balance following the cellular stress, synaptic activity, and energy expenditure accumulated during wakefulness. Without adequate sleep, neurons, metabolic pathways, and immune responses can gradually deteriorate (2). It may also result in slower reaction times, poor focus and memory, mood swings, and trouble staying awake or falling asleep (3). Further, chronic sleep deprivation results in cognitive impairments, metabolic issues, mood disorders, and immune dysfunction (2).

Since technology is heavily integrated into everyday life, it is essential to understand its impact on the brain. Despite awareness that blue light is harmful, screen time continues to increase. In fact, over half of Americans watch TV or stream media before going to bed (4). Despite the variety of purposes for which technology is

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used (e.g., work, communication, entertainment) nearly all electronic devices emit blue light (5). Therefore, consumers need to recognize the implications of this light exposure and its potential consequences for sleep and overall health.

Virtually all light-emitting technologies expose the user to blue light (5). As people increasingly use technology at work, in school, or at home, society has become increasingly dependent on it. This dependence is reflected in global screen time statistics, with the average person spending approximately 6 hours and 45 minutes per day using screens, nearly 30% of their 24-hour day. In the US, the average screen time is 7 hours, with teenagers and young adults consuming the most technology at an average of 7 hours and 20 minutes per day (6). Furthermore, 41% of American teenagers report a screen time of over 8 hours (7).

As screen time continues to increase, the average sleep duration declines. Despite the recommendation of 7+ hours of sleep per night, over a third of Americans fall short of this target. Additionally, 20% of Americans sleep less than 5 hours, and 100 million Americans claim they do not get enough sleep (4). To minimize the effect of technology's blue lights, it is recommended to establish a nighttime routine and to avoid using technology 30-60 minutes before bed. This review presents information from contemporary literature, compiled from online databases such as Google Scholar and PubMed, to help individuals gain a deeper understanding of the impact of blue light on sleep quality, overall health, daily routines, and cognitive performance.

BLUE LIGHT AND SLEEP

Throughout most of recorded history, exposure to blue light at night was minimal. Today, nighttime exposure to blue light is common, and experts are only now beginning to understand the full extent of its effects on human physiology (8). While blue light can be beneficial during the day by synchronizing the circadian clock, supporting non-image-forming (NIF) functions, and being used in therapy to treat mood disorders, nighttime exposure results in suppressed melatonin levels, disrupted sleep quality, delayed circadian rhythms, and impaired morning cognition (8).

The two-process model of sleep states that there are two separate processes controlling sleep in the body: the homeostatic process and the circadian rhythm process. The homeostatic sleep drive, also known as sleep pressure, decreases when someone is asleep and increases while they are awake. Increased sleep pressure is associated with higher levels of sleepiness and fatigue. On the other hand, the circadian rhythm process is controlled by the body's internal clock, which cycles approximately every 24 hours and regulates many biological functions, including the sleep-wake cycle (3). It regulates hormone secretion timing, wakefulness, body temperature, metabolism, digestion, hunger, memory consolidation, and body healing (9). In mammals, the circadian rhythm is synchronized by the suprachiasmatic nuclei (SCN) in the hypothalamus, and is controlled by hormones (3). In healthy individuals, the homeostatic and circadian processes align and work together to induce sleep.

Modern research supports the notion that the circadian system is highly sensitive to all light, including candlelight, household lighting, and light emitted by technology, contrary to previous claims suggesting otherwise. Recent research further confirms that the initial part of light exposure is the most effective. One hour of bright light (10,000 lux) consumption alone is associated with about 40% of the impact caused by a 6.5 hour light session. Intermittent light is also highly effective at resetting the circadian rhythm (3). However, blue light exposure at night shifts circadian rhythms the most and is therefore the most potent suppressor of melatonin (3). In fact, it suppresses melatonin almost twice as much as green light (10). As a result, lower melatonin secretion from blue light exposure worsens sleep quality, leading to fatigue, irritability, mood swings, and worsened concentration. Blue light exposure before bed also results in reduced sleepiness, trouble falling asleep, and decreased alertness the next morning (1).

An experiment was conducted in which researchers asked young medical students about their use of technology before bed and analyzed their responses in relation to the side effects they reported. 97.3% of the population used technology at bedtime (76.9% of them in the dark) for an average of 2 hours and 23 minutes. Moreover, 87.1% of students did not switch off their smartphones or tablets before going to sleep, 19.2% of them put them under their pillow, and 59% of the students' sleep was interrupted by notifications. As a result, ⅓ of the population reported poor sleep quality. Side effects the students encountered include fatigue, the impression of not having slept enough, irritability, and headaches. To further support this, research over the past 20 years has identified a reduction in the

average time of sleep among college students, and up to 50% of students report poor sleep quality (11). However, this study has its limits: since this study relies on self-reported data, it leaves room for recall bias and social desirability bias. In summary, blue light exposure during the pre-sleep period is correlated with worsened sleep quality and melatonin suppression, and also shifts the circadian rhythm.

BLUE LIGHT AND EYES

The eye functions as a camera for vision and a sensor for light-driven physiological processes, including the circadian system and light adaptation. Light adaptation is the eye's ability to adjust from a dark place to a brighter one. Light adaptation in mammals involves two systems: the non-image-forming (NIF) system, which regulates physiology and behavior, and the image-forming (IF) system, which is responsible for vision. Specifically, the NIF system regulates pupil size, circadian rhythm, sleep-wake cycle, melatonin suppression, memory, vigilance, and seasonal behaviors. In contrast, the IF system utilizes rods and cones in the retina and transmits visual signals to the brain via retinal ganglion cells (RGCs), which are neurons that convey information from the retina to the brain. Intrinsically photosensitive retinal ganglion cells (ipRGCs) make up 1-2% of these RGCs and contain melanopsin, a light-sensitive protein, making them sensitive to blue light (Figure 1). The ipRGCs send signals to the SCN, which in turn affects the intergeniculate leaflet, involved in regulating the circadian rhythm, as well as the olivary pretectal nucleus, which controls pupil constriction, and areas associated with emotion, cognition, and memory. To summarize, neurons in the retina receive the blue light and respond by sending signals to the brain. This further proves that blue light, which is high in photon energy, can cause damage to the retina (8).

Alternatively, one review from 2022 analyzed the effect of blue light on eye health and visual performance, and found many side effects of blue light to be debated. For instance, studies have shown that blocking blue light may lower intraocular pressure (IOP) – which is the measurement of fluid in the eyes – and raise melatonin levels. However, these findings have been gathered through animal studies, so more human studies need to be conducted. Additionally, other studies find that short-term effects of blue light on retina health is negligible, but long-term effects on macular health continue to be debated. Other studies regarding the impact of blue light and visual eye strain are mixed and inconclusive. Lab studies suggest possible damage to lens health, its real-world relevance is unclear (12). More research is needed to deduce accurate findings.

Blue light is made of short, high-energy waves that are almost as powerful as ultraviolet (UV) light, which cannot be detected by the naked eye (5). Human eyes have structures that protect them from certain kinds of light. For instance, the cornea and lens protect the light-sensitive retina in the back of the eye from UV ray damage. On the other hand, the retina remains vulnerable to damage from blue light (5). Since blue light is a relatively new advancement, further research is needed on its long-term effects on the eye. However, blue light can certainly lead to computer vision syndrome (CVS), also known as digital eye strain (1). Symptoms of CVS may include eye strain, redness, dryness, aches, double vision, or blurred vision (1). To reduce eye strain, the American Academy of Ophthalmology (AAO) suggests keeping the eyes moist with eye drops, using eyeglasses with the proper

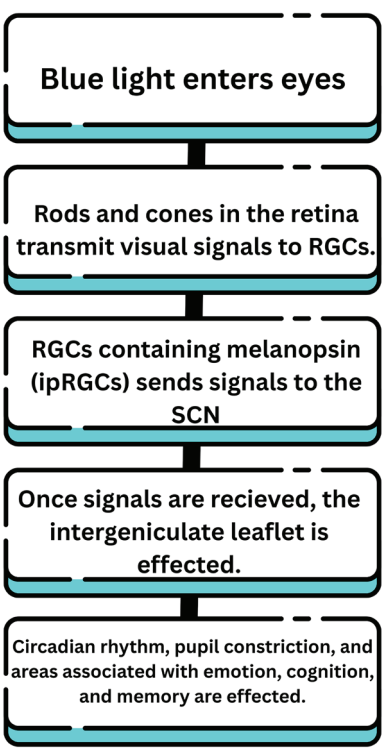

Figure 1. Custom visualization of the IF system's response to blue light.

prescription, and practicing the 20/20/20 strategy (after 20 minutes of blue light exposure, focus on an object 20 feet away for 20 seconds). Recent research suggests a correlation between exposure to blue light and eye strain. However, since blue light is a relatively new advancement, further research is needed to determine if there is a relationship between blue light and permanent eye damage. Ultimately, prolonged exposure to blue light may lead to CVS, irritated eyes, or worsened vision. In summary, the human eye is not protected from blue light, so it sends signals to the SCN, which controls the circadian rhythm. Nighttime exposure to blue light can increase the likelihood of developing CVS.

BLUE LIGHT AND HEALTH

In addition to the circadian system and sleep, nighttime exposure to blue light can lead to several health concerns, including obesity, poor heart health, and decreased mood. Exposure to blue light can either directly alter biological processes in our body, or the lack of sleep resulting from blue light exposure can lead to some of the issues listed above. While recent studies have highlighted the medical issues related to blue light, further research is needed to investigate the long-term health effects of blue light. This has yet to be achieved, as blue light is a relatively recent advancement (Figure 2).

Impact of Blue Light on BMI and Obesity

Blue light may be related to weight gain and obesity. People primarily lose weight during sleep. The intense blue light from technology before sleep can diminish sleep quality, which in turn, affects the body's ability to lose weight at night. High-energy blue light can also invoke stress responses and raise cortisol levels. Cortisol is a hormone triggered by stress, which can lead to increased fat storage and weight gain. Cortisol also causes blood sugar levels to spike, triggering hunger and cravings for sugar and carbohydrates (13).

A 2019 study was conducted to investigate the relationship between weight gain and exposure to artificial light at night. The researchers gathered data from 43,722 women, aged 35 to 74, from the 50 states and Puerto Rico, and compared their initial BMI to their BMI after the study. The women reported the number of sources of blue light present during sleep. Sources include television, digital alarms, nightlights, etc. The women underwent a baseline screening and then repeated it after five years. The study found a possible correlation between artificial light exposure during sleep. For instance, sleeping with a television or a light on in the room was positively associated with gaining

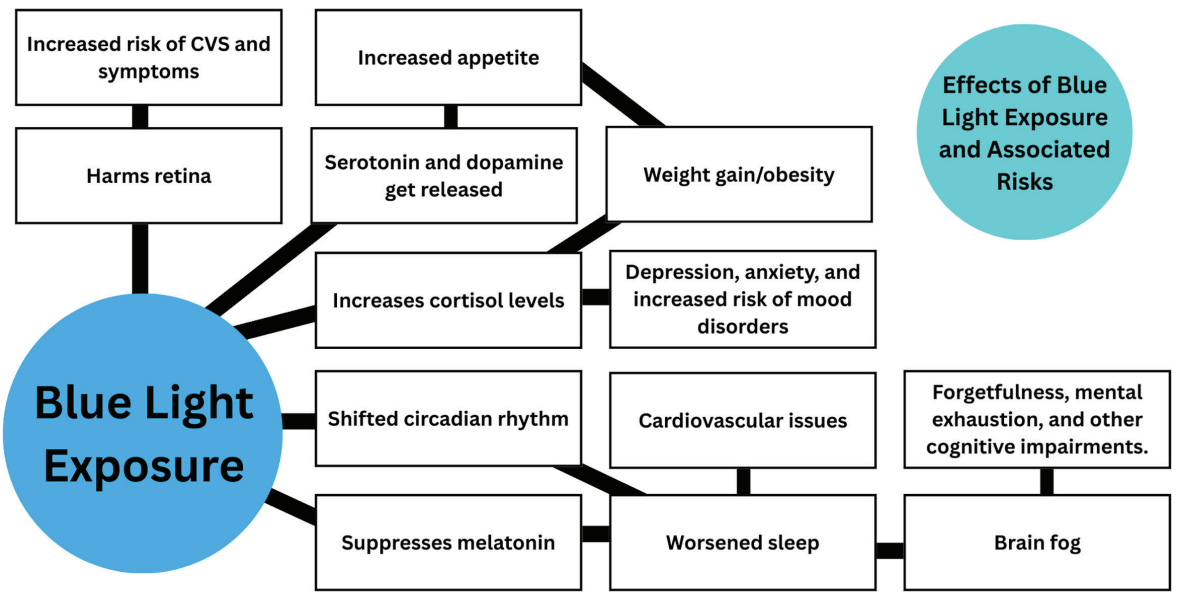

Figure 2. Custom visualization of the effects of blue light exposure and associated risks.

at least 11 pounds and developing obesity, despite the women adjusting their daily routine for insufficient sleep, diet, and physical activity. Although this study's findings align with similar studies on animals, it is one of the first to provide evidence supporting the correlation between light from technology and weight gain. That being said, one limitation of this study is its observational design. While a positive correlation was identified between obesity and blue light exposure, confounding variables – such as stress, lifestyle factors, genetics – are unmeasured, which may have influenced weight gain. More studies are needed to confirm or deny this finding (14). In summary, nighttime blue light exposure is positively correlated with weight gain.

Impact of Blue Light on Cardiovascular Health

Although blue light and heart health are not directly connected, blue light's effect on sleep can lead to problems with the cardiovascular system. Fragmented sleep may lead to inflammation and the early stages of atherosclerosis (15). Atherosclerosis occurs when atheroma (plaque), composed of fat, cholesterol, and other substances, builds up in the arteries (16). This may cause blood clots. Atherosclerosis is a common health issue, and plaque buildup is the leading cause of death worldwide (16). Additionally, individuals who frequently wake up throughout the night have a higher risk of developing atrial fibrillation (15). Atrial fibrillation (AFib) occurs when the heart's electrical system functions abnormally, leading to an irregular heart rhythm that originates in the atria, the upper chambers of the heart (17). While the electrical system should be sending electric signals in a steady pattern, in an individual with AFib, it sends multiple different signals simultaneously (17). AFib is a very serious health concern, as it may lead to strokes or heart failure (17). Furthermore, sleep-deprived people tend to crave more carbohydrates for energy. This increases a person's risk of developing metabolic syndrome (15). Metabolic syndrome is a combination of certain conditions that increases the risk of cardiovascular disease, strokes, and Type 2 diabetes (18). These conditions include excess abdominal weight, hypertriglyceridemia (when triglyceride levels exceed 150mg/dL), low levels of high-density lipoprotein (HDL, also known as "good cholesterol"), high blood sugar levels, and high blood pressure (18). A person with metabolic syndrome has at least three of these symptoms (18). All in all, blue light's effect on sleep quality may lead to the development of cardiovascular disease.

Impact of Blue Light on Mood

Evidence describing the relationship between blue light exposure and mood is ambiguous. Exposure to technology at night can contribute to worsened moods. Blue light can disrupt the circadian rhythm, and an irregular circadian rhythm is associated with an increased risk of depression. In fact, most people diagnosed with depression have shifted circadian rhythms. In turn, people who are forced to ignore their body's circadian clock (such as shift workers) are more likely to experience depression. Anxiety is also correlated to blue light exposure in the same way (2). Lack of sleep can also lead to mood swings (3), and chronic sleep deprivation can lead to mood disorders like depression and anxiety (2).

On the contrary, other studies suggest that blue light consumption can boost mood. Some studies show that blue light stimulates the production of serotonin and dopamine, which are hormones that influence mood, sleep, appetite, and social behavior (1). The release of these hormones makes people feel pleasure, calm, and motivated. To summarize, nighttime blue light exposure may lead to the development of mood disorders, such as anxiety and depression, while daytime blue light exposure encourages the secretion of serotonin and dopamine, promoting positive feelings.

Further, one particular study from 2022 claimed there is no correlation to device use and mood at all. This double blind study gathered 144 participants and randomly distributed them into three groups: one with cell phones in possession and on, one with cell phones in possession but turned off and put away, and the last with cell phones removed from the room entirely. The experiment resulted in a negligible difference in positive and negative effects on mood between the groups. Both of these measurements were either stable or statistically similar across all conditions. However, this study relied on self-report, which can lead to bias in responses. Additionally, participants never directly interacted with their phones; phone presence was passive. This could disregard the effects of notifications or social media engagement, which can affect mood. Lastly, this study also analyzes the short-term effects of phone possession. More studies that analyze the long-term effects of phone usage are needed to strengthen any claims (19).

Impact of Blue Light on Cognitive Performance

Blue light during the day is beneficial. Blue light exposure may enhance a person's ability to learn

new things (20). Some research reports a decrease in fatigue and an increase in cognitive performance (21). However, nighttime blue light that disrupts sleep can lead to decreased cognitive performance the next day or lead to brain fog (20). Brain fog is a group of symptoms that affect a person's cognitive performance (22). These symptoms include confusion; fatigue; forgetfulness; mental exhaustion; slow thinking and processing; and difficulty speaking, paying attention, and concentrating (1). A disturbance in sleep caused by nighttime exposure to blue light can also interfere with decision-making, memory consolidation, emotional regulation, creativity, problem-solving skills, and attention (23). When blue light suppresses melatonin, it prevents us from falling into deep REM sleep (1). REM sleep is crucial for emotional regulation, creativity, and retaining essential information (23). Meanwhile, non-rapid eye movement (NREM) sleep is involved with memory consolidation and learning (23). During NREM sleep, the hippocampus and neocortex transfer short-term memories into long-term ones, which is essential for learning (23). Research further supports that sleep deprivation hinders learning, decision making, attention, memory, and it affects the prefrontal cortex, a part of the brain responsible for impulse control and decision making (23). To summarize, while daytime blue light exposure can enhance cognitive performance and reduce fatigue, nighttime blue light exposure can lead to brain fog, fatigue, forgetfulness, mental exhaustion, and other cognitive impairments.

BLUE LIGHT AND DAILY ROUTINES

Blue light has the power to both directly and indirectly change the way people live their everyday lives. It can alter an individual's appetite, cognition (as explained above), and physical performance. While blue light may be beneficial during the day, at nighttime, its effects may prompt people to reconsider endlessly scrolling or binge-watching before bed.

Impact of Blue Light on Appetite

Appetite is influenced by the hormones ghrelin and leptin (24). Ghrelin makes a person feel hungry, while leptin makes a person feel full (24). The hypothalamus is the brain's center for hunger management (24). The hormones dopamine and serotonin, both capable of being stimulated by blue light exposure, send signals to the hypothalamus to control feelings of hunger (24). Consequently, after nighttime exposure to blue light, activity in the hypothalamus changes, leading to increased cravings for snacks after dark (24). (This may also be a factor in weight gain after blue light exposure.) Previous studies have shown that leptin levels decrease by 13% and ghrelin levels increase by 17% after blue light exposure at night (24). Research further indicates a decline in insulin levels and an increase in insulin resistance (24, 25). Insulin is a hormone that regulates blood sugar after eating (24). Another study shows that blue light exposure at dinner time, compared to dim light exposure, is correlated with increased hunger that starts 15 minutes after exposure to blue light and lasts for up to two hours after the meal (25). In summary, exposure to blue light increases feelings of hunger and cravings.

Impact of Blue Light on Physical Performance

When it comes to physical performance, blue light is a mixed blessing. Blue light exposure during the day promotes alertness and reaction time (26). In a systematic review of studies on the influence of blue light, 70% of the studies on alertness reported an increase in alertness after blue light exposure. Further, another 70% of studies on reaction time showed a decrease in reaction time (21). However, although not directly related, nighttime exposure to blue light can negatively impact physical performance. The reduced sleep caused by blue light can impact sports performance and exercise habits. Studies have shown that reduced sleep leads to higher heart rate, ventilation, respiratory frequency, exhaustion, and lactate levels (21, 27). It also decreases VO2max levels, which measure how efficiently the body takes in and uses oxygen, leading to decreased aerobic performance (27). Additional studies indicate that insufficient sleep has a negative impact on anaerobic power, accuracy, strength, hormone levels, and endurance during exercise (27). Muscle glycogen, the glucose in the muscles and liver that converts into energy during exercise, also decreases, and insufficient sleep further impairs muscle glycogen recovery (27). All in all, daytime blue light can enhance physical performance, while nighttime blue light significantly decreases an individual's physical potential.

CONCLUSION

Society has become increasingly dependent on technology. Now, with advanced algorithms and artificial intelligence, screen usage only continues to soar. Further, many individuals repeatedly find themselves doomscrolling or binge-watching their

favorite show late at night. The findings in this review are essential for the public to know because, while technology can be entertaining, addictive, and efficient, it is crucial to understand the underlying consequences of prolonged exposure to blue light. By understanding the impact of technology, individuals can develop healthy technology consumption habits that allow them to continue using technology while minimizing the risk of blue light-related health concerns. These concerns, gathered from previous studies, include negatively impacted sleep, eye health, BMI, heart health, mood, cognition, appetite, and physical performance. Specifically, blue light is associated with worsened sleep quality, eye strain, weight gain, cardiovascular issues, mood disorders, increased hunger, and fatigue.

However, this review has some limitations. Technology is a relatively new advancement, so the long-term effects of blue light have yet to be fully understood. Additionally, some findings contradict each other because daytime blue light exposure can be beneficial, affecting the results of some studies. Furthermore, not every finding is directly caused by blue light; some findings are a symptom of an issue that is otherwise caused by blue light, such as sleep deficiency. In other words, blue light exposure is not one-sided; its impact depends on the time of day and the duration of exposure to blue light. That being said, a large majority of findings are consequences of nighttime blue light exposure, and only a few health issues or benefits are not directly caused by blue light.

To prevent blue light-related health issues, experts recommend avoiding technology use 30 to 90 minutes before bed. Instead, individuals can read physical books in dim light, listen to music, meditate, journal, or practice mindfulness and meditation. It is also recommended to establish a nighttime routine and get exposed to lots of bright light during the day. This can help regulate the circadian rhythm and sleep schedule. Lastly, experts also recommend wearing blue-light-blocking glasses or installing an app that filters the blue light at night to minimize its effect.

In conclusion, blue light is ubiquitous in contemporary life; therefore, it is essential to understand the costs associated with blue light on sleep, health, and daily life.

CONFLICT OF INTERESTS

The author declares that there are no conflicts of interest regarding the publication of this article.

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