Original Article

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Physiology Section

Effect of Smartphone usage on Visual Fatigue Assessed by Critical Flicker Fusion Frequency among MBBS Students Aged 18-25 Years: A Pre-post Experimental Design

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ABSTRACT

Introduction: Prolonged smartphone usage has been linked to visual fatigue, primarily due to continuous exposure to blue light emitted from screens. Critical Flicker Fusion Frequency (CFFF) is a well-established physiological marker for assessing visual fatigue, where a decline in CFFF values indicates increased ocular strain and reduced visual efficiency. Medical students, who extensively use smartphones for both academic and personal activities, are particularly vulnerable to digital eye strain. Understanding the impact of sustained screen exposure on CFFF is essential for promoting visual health and implementing preventive strategies to mitigate screen-induced fatigue.

Aim: To assess the effect of one hour of smartphone usage on CFFF as a marker of visual fatigue among MBBS students aged 18-25 years.

Materials and Methods: This pre-post experimental study was conducted over a period of six months, from October 2023 to April 2024, at SRM Medical College and Hospital, Kattankulathur, Tamil Nadu, India involving 182 MBBS students aged 18-25 years with daily smartphone usage exceeding three hours. Baseline CFFF values were recorded using a flicker fusion apparatus, followed by one hour of smartphone usage that involved reading text and watching videos. Postexposure CFFF values were then measured under standardised conditions. Data were analysed using Statistical Package for the Social Sciences (SPSS) version 21.0 and a paired t-test was performed to assess statistical significance (p-value <0.05).

Results: A statistically significant reduction in CFFF was observed following one hour of continuous smartphone usage, indicating increased visual fatigue. The baseline CFFF values averaged 35.46±3.58 Hz, which declined to 25.91±3.50 Hz postexposure. The mean difference in CFFF values was 9.555±4.770 Hz, confirming a notable reduction in visual processing efficiency which was statistically significant (p-value of 0.001) highlighting the impact of prolonged smartphone exposure on visual strain and fatigue.

Conclusion: This study demonstrated that one hour of continuous smartphone usage leads to a measurable decline in CFFF, indicating significant visual fatigue. Implementing preventive strategies, such as the 20-20-20 rule, blue light filters and controlled screen brightness, may help mitigate screen-induced eye strain among medical students. Further research is recommended to explore the long-term impact of smartphone-induced ocular fatigue and its potential implications for digital eye health.

Keywords: Blue light, Digital ergonomics, Eye strain, Flicker

INTRODUCTION

In the era of artificial intelligence and digital advancements, smartphones have become an integral part of daily life, significantly influencing communication, work and learning. Their convenience and multifunctionality have led to widespread, prolonged use, particularly among college students and young adults [1]. However, increasing screen time raises concerns about its impact on visual health, particularly in the form of visual fatigue due to prolonged exposure to LED light emitted from smartphone screens [2]. The prevalence of social media and digital engagement continues to rise, with 4.89 billion users globally by 2023, representing 58.4% of the world's population. Additionally, 78% of users spend an average of two hours and 27 minutes per day on social media, primarily accessed via smartphones [3]. Given this upward trend, predictions indicate that social media use will continue to rise in 2025, further contributing to increased screen exposure and potential visual strain [4]. Considering this trend, it is crucial to understand the visual strain associated with digital screen exposure. One established method to evaluate visual fatigue is the measurement of CFFF, a widely used neurophysiological marker that reflects the ability of the human visual system to detect flickering light [5].

CFFF declines with visual stress and fatigue, making it a reliable tool for assessing the effects of prolonged screen exposure [6]. The process involves a coordinated response between the retina and the brain, where the eye detects flickering light and the brain processes it to determine whether the light appears continuous. Studies indicate that higher CFFF values correlate with better perceptual accuracy and reduced visual fatigue [6]. Long-term exposure to blue light from smartphone screens has been associated with visual discomfort, sleep disturbances and mood fluctuations, which may contribute to eye strain and visual fatigue [7]. Continuous screen exposure can also disrupt the circadian rhythm, leading to reduced melatonin levels, sleep impairment and cognitive inefficiency over time [8].

Although some studies report no significant physiological changes, night-time smartphone use has been shown to increase confusion, reduce drowsiness and elevate commission errors, highlighting its potential to adversely impact visual function [7]. Existing research on CFFF and screen exposure has yielded mixed findings. Previous literature has demonstrated that excessive screen time leads to a measurable decline in CFFF values, supporting the hypothesis that prolonged screen use induces visual fatigue [9]. However, certain studies suggest that changes in CFFF following screen exposure are not always statistically significant, necessitating further exploration of its reliability as a biomarker of visual fatigue [10,11]. Additionally, most prior research has focused on general populations, with limited data specifically examining medical students, who are a unique demographic due to their prolonged and intensive use of digital screens for academic purposes.

This study provides a unique contribution to the existing literature by specifically investigating the impact of smartphone usage on CFFF among MBBS students aged 18-25 years, a population highly dependent on digital devices for both education and leisure. Unlike previous research, this study focuses on one hour of smartphone exposure, allowing for a controlled assessment of short-term visual fatigue [12]. Additionally, while prior studies have assessed CFFF before and after screen use, few have examined its specific association with smartphone usage alone, making this study particularly relevant in the current digital age [12,13].

Given the increasing reliance on smartphones and digital devices, particularly among young adults, understanding changes in CFFF due to smartphone exposure is essential for monitoring visual health and developing preventive strategies. This study aimed to investigate the effect of one hour of smartphone usage on CFFF variations, providing insights into digital eye strain and its impact on medical students.

MATERIALS AND METHODS

This pre-post experimental study was conducted from October 2023 to April 2024 over a period of six months to assess CFFF among MBBS students in their second to final year, aged 18-25 years. The primary focus was to evaluate visual fatigue induced by one hour of smartphone usage. Participants were recruited from SRM Medical College and Hospital, Kattankulathur, Tamil Nadu, India with the objective of determining the relationship between CFFF values and prolonged digital screen exposure. Participants were informed of their right to withdraw at any time and no invasive or harmful procedures were involved.

The study received prior approval from the Institutional Ethics Committee (IEC) of SRM Medical College Hospital and Research Centre (Approval No: SRMIEC-ST0723-549). Written informed consent was obtained from all participants and ethical guidelines were strictly followed.

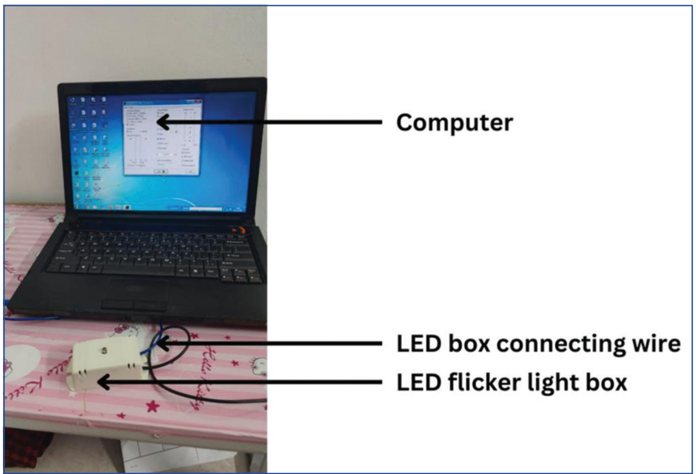
Inclusion criteria: A total of 182 MBBS students (aged 18-25 years) from their second to final year were recruited based on their daily smartphone usage exceeding three hours were included in the study.

Exclusion criteria: Students with pre-existing visual impairments (e.g., uncorrected refractive errors, glaucoma, or retinal disorders), neurological disorders (e.g., epilepsy, migraine, multiple sclerosis), or those taking medications that could affect visual processing (e.g., antiepileptics, sedatives, antipsychotics). These criteria ensured that CFFF measurements were not influenced by underlying medical conditions and were excluded from the study.

Sample size: For practical feasibility and based on previous research methodologies [2], the final study sample was set at 182 participants, ensuring sufficient statistical power for detecting significant changes in CFFF values. The study by Gautam D and Vinay D [2] used 160 participants, with a subset of 16 for pre-post analysis. Present study included 182 participants, which was larger than similar studies and ensures greater statistical validity.

Equipment and Test Procedure

CFFF values were measured using a flicker fusion apparatus [Table/Fig-1], a device specifically designed to deliver light stimuli at varying frequencies to determine the point at which flickering light is perceived as continuous [14]. The measurement was conducted using a standard electronic module that generated red-light stimuli at adjustable frequencies ranging from 12 to 120 Hz [15]. The system was controlled using SweepGen software, which automatically recorded performance data [16]. To ensure consistent contrast perception, the red-light stimulus was surrounded by a white background [17]. Participants were positioned at a fixed distance from the apparatus in a controlled environment to minimise external light interference [15].



[Table/Fig-1]: Flicker fusion apparatus setup used for CFFF measurement.
(Flicker fusion apparatus used for measuring Critical Flicker Fusion Frequency (CFFF). The device was connected to a laptop running SweepGen software, which modulated the light stimulus frequencies and recorded the responses automatically)

Participants were positioned 80 cm away from the stimulus in a semi-dark room, where a single 40 W bulb was placed behind them to eliminate external light interference. After a brief practice phase, the flicker frequency was gradually increased from the minimum threshold of 12 Hz until participants reported that the flickering light appeared constant or fused. The final frequency at which flickering was no longer perceived was recorded as the CFFF.

Performance data were automatically extracted from SweepGen software, with the last presented frequency used for analysis. This provided an accurate measure of the highest frequency at which participants could no longer perceive flickering, serving as the critical fusion threshold for each individual.

Baseline CFFF values were recorded before smartphone exposure. Participants then engaged in one hour of continuous smartphone usage, involving reading text and watching videos under controlled conditions. Postexposure CFFF values were subsequently recorded to measure changes in visual perception and fatigue [18].

To ensure standardised testing conditions, participants were seated in a controlled environment designed to eliminate external light interference, which could otherwise affect flicker fusion readings.

- **Ambient lighting control:** The testing room was set up with uniform, dim lighting to minimise variations in brightness and glare. No direct light sources or reflections were allowed in the participant's line of sight to ensure consistent flicker perception.
- **Screen brightness standardisation:** The smartphone screens were set to a fixed brightness level (50% of maximum) across all participants to reduce variations in luminance-induced fatigue. However, as different smartphone models were used, variations in display characteristics (such as refresh rate, pixel density and contrast levels) were not controlled, which may have introduced minor inconsistencies in screen exposure.
- **Viewing distance and angle:** Each participant was instructed to maintain a fixed distance (30-40 cm) from the screen and a neutral gaze angle, ensuring uniform eye strain conditions across participants.

- **Noise and distraction control:** Testing was conducted in a quiet room to eliminate external distractions, allowing participants to focus solely on the flicker perception task.
- **Device consistency for CFF measurement:** The same flicker fusion apparatus was used for all participants to ensure consistency in CFFF measurements and eliminate device-related variability in flicker frequency generation.

These standardisation measures ensured that external environmental factors did not influence CFFF measurements, thereby improving the reliability and reproducibility of results. However, due to the use of different smartphone models, variations in display properties could not be fully standardised, which remains a limitation of the study.

STATISTICAL ANALYSIS

Data analysis was conducted using paired t-tests to compare baseline and postexposure CFFF values. Statistical analysis was done by SPSS version 21.0, ensuring a precise evaluation of perceptual sensitivity changes related to smartphone-induced visual fatigue [10]. This statistical method was selected due to its suitability for assessing within-subject variations in visual fatigue induced by prolonged screen usage. A p-value of <0.05 was considered statistically significant for determining meaningful differences in CFFF before and after smartphone exposure.

Category	n (%)
Male participants	92 (50.55)
Female participants	90 (49.45)

[Table/Fig-2]: Gender distribution of study participants (N=182).

RESULTS

A total of 182 MBBS students (aged 18-25 years, second to final year) participated in the study. The mean age of participants was 21.5±2.3 years. The gender distribution is shown in [Table/Fig-2].

Condition	Mean±SD	N	Std. Error mean
CFFF before	35.46±3.584	182	0.266
CFFF after	25.91±3.503	182	0.26

[Table/Fig-3]: Descriptive statistics of CFFF values (in Hz) before and after one hour of smartphone exposure.

The baseline CFFF values, recorded before smartphone usage, averaged 35.46±3.584 Hz, while postexposure CFFF values dropped to 25.91±3.503 Hz. This indicates a significant increase in visual fatigue following smartphone exposure [Table/Fig-3].

Condition	Mean difference	Std. Deviation	Std. Error mean	95% CI lower	95% CI upper	t	df	p-value
CFFF before - CFFF after	9.555	4.77	0.354	8.857	10.253	27.022	181	<0.001

[Table/Fig-4]: Paired t-test results for pre- and postexposure CFFF values (in Hz).

The reduction in CFFF values was statistically significant (p-value <0.001, [Table/Fig-4]), confirming that the observed effect was unlikely to be due to chance. The decline in CFFF highlights the visual fatigue induced by prolonged screen exposure, with no confounding variables such as ambient lighting or screen brightness inconsistencies, as standardised conditions were maintained throughout the study.

These findings align with previous research, demonstrating that prolonged exposure to smartphone screens, particularly with blue light emission, contributes to visual fatigue. This is evident in the marked reduction in flicker fusion thresholds, indicating increased visual stress.

The decline in CFFF suggests that extended screen exposure impairs visual processing efficiency, which may have implications for students engaged in long study sessions, clinical tasks, or digital learning. This study reinforces the need for preventive measures such as the 20-20-20 rule, blue light filters, screen brightness adjustments and scheduled breaks to reduce visual strain and maintain optimal eye health.

A paired t-test was conducted to compare pre- and postexposure CFFF values. The results demonstrated a significant decrease in CFFF values after smartphone exposure (p-value <0.001), confirming that the observed effect was unlikely to be due to chance [Table/Fig-4]. The mean difference in CFFF before and after smartphone usage was 9.555 Hz.

These findings confirm a statistically significant reduction in CFFF values, indicating a 27% decline in visual processing efficiency due to prolonged smartphone exposure. Additionally, standardised testing conditions eliminated potential confounding variables, such as variations in ambient lighting and screen brightness, ensuring the validity of the findings.

DISCUSSION

The present study reveals significant findings regarding the impact of smartphone usage on CFFF among MBBS students. The observed reduction in CFFF values from 35.46 Hz to 25.91 Hz after 60 minutes of screen exposure highlights the potential adverse effects of prolonged smartphone usage on visual processing and ocular fatigue. This decline was consistent with findings from previous studies that report a significant reduction in CFFF values following extended digital screen exposure, attributed primarily to retinal stress and visual fatigue [2].

Prolonged exposure to blue light (400-500 nm) has been implicated in ocular strain and visual discomfort, primarily through photochemical reactions that increase oxidative stress in retinal cells. Blue light exposure has been shown to trigger the production of reactive oxygen species, lipid peroxidation and apoptosis of photoreceptor cells. The extent of damage depends on both exposure duration and intensity. Previous literature has categorised this damage into two types: long-term, low-irradiance exposure affecting photoreceptors and short-term, high-irradiance exposure damaging the retinal pigment epithelium. These mechanisms align with the present findings, which demonstrate a substantial decline in CFFF values after smartphone use, suggesting that even relatively short periods of exposure may have measurable effects on visual processing [2].

Visual fatigue is a key factor contributing to the observed reduction in CFFF values. Prolonged near-focus tasks, such as smartphone usage, induce sustained contraction of ocular muscles, leading to eye strain and fatigue. This effect has been extensively documented in individuals aged 18-25 years, who exhibit significant decreases in CFFF following continuous screen engagement. In the present study, the impact of smartphone screen size on visual fatigue was not specifically analysed. However, existing literature suggests that screen size alone does not significantly influence the degree of visual fatigue, as the primary determinant remains the duration of screen exposure. Factors such as gaze angles and usage patterns across devices are likely to play a more substantial role in visual strain rather than variations in screen dimensions [19,20].

While some studies have linked sustained digital exposure to cognitive fatigue, this study primarily assessed CFFF as a marker of visual fatigue rather than cognitive performance [11,21]. The decline in CFFF reflects ocular strain and a temporary reduction in visual processing efficiency rather than deficits in cognitive function. Although visual attention and perceptual speed are influenced by sustained screen use, these parameters were not directly measured in this study. Thus, while existing literature suggests a possible association between prolonged digital exposure and reduced visual attention capacity, further research would be required to confirm such relationships [5,22,23].

Higher CFFF values are generally associated with frequent screen use, as visual sensitivity and reaction times tend to improve with training. However, excessive screen exposure, particularly when coupled with sleep deprivation and prolonged study hours, has been shown to reduce CFFF, leading to increased visual fatigue and a temporary decline in visual performance. Studies indicate that the typical CFFF range for young adults is between 30-40 Hz [10], which aligns with the baseline values observed in this study. The significant reduction in postexposure CFFF values emphasises the measurable impact of smartphone use on visual fatigue. The present findings also align with previous research indicating that reduced CFFF values correlate with digital eye strain rather than cognitive inefficiency [10,11].

The observed decline in CFFF suggests that extended screen exposure significantly impairs visual processing efficiency, which may have implications for students engaged in long study sessions, clinical tasks, or digital learning. These results emphasise the need for preventive measures, such as:

- The 20-20-20 rule (taking a 20-second break every 20 minutes and looking at something 20 feet away).
- Blue light filters to reduce retinal stress.
- Screen brightness adjustments to optimise visual comfort.
- Scheduled breaks to reduce visual strain and maintain optimal eye health.

Given these findings, it is crucial to implement preventive strategies to reduce screen-induced visual fatigue among students. Institutions should consider integrating structured breaks into academic schedules, following the 20-20-20 rule and promoting awareness of digital eye health [24].

While the feasibility of implementing such strategies within academic settings remains a challenge, institutions could adopt policies regulating digital device use during lectures and study sessions, ensuring that students incorporate regular screen breaks. Additionally, mobile applications designed to enforce structured screen time management could be introduced as part of academic wellness programmes. Ergonomic positioning while using digital devices, coupled with institutional policies encouraging balanced screen time, could help preserve both visual performance and ocular health [25].

Creating a culture that prioritises visual wellbeing through institutional interventions and awareness campaigns is essential not only for enhancing academic performance but also for ensuring long-term professional success in visually demanding fields such as medicine.

Limitation(s)

This study had several limitations that should be considered. Self-reported smartphone usage may introduce recall bias, affecting the accuracy of the results. The study did not account for other blue light sources, such as computers and artificial lighting, making it difficult to isolate the effects of smartphone exposure. Additionally, the absence of a control group limits the ability to attribute observed CFFF reductions solely to smartphone use. The study assessed only short-term screen exposure (60 minutes), which may not reflect long-term effects on visual processing and eye health. Future research should incorporate objective tracking methods, a cumulative blue light exposure analysis and control groups to improve the reliability of the study.

CONCLUSION(S)

This study demonstrated that one hour of smartphone use significantly reduces CFFF values, indicating visual fatigue. The findings reinforce concerns about digital eye strain, particularly among medical students who rely heavily on screens. Adopting preventive strategies, such as the 20-20-20 rule, blue light filters and structured breaks, can help mitigate visual strain. Future research should explore long-term effects and personalised interventions to enhance visual resilience in high-exposure groups.

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