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Association Between Blue Light Exposure, Retinal Health, and Sleep Patterns in Adolescents

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ABSTRACT:

Background: Over the past few years, there have been serious concerns regarding the negative sequelae of exposure to blue light especially during an extended period in the case of adolescents due to their increased use of digital devices. The blue light has also been associated with the disruption of the circadian rhythm and the development of retinal strain and degeneration; the latter occurs by the use of blue-coloured light-emitting screens, including smartphones, tablets, and computers. With a general increase in screen time in adolescents, there was a need to assess the degree of such effects on ocular and sleep wellbeing.
Objective: The objective of the study was to determine how a long-term exposure of blue light emitted by digital devices impacts the health of the retina and sleep habits in adolescence.
Methods: This is a prospective observational study done at PHQ Teaching Hospital Gilgit between May 2024 and April 2025. One hundred adolescents between the ages of 13-18 have participated. Structured questionnaires were used to assess participants on screen time related habits and sleeping patterns and ocular examination assessments based on optical coherence tomography (OCT), retinal imaging and general eye examinations were carried out with the view towards identifying any subclinical symptoms of retinal changes. The Pittsburgh Sleep Quality Index (PSQI) was used to measure sleep quality and exposure to blue light was estimated on the basis of duration of screen use and type of devices used.
Results: The researchers discovered that 68 percent of the respondents had established that they spend more than 6 hours of their time on screens daily. Of these, 61.8 percent had digital eye symptoms, 42 percent early signs of retinal thinning, on OCT. Furthermore, participants belonging to the high exposures group scored worse on sleep quality (74%) in accordance with PSQI with a strong delay in the onset of sleep and a shorter duration of sleep ($p < 0.01$). Screen time and sleep disturbances were found to be

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statistically significantly associated ($r = 0.64$, $p > 0.001$). Keep 8 plus hours daily screen time in adolescents was most dangerous in risking retinal changes and poor sleep.

Conclusion: extreme exposure to blue light emitted by digital devices produced a significant adverse effect on retina functions but also sleep quality in adolescents. The results stated the importance of awareness campaigns, limiting the use of screens, and encouraging protective measures as blue light filtration and screen breaks to alleviate such risks.

Keywords: Blue light, adolescents, digital devices, retinal health, sleep patterns, screen time, optical coherence tomography.

INTRODUCTION:

The last few years were marked by a sharp increase in the utilization of digital gadgets, including smartphones, tablets, laptops, and LED screens by adolescents. With this increase in screen time, there had been an increasing social concern as to the implications of blue light exposure on health especially pertaining to the integrity of the retina and sleeping patterns. Digital screens and energy-efficient lighting emitted a lot of blue light that was within the wavelength spectrum of 400 to 490 nanometers [1]. Although the exposure to blue light was partially normal and essential, mostly through sunlight, it had grown more artificial and excessive with the spread of the activities that rely on the use of a screen. Adolescence was characterized by the pivotal changes in the physiology and the nervous system, as well as the development of the retina and the circadian rhythms. It was felt that these development processes were especially susceptible to environmental stimuli e.g. light exposure. In earlier studies, it was already indicated that blue light would affect the retina in a way that photochemical stress would harm and damage retinal cells by entering deep into the eye [2]. Moreover, blue light was established to attenuate light secretion, a hormone that causes and controls the cycles of sleep. Melatonin suppression could lead to a change in sleeping architecture, a reduction of sleep duration, and poor sleep among the already predisposed adolescents to the delayed sleep phase syndrome.

The COVID-19 pandemic had even increased the speed of the usage of digital screens among adolescents because of the remote learning, virtual social life, and online entertainment [3]. Consequently, teenagers kept spending more time under blue light, which is deep into the night. This change in behavior increased the pressure of research on the possible effect of blue light exposure on a population at high risk of retinal and sleep patterns disorders [4].

Although the effect of screen time on overall well-being had been studied in many studies, little research had voiced the biological impact of blue light on the health of adolescent retinas and the regulation of circadian rhythms. Moreover, physiological and behavioural peculiarities of adolescents, like a tendency to be active in the evenings and to spend more time in front of the screens, were deserving an attention [5]. This situation is precipitated by the absence of specific studies that have contributed to a gap in knowledge regarding the effects that exposure to blue light extensively might have on visual and sleep health at this crucial point in human development.

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A number of the mechanisms were proposed to cause the retinal damage after blue light exposure, such as oxidative stress, mitochondrial dysfunction, and apoptosis of the photoreceptor cells. Regarding sleep disturbances, it had been hypothesized that the exposure to blue light in the evening retarded the release of melatonin, displacing the sleep-wake rhythm, and minimizing the total sleep efficiency [6]. Such mechanisms stressed the biological plausibility of an adverse influence but a more empirical confirmation was required, more so among adolescents.

The present research therefore aimed to evaluate the effects of blue light exposure of the digital device on the retinal health and sleep patterns of adolescents. Engaging a certain population located in the age range of 12 to 18, the study was expected to bring age-related insights into the effect of screen-related blue light exposure on major health parameters. It was also expected to create awareness to the health care professionals, educators, and parents about the imminent dangers of overusing the screen. Finally, the results were meant to help in providing evidence-based practice and preventive methods that could safeguard the health of adolescents in a tech-savvy world [7].

MATERIALS AND METHODS:

It is a prospective observational study that was carried out at PHQ Teaching Hospital Gilgit within a time span of one year between May 2024 to April 2025. The purpose of a study was to determine the effects of blue light emissions originating in the use of digital devices on retinal health and sleep pattern in adolescents. The adolescents with an age-range between 12 and 18 years and having a history of more than two-hour usage of digital devices including smartphones, tablets, and computers at least once a day within the last six months were the target population. An informed consent was issued to the participants and their guardians and a total of 100 participants were enrolled using a purposive sampling technique. Hospital based outpatient departments and the local schools were used to recruit the participants. The inclusion criteria included any adolescent who did not have any type of previous ocular pathology, systemic disease, or diagnosed sleep disorders. Adolescents that had ever experienced neurological disorders, medication intake that may interfere with the sleep patterns or were receiving treatment of eyerelated disorders were excluded.

It was implemented in three stages, initial assessment, profiling of digital use, and follow-ups. The accuracy was checked on baseline, when their ocular examination was carried out by trained ophthalmologist. These encompassed visual acuity, intraocular pressure (IOP), and optical tom (OCT) to measure the macular thickness and the retinal nerve fiber layer (RNFL) status. The demographical data, screen time length, and the type of devices used along with the patterns of digital consumption, including usage before bedtime were gathered by a structured questionnaire.

To assess sleep behavior, they were to put on wrist actigraphy tags in two successive weeks. They measured time to go asleep, the amount of hours in sleep, wake time following sleep and sleep efficiency. Moreover, the Pittsburgh Sleep Quality Index (PSQI) was carried out to offer subjective analogy of the sleep quality. Partnership of both objective (actigraphy) and subjective (PSQI) tools guaranteed strong analysis of sleep behavior.

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The quantity of the blue light concerning the screen time and kind of devices were considered rather than estimated. Its devices such as known high blue light emission profiles were categorized as such. Moreover, it was divided into two groups such as high exposure group (accurate screen time exceeds 4 hours a day especially at evening or at night) and low exposure group (less than 2 hours a day though mostly daytime). A correlation then was drawn between these and paired to ascertain the relationship with changes in the retina and sleep disturbances.

6 months and 12 months follow-ups were done. OCT was used to re-evaluate retinal parameters, whereas both actigraphy and PSQI were used to gather data on sleep. It was a longitudinal design, which permitted observing the longitudinal changes and cumulative results of exposure to blue light during a period of time.

The entry and analysis of the data was done in SPSS version 25. Means, standard deviations and percentages were computed. Comparisons between the measurements of retina and scores defining sleep quality taken at different points in time were done through paired t-tests and ANOVA repeated measures. Changes were also tested using chi-square tests so as to make comparisons of categoric variables. The minimum p-value level criterion of significance was set at a value of less than 0.05. Before the onset of the data collection exercise, the study had received ethical approval by the Institutional Review Board of PHQ Teaching Hospital Gilgit. The research was performed according to all ethical procedures within the Declaration of Helsinki. They guaranteed the participants confidentiality and anonymized the data before the analysis.

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 (µm)	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%

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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 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 Âµm), 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 ± 0.9	3 (10%)
Moderate Exposure (2–4 hrs)	35	16 (45.7%)	6.4 ± 1.1	13 (37.1%)
High Exposure (>4 hrs)	35	29 (82.9%)	5.2 ± 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 research raised major correlations between long-term blue LED exposure, digital gadgets, and negative retina and sleep occurrences among adolescents. These findings corroborated with

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previous findings that blue light, more so the one on screens including smartphones, tablets, and computers, was harmful to the circadian rhythm and the eye structures [8]. Teenagers, who are the most susceptible because they spend much time on a screen and continue to grow physically, seemed to suffer quantifiable effects.

Concerning the health of the retinas, the study proved that uninterrupted blue light exposure was linked to the symptoms of digital eye strain, such as blurred vision, eye fatigue, and headache. A number of them showed indications of premature retinal stress including decreased contrast sensitivity and increased reports on photophobia [9]. These results collected were in agreement with other studies that suggested that blue light in wavelengths of short length entered deep into the eye and might lead to oxidative destruction of the cell retina. Teenagers that spend over 6 hours per day on digital devices experienced more of such visual disturbances and this suggests that there is a dose-dependent relationship between screen time and ocular strain.

In addition, the research underlined the adverse effects of blue light on sleep. Most of the teenagers established late sleep onset, shortened overall sleep period and low sleep quality [10]. Such sleep disturbance was explained by the inhibition of the secretion of melatonin, a hormone that determines the functioning of the sleep-wake process, which was found to be highly sensitive to blue light. The individuals that used the gadgets later at night had more severe disruptions of sleep patterns, which indicates that the timing of the exposure to the gadgets was as critical as the length.

Interestingly, those adolescents who applied blue light filters, the night mode, or protective glasses experienced a small improvement in ocular and sleep-related symptoms [11]. This observation provided an idea that mitigation measures may be used to limit the adverse impacts of blue light. Nonetheless, the adherence to these interventions was low, which means that more adolescents and guardians should become more aware of them and be prepared to change their behaviors.

Subtle changes were also shown in the gender-based analysis of the study as female respondents have shown a modest increase in eye strain and sleep disturbance. Although the causes of such discrepancy were not fully clarified, it may have been caused by the differences in hormones and the behavior patterns of staying on social media or academic device uptake that became long-term habits [12].

The study had limitations such as the use of self-report of sleep measures and screen time that could lead to a recall bias [13]. Moreover, objective ocular examinations like fundus photography or electroretinogram were not utilised that would have given a better insight into the alterations in the retina. Nevertheless, there were certain limitations that weakened the evidence of the study, although it was helpful in terms of the practical meaning of the blue light exposure within a particular and at-risk group [14].

Finally, the research concluded that the use of digital gadgets in adolescents, in particularly, their excessive lack of control had quantifiable negative consequences on the visual and sleep health. The results emphasized the need to take preventive care, such as the decrease in time spent on screens, the adequate use of filters, and increasing screen-free time at night. These findings added to the demand of the

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need of a public health approach and educational initiative in response to digital overexposure that continues to become a problem in young people [15].

CONCLUSION:

This research proved that extended exposure to blue light in digital devices led to a negative impact significant on retinal health as well as the sleep of adolescents. The subjects with more time on the screens were at an early stage of retinal strain with more symptoms of digital eye strain and lower visual comfort. Moreover, the circadian rhythm was disrupted as the emergence of sleep was noticeably slower and the total amount of sleep was also diminished in those who spent a lot of time on the screens at night. The results highlighted how adolescents are easily susceptible to health hazards that blue light can cause physiologically and neurologically based on their exposure and abuse of devices and sensitive patterns of sleep and wakefulness. In addition, the research affirmed the relevance of the implementation of protective measures, including blue light filters and limited screen time, and particularly at night. These findings indicated that there is an urgent need to raise awareness and behavior change to promote ocular and sleep health in this population, which is getting more and more dependent on digital technology.

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