International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Scholarly Publisher
RS Global Sp. z O.O.
ISNI: 0000 0004 8495 2390

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ARTICLE TITLE	NARRATIVE REVIEW: THE IMPACT OF BLUE LIGHT EXPOSURE ON MENTAL HEALTH AND CIRCADIAN RHYTHM
DOI	https://doi.org/10.31435/ijitss.3(47).2025.3964
RECEIVED	22 August 2025
ACCEPTED	27 September 2025
PUBLISHED	30 September 2025
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NARRATIVE REVIEW: THE IMPACT OF BLUE LIGHT EXPOSURE ON MENTAL HEALTH AND CIRCADIAN RHYTHM

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ABSTRACT

Increasing exposure to blue light is a major problem in the modern lifestyle of individuals. The increasing use of digital devices and LED lighting is recognised as a major environmental factor affecting human health. While it has a positive effect on alertness during the day, excessive or late-night exposure disrupts the circadian rhythm by affecting the intrinsically photosensitive retinal ganglion cells (ipRGCs), which regulate melatonin secretion and the sleep-wake cycle. The main negative consequences of evening blue light exposure include: disrupted sleep architecture, particularly by reducing slow-wave and REM sleep, which are essential for recovery processes, impaired cognitive performance, increased daytime sleepiness and a higher risk of mood disorders, including depression and anxiety. Interventions and prevention strategies aimed at reducing evening blue light (through filters, night mode settings or glasses) and morning exposure to bright light have been shown to be beneficial for sleep quality, circadian phase regulation and mood stabilisation. Despite progress in this area, there are still significant research gaps, particularly in relation to individual differences in light sensitivity, long-term effects and the optimal timing and intensity of interventions. This review summarises the latest results of 33 studies and provides a structured overview of the current evidence on the short- and long-term effects of blue light on circadian rhythms, sleep and mental health. It highlights practical measures to minimise harmful exposure suggesting the directions for future research to promote circadian health and general well-being in the context of modern lifestyles.

KEYWORDS

Blue Light, Circadian Rhythm, Sleep, Mental Health, Depression, Artificial Light At Night, Light Therapy

CITATION

Michał Gniedziejko, Jakub Roszak, Paulina Bernecka, Oliwia Sójkowska-Sławińska, Anna Leśniewska, Patryk Macuk, Natalia Strumnik, Klaudia Malec, Julia Konat. (2025) Narrative Review: The Impact of Blue Light Exposure on Mental Health and Circadian Rhythm. *International Journal of Innovative Technologies in Social Science*, 3(47). doi: 10.31435/ijitss.3(47).2025.3964

1. Introduction

Exposure to blue light has increased significantly nowadays. It is a type of visible light with a wavelength of approximately 380–500 nanometers. Blue light is mainly emitted by numerous electronic devices such as tablets, smartphones, laptops, computers and LED lightning. The use of the above-mentioned devices has become widespread in recent years, particularly among children and young adults [1, 2, 3]. Blue light exposure, especially in the evening and night hours, affects melatonin secretion by the photosensitive retinal ganglion cells (ipRGCs) in the pineal gland, disrupting the circadian rhythm. This can lead to an increased risk of circadian sleep-wake cycle disorders (CRSWD) [4, 5]. In addition, long-term sleep disturbances impair well-being and are associated with a higher risk of developing mood disorders [6, 7]. This review aims to provide a structured overview of the positive and negative outcomes of a chronic exposure to blue light, its short- and long-term effects on the circadian rhythm and its relationship with personal well-being and mental health. It also identifies existing methods to minimize harmful exposure and points out gaps in the literature to provide a basis for future studies on this topic.

2. Mechanisms of Light Effects on Circadian Rhythms and Brain Function

The main biological clock in mammals, including humans, is the suprachiasmatic nucleus (SCN), a paired structure located in the hypothalamus. For effective coordination between the body and its environment requires more than just a central clock is necessary. The SCN relies on input pathways that provide signals from both the environment and the body to ensure proper synchronization, as well as output pathways that transmit temporal signals to connect physiological processes to the circadian rhythm. One of the most important stimuli that modulates the natural circadian rhythm is the natural and artificial light in the environment [4]. This stimulation is possible via various structures such as the retina, which consists of cones, rods, retinal ganglion cells and melanopsin, which was only discovered about two decades ago [8]. This unique photopigment is sensitive to short wavelengths near 480nm. It is found in the cell bodies and projections of a specific group of retinal ganglion cells known as intrinsically photosensitive retinal ganglion cells (ipRGCs). Thanks to this photopigment, these cells are able to recognise and signal light independently of cone and rod input [9]. Nowadays, exposure to blue short-wavelength light through the use of digital devices is almost as common as an exposure to natural light. Studies on human sleep and the circadian rhythm have mostly looked at two main effects of light: its rapid ability to lower melatonin levels when we are exposed to it, and its role in shifting the circadian phase. These effects are not achieved through the same pathway, so the lowering of melatonin levels and the shift in circadian phase are not directly linked. New findings suggest that these two processes may actually work separately [10]. The effect of light on our internal clock depends on the time of day when we are exposed to it. Morning light usually pushes the clock forward, helping the body shift toward earlier sleep and wake times. In contrast, evening or nighttime light moves the clock backward, leading to later sleep and wake times. Light therefore works as a signal that can either advance or delay our daily rhythm. The human circadian system is able to process and respond to a series of light exposures, even if each one is very short - lasting only five minutes [11]. Research shows that not only continuous light, but also short and intermittent periods of bright light are sufficient to trigger measurable changes in the circadian phase [12, 13]. This mechanism highlights how sensitively the natural human clock reacts to light signals from the environment. In addition, the theory of „photic history" has been described in recent years. It refers to the overall light exposure to which a person is exposed during the course of the day. This previous exposure determines how sensitive the circadian system is to light and influences both melatonin suppression and the extent of circadian phase shift [14, 15, 16]. That said, overall exposure to blue light sources throughout the whole day can seriously affect one's circadian rythm and melatonin secretion. Therefore, spectral diet in everyday conditions stands as a significant topic for future scientific investigations [17].

3. Effects of Blue Light Exposure on Sleep Quality and Architecture

Pre-sleep blue- light exposure activates photosensitive retinal ganglion cells that project to the suprachiasmatic nuclei. This suppresses the production of melatonin in the pineal gland, a key hormone responsible for signaling the onset of sleep. The quality of sleep is disrupted as the time it takes to fall asleep, also known as sleep latency, increases [18]. Suppression of melatonin secretion not only prolongs sleep latency, but also impairs both subjective and objective sleep quality, leads to later wake times and can result in fragmented sleep with a reduction in the deep non-REM and REM stages that are essential for recovery processes [19, 20]. The duration of light exposure also affects the distribution of NREM and REM sleep phases throughout the night. When bright light is used at different times of the day, it can alter the internal circadian rhythm, even if the sleep schedule remains constant. This leads to predictable changes in the expression of sleep stages, such as a reduced slow wave pressure in the early hours of the night or an altered REM propensity, reflecting a lack of synchronization between sleep homeostasis and circadian phase [21]. Experimental studies demonstrate a detectable decrease in the proportion of slow waves (deep sleep) after just one hour of exposure to blue light before bedtime. This indicates a qualitative impairment of regeneration processes, not a significant reduction in sleep duration [20].

As a result, prolonged or more intense exposure to blue light is reported to increase sleepiness before bedtime, leading to decreased evening alertness, poorer cognitive performance and delayed wake-up time the next morning. The physiological effects were more pronounced in people with pre-existing sleep disorders, highlighting the interplay between environmental factors and personal behaviour [19].

It is important to emphasize that melatonin suppression and circadian phase resetting are not perfectly coupled. Human experiments demonstrate a"functional dissociation" in which significant melatonin suppression may appear without corresponding phase shifts -and vice versa - indicating partially different signaling pathways and dose–response dynamics. This dissociation clarifies the heterogeneous architectural changes under the influence of visually similar evening light exposure [10].

Summing up, the evidence suggests that blue-enriched evening light delays internal timing and impairs sleep microstructure, principally by reducing slow-wave sleep. Managing the spectral composition, intensity and rhythm of light a few hours before bedtime is a practical way to maintain the quality and structure of sleep.

4. Impact of Blue Light on Mental Health and Mood Disorders

Over the last century, electric lighting has reshaped the natural connection between human activity and the cycles of light and darkness with which our bodies have evolved. Today, we spend our days in lighting that is much weaker than sunlight and our nights in conditions that are much brighter than true darkness [22]. These altered patterns affect the circadian system and, as research shows, can also affect mood. Mood depends on both the circadian phase and how long we have been awake, and even small shifts in the sleep-wake schedule can noticeably alter emotional state [23].

A systematic review by Andy Deprato et al. that included nineteen studies with a total population of 556, 861 people found an association between nighttime light exposure and circadian rhythm disruption by altering the natural light-dark cycle [24]. Evidence from a population-based study by Jean M. Twenge and W. Keith Campbell, in which 40, 337 US children and adolescents aged 2–17 years participated in 2016, examined the relationship between screen use and psychological well-being. The results showed that screen time longer than one hour per day was associated with lower well-being, reflected in reduced curiosity, diminished self-control, higher distractibility, difficulties with peer relationships, lower emotional stability, and problems completing tasks. Among adolescents aged 14–17 years, heavy screen users (7+ hours per day) were more than twice as likely to have ever been diagnosed with depression or anxiety and to have received treatment from a mental health professional than low users (1 hour per day) [2].

The exact mechanisms by which light affects mood remain unclear. While the circadian effects mediated by the SCN are well established, studies in animal models suggest the existence of an additional pathway from the retina to the habenula, specifically the perihabenular nucleus. This connection, which involves specific ipRGCs and bypasses the SCN, has been proposed as a pathway through which light can directly modulate mood [25]. It is still uncertain whether the results observed in animal studies can be fully translated to humans. However, evidence from neuroimaging research provides important clues suggesting that the human habenula is not indifferent to light. Instead, it appears to respond to fluctuations in ambient light, implying that this small but significant brain structure may also play a role in how light affects mood and behaviour in humans [26].

Further studies are needed to better understand the mechanisms by which light exerts its effect on mood disorder therapy. In the next section, we will first outline the main clinical applications and then provide a brief guide on how light therapy can be implemented in daily clinical practice.

5. Therapeutic indications of light

Bright Light Therapy (BLT) is a non-pharmacological treatment that uses controlled exposure to intense artificial light, usually in the morning, to compensate for reduced natural daylight. The therapy was first described by Rosenthal et al. (1984) in patients with Seasonal Affective Disorder, where daily sessions of bright light were shown to reduce depressive symptoms [27]. BLT is thought to act primarily through its influence on the circadian system and regulation of neurotransmitters, such as serotonin, thereby improving mood and stabilizing sleep–wake patterns. Today, BLT is recognized as the first-line treatment for Seasonal Affective Disorder, with noticeable symptom improvement often appearing within just a few days [28]. Light therapy has also been found effective for non-seasonal depression, although it is typically considered a second-line treatment. In such cases, therapeutic effects tend to emerge more gradually, often taking between two and five weeks to reach it [28, 29].

In individuals suffering from chronic depression, Bright Light Therapy has demonstrated significantly higher remission rates when compared with placebo, highlighting its strong therapeutic potential [30]. Beyond chronic forms of depression, BLT is also regarded as a valuable treatment approach in mood disorders linked to hormonal and gender-related factors, including premenstrual dysphoric disorder and depression occurring during the perinatal period [31, 32]. This suggests that its benefits extend across a range of affective conditions, not only seasonal ones.

Bright Light Therapy has proven effective for individuals whose depressive symptoms are linked to insufficient exposure to natural daylight. This applies, for instance, to shift workers whose schedules limit sunlight exposure, patients experiencing disruptions in their sleep-wake cycles, such as delayed sleep-wake phase disorder, as well as people facing social withdrawal, including those with psychiatric conditions or elderly individuals. In such cases, BLT offers not only a beneficial treatment but also a meaningful alternative to traditional pharmacological therapies [33].

6. Interventions and Preventive Strategies

Studies show that preventive strategies to reduce evening blue light exposure through the use of screen filters, night shift settings on digital devices and blue light protection glasses improve sleep parameters and shift melatonin secretion in clinical trials [34, 35]. Morning bright light therapy is an effective measure to shift the circadian phase and can counteract the negative effects of evening exposure. It has been used effectively in the treatment of delayed sleep-wake phase disorder and seasonal affective disorder. The timing of exposure is crucial - morning or evening exposure to blue light can lead to opposite effects [36, 37]. With regard to mental health (including mood disorders, seasonal affective disorder, bipolar disorder), both evening reduction of blue light and targeted bright light therapies have been used. Randomised controlled trials and clinical protocols are promising, but larger studies are still needed [38].

Environmental light design, reducing exposure to high-intensity blue light at night, is recommended. Practical, low-cost prevention strategies include: increasing exposure to natural light in the morning, limiting exposure to blue light in the evening (by switching off electronic devices, using night mode, filters, glasses) or using morning light therapy [39].

7. Discussion and Future Directions

Research shows that blue light can be both helpful and harmful, depending on the time, intensity and duration of exposure. It is an important signal for the body clock, but in the evening it often disrupts the circadian rhythm, lowers sleep quality and increases the risk of developing mood problems. These effects are particularly relevant for teenagers, people with sleep disorders and those who spend a lot of time in front of screens at night. At the same time, the controlled use of light, such as bright light therapy in the morning for delayed sleep-wake phase disorder and seasonal affective disorder, or reducing blue light in the evening with filters, night modes or glasses shows clear benefits for sleep and mood.

Still, many studies so far have been short, based on small groups, or carried out in lab settings that do not fully reflect everyday light exposure. Future research should focus on several key areas. Long-term, large-scale studies are needed to better understand how daily light exposure affects sleep and mental health. Future studies should also consider individual variability, including genetic background, previous light exposure and light sensitivity. Researchers should create and take objective measurements of circadian rhythms, sleep quality and mood should be used to ensure methodological consistency. Moreover, future studies should not only focus on how light affects the circadian rhythm, but also explore how light signals travel through the brain and influence emotions directly. These neural pathways start with the eyes detecting light and sending this information to specific brain regions that control mood and stress responses. By understanding these connections, researchers can learn how light exposure might play a role in conditions such as depression, anxiety, or overall emotional well-being.

Taken together, these points emphasise that blue light is a powerful but double-edged factor: while it is essential for regulating our biological clock, too much of it at the wrong time can disrupt sleep and mood. Clearer evidence will help to provide better guidelines for the safe use of light in daily life.

8. Conclusion

As mentioned before, light plays a dual role in human biology. Beyond its fundamental function of vision, which enables us to perceive details, color, and movements, it also exerts powerful non-visual influences on circadian rhythms, sleep regulation and emotional well-being. If we perceive light at inappropriate times, it can disrupt the circadian timing and affect sleep quality. However, when applied in a controlled and therapeutic way, as in bright light therapy, targeted light exposure can be an effective intervention for psychiatric disorders and other medical conditions. This emphasises the importance of understanding light not only as a visual stimulus, but also as a biological signal with significant clinical relevance.

Conflict of Interest: The author declares no conflict of interest.

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