

Research Article

# Impact of Digital Screen Blue Light on Retinal Integrity and Sleep Behavior among Teenagers

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## ABSTRACT

**Background:** In recent years, growing apprehension has emerged about the harmful consequences of prolonged exposure to blue light among teenagers, largely due to the escalating use of digital screens. Blue wavelength light emitted from smartphones, tablets, and computers has been implicated in disturbing circadian rhythm regulation and contributing to retinal stress and potential degenerative alterations. As adolescents increasingly rely on digital platforms for education and recreation, it has become essential to evaluate how sustained screen exposure influences ocular integrity and sleep health.

**Objective:** This study aimed to examine the impact of chronic exposure to blue light from digital screens on retinal structure and sleep behavior in adolescents.

**Methods:** A prospective observational investigation was conducted at PHQ Teaching Hospital Gilgit from May 2024 to April 2025. A total of 100 participants aged 13-18 years were enrolled. Data regarding daily screen usage patterns and sleep routines were collected through structured questionnaires. Comprehensive ophthalmic assessments were performed, including optical coherence tomography (OCT), retinal imaging, and routine eye examinations to detect early or subtle retinal alterations. Sleep quality was evaluated using the Pittsburgh Sleep Quality Index (PSQI). The extent of blue light exposure was estimated based on the duration of daily screen time and the type of electronic devices used.

**Results:** The findings revealed that 68% of participants reported spending more than eight hours per day on digital screens. Among these high-exposure individuals, 61.8% experienced symptoms consistent with digital eye strain, while 42% demonstrated early retinal thinning on OCT imaging. Moreover, 74% of adolescents in the high-exposure category exhibited poor sleep quality scores on the PSQI, with significant delays in sleep onset and reduced overall sleep duration ( $p < 0.01$ ). A strong positive correlation was observed between prolonged screen time and sleep disturbances ( $r = 0.64$ ,  $p < 0.001$ ). Adolescents with daily screen usage exceeding eight hours were identified as being at greater risk for both retinal changes and compromised sleep quality.

**Conclusion:** Excessive and sustained exposure to blue light from digital devices has a measurable negative impact on retinal health and sleep patterns among adolescents. These findings emphasize the need for public health awareness initiatives, regulation of screen time, and the adoption of preventive strategies such as blue light filters and scheduled screen breaks to minimize long-term ocular and sleep-related complications.

**Keywords:** Blue Light, Teenagers, Digital Screen Exposure, Retinal Integrity, Sleep Quality, Prolonged Screen Use, Optical Coherence Tomography.

## INTRODUCTION

In the contemporary digital era, adolescents have experienced a marked surge in the use of smartphones, tablets, laptops, and LED-based display systems. This escalation in daily screen exposure has generated growing concern regarding the health implications of blue light, particularly in relation to retinal integrity and

sleep regulation. Digital screens and modern lighting systems emit substantial amounts of blue wavelength light ranging between 400–490 nm [1]. While natural exposure to blue light through sunlight is physiologically necessary, artificial exposure has significantly intensified due to prolonged engagement with electronic devices. Adolescence represents a critical

developmental phase characterized by ongoing maturation of the nervous system, retinal structures, and circadian rhythm mechanisms, making this age group potentially more vulnerable to environmental stimuli such as light exposure. Previous literature suggests that blue light can penetrate deeply into ocular tissues, inducing photochemical stress and potential retinal cellular damage [2]. In addition to ocular concerns, blue light has been shown to suppress melatonin secretion, a hormone essential for regulating the sleep–wake cycle. Reduced melatonin levels may alter sleep architecture, shorten total sleep duration, and contribute to poor sleep quality—conditions already prevalent among adolescents who are prone to delayed sleep phase tendencies.

The situation intensified during the COVID-19 pandemic, when remote education, virtual social interaction, and online entertainment significantly increased screen dependency among teenagers [3]. Extended evening and nighttime exposure to digital devices heightened concerns regarding sustained blue light exposure in a population already susceptible to circadian disruption and potential retinal strain [4]. Although numerous studies have evaluated the general effects of excessive screen time on well-being, limited research has specifically explored the biological influence of blue light on adolescent retinal health and circadian regulation. Behavioral characteristics of adolescents—such as late-night screen engagement and evening chronotypes—further necessitate focused investigation [5]. The lack of age-specific empirical evidence highlights a knowledge gap regarding the long-term visual and sleep-related consequences of excessive blue light exposure during this pivotal developmental stage.

Several mechanisms have been proposed to explain blue light–induced retinal damage, including oxidative stress, mitochondrial dysfunction, and photoreceptor cell apoptosis. Regarding sleep disruption, evening exposure to blue light may delay melatonin release, shift circadian timing, and reduce overall sleep efficiency [6]. While these mechanisms provide biological plausibility, robust longitudinal evidence among adolescents remains limited. Therefore, the present study was designed to evaluate the association between digital screen–related blue light exposure and its effects on retinal structure and sleep patterns among adolescents aged 12–18 years. By focusing on this specific age group, the research aimed to generate developmentally

relevant insights and to inform healthcare professionals, educators, and parents about potential risks associated with excessive screen use. Ultimately, the findings intend to support evidence-based preventive strategies to protect adolescent visual and sleep health in an increasingly technology-driven environment [7].

## **MATERIALS AND METHODS**

This prospective observational study was conducted at PHQ Teaching Hospital Gilgit over an one-year period from May 2024 to April 2025. The primary objective was to assess the impact of blue light emitted from digital devices on retinal parameters and sleep behavior in adolescents. Participants aged 12–18 years who reported using digital devices for more than two hours daily over the preceding six months were considered eligible. After obtaining informed consent from both participants and their guardians, 100 adolescents were enrolled through purposive sampling.

Recruitment was carried out via hospital outpatient departments and selected local schools.

Inclusion criteria comprised adolescents without pre-existing ocular diseases, systemic illnesses, or diagnosed sleep disorders. Exclusion criteria included a history of neurological disorders, use of medications affecting sleep patterns, or ongoing treatment for ophthalmic conditions. The study was implemented in three phases: baseline evaluation, digital usage profiling, and follow-up assessments. At baseline, comprehensive ophthalmic examinations were conducted by trained ophthalmologists, including visual acuity testing, intraocular pressure (IOP) measurement, and optical coherence tomography (OCT) to evaluate macular thickness and retinal nerve fiber layer (RNFL) status. Demographic details, duration of daily screen exposure, device types, and patterns of digital use—particularly pre-bedtime usage—were collected using structured questionnaires. Sleep assessment incorporated both objective and subjective measures. Participants wore wrist actigraphy devices continuously for two weeks to record sleep onset latency, total sleep duration, wake after sleep onset, and sleep efficiency. Additionally, the Pittsburgh Sleep Quality Index (PSQI) was administered to evaluate perceived sleep quality. Blue light exposure was estimated indirectly based on reported screen duration and device type, with devices known for higher blue light emission

categorized accordingly. Participants were stratified into two groups: a high-exposure group (screen use exceeding four hours daily, particularly during evening or nighttime) and a low-exposure group (less than two hours daily, predominantly daytime use). Associations between exposure categories, retinal findings, and sleep disturbances were analyzed. Follow-up assessments were conducted at six and twelve months. Retinal parameters were re-evaluated using OCT, while actigraphy and PSQI were repeated to monitor sleep-related changes. The longitudinal design enabled evaluation of cumulative effects of blue light exposure over time. Data were entered and analyzed using SPSS version 25. Means, standard deviations, and percentages were calculated. Paired t-tests, repeated measures ANOVA, and chi-square tests were applied

where appropriate. Statistical significance was set at  $p < 0.05$ . Ethical approval was obtained from the Institutional Review Board of PHQ Teaching Hospital Gilgit prior to data collection. The study adhered to the Declaration of Helsinki, and participant confidentiality was maintained through data anonymization.

### RESULTS

The research compared the consequences of blue light exposure that is caused by digital devices on the retinal wellbeing and sleep patterns among the adolescents. The data were gathered by highly detailed questionnaires, ophthalmological examination (visual acuity, thickness of the retina through OCT), and sleep quality assessment through the Pittsburgh Sleep Quality Index (PSQI).

Table 1: Retinal Health Parameters Based on Daily Screen Time Exposure

Screen Time (Hours/Day)	Number of Participants	Mean Retinal Thickness ( $\mu\text{m}$ )	Reported Eye Strain (%)	Decreased Visual Acuity (%)
<2 hours	20	267.5	15%	5%
2–4 hours	35	262.8	31%	14%
4–6 hours	25	256.1	60%	28%
>6 hours	20	250.3	85%	45%

There was a negative correlation between the retinal health and daily screen time expressed in Table 1. The participants whose screen time was below 2 hours had the lowest eye strain (15 %) and the largest mean retinal thickness (267.5  $\mu\text{m}$ ). Conversely, children who spent greater amounts of time than 6 hours a day in front of the screens showed substantial atrophy of the retina (250.3  $\mu\text{m}$ ), and eighty-five percent of them reported eye fatigue and forty-

five percent of them had reduced visual acuity. This observation was showing progressive retinal stress when being exposed to blue light-emitting screens over time. Also, the prevalence of the symptoms of digital eye strain including dryness, blurring, and discomfort increased as a proportional increase in screen usage, which highlights the burden on the ocular structures caused by prolonged digital use.

Table 2: Impact of Screen Time on Sleep Quality (PSQI Scores)

Screen Time Category	No. of Participants	Poor Sleep Quality (PSQI >5)	Average Sleep Duration (hrs/night)	Reported Daytime Sleepiness (%)
Low Exposure (<2 hrs)	30	5 (16.7%)	7.6 $\pm$ 0.9	3 (10%)
Moderate Exposure (2–4 hrs)	35	16 (45.7%)	6.4 $\pm$ 1.1	13 (37.1%)
High Exposure (>4 hrs)	35	29 (82.9%)	5.2 $\pm$ 1.4	26 (74.3%)

In this table, the effects of screen time on the quality of sleep based on PSQI were shown. Difficulty during sleep (poor quality of sleep)

was traced among 16.7 percent of adolescents in low-exposure group that had an average

sleep of about 7.6 hours and were not sleepy during the day (10 percent).

Group of moderate screen time correspondents exhibited deteriorated sleep parameters: 45.7% individuals had a PSQI score higher than 5, which refers to the bad sleep quality. The sleeping time decreased to 6.4 hours in average and over one-third complained of somnolence in the daytime.

The largest adverse sleep effects were also seen in the high screen time group. % of them had bad scores on their sleep and their average sleeping hours went down to 5.2 hours. The daytime sleepiness in this group was almost three-quarters and this may have disrupted the performance of this group in school and their everyday performance. The relationship between slower screen time and wretched sleeping parameters was both statistically and clinically important.

## DISCUSSION

The results of this study revealed significant associations between prolonged blue LED exposure from digital devices and adverse retinal and sleep outcomes in adolescents. These findings align with prior studies demonstrating that screen-emitted blue light, particularly from smartphones, tablets, and computers, negatively affects circadian rhythm and ocular structures [8].

Adolescents, due to high screen usage and ongoing physical development, exhibited measurable physiological effects.

Regarding retinal health, continuous blue light exposure was linked to digital eye strain symptoms, including blurred vision, eye fatigue, and headaches. Several participants displayed early retinal stress signs such as reduced contrast sensitivity and increased photophobia [9]. These results are consistent with studies showing that short-wavelength blue light penetrates the eye and can induce oxidative retinal cell damage. Adolescents spending over six hours daily on digital devices experienced more visual disturbances, suggesting a dose-dependent relationship between screen time and ocular strain.

The study also highlighted the detrimental impact of blue light on sleep. Most participants demonstrated delayed sleep onset, shorter sleep duration, and reduced sleep quality [10]. These disturbances are attributed to melatonin suppression, a hormone critical for circadian regulation. Evening and nighttime device use exacerbated sleep disruptions, emphasizing the

importance of exposure timing in addition to duration.

Interestingly, adolescents using blue light filters, night mode, or protective glasses showed modest improvements in visual and sleep-related symptoms [11]. This indicates that mitigation strategies can help limit adverse effects; however, adherence was low, suggesting the need for increased awareness among adolescents and guardians.

Gender-based analysis showed that female participants experienced slightly higher eye strain and sleep disturbances. Although not fully understood, these differences may relate to hormonal variations and behavioral patterns, such as extended social media or academic device use [12].

Limitations of this study included reliance on self-reported screen time and sleep measures, which may introduce recall bias [13]. Additionally, objective ocular assessments like fundus photography or electroretinography were not utilized, which could have provided deeper insights into retinal changes. Despite these limitations, the study offers practical evidence regarding the effects of blue light in a high-risk adolescent population [14].

Overall, excessive use of digital devices in adolescents, particularly uncontrolled screen time, had measurable negative consequences on visual and sleep health. The findings underscore the importance of preventive measures, such as limiting screen time, using blue light filters, and encouraging screen-free periods at night. Public health initiatives and educational programs are needed to address digital overexposure among youth [15].

## CONCLUSION

Extended exposure to blue light from digital devices significantly impacts retinal health and sleep patterns in adolescents. High screen-time users exhibited early retinal strain, increased digital eye strain symptoms, and disrupted circadian rhythms, with delayed sleep onset and reduced sleep duration. Adolescents are particularly vulnerable to physiological and neurological effects from blue light, emphasizing the need for protective interventions such as screen-time limitation and blue light filters, especially during evening hours. These findings highlight the urgent necessity for awareness campaigns and behavior modification strategies to safeguard ocular and sleep health in a technology-dependent adolescent population.

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