

Tear Film Dysfunction and its Association with Smartphone Usage in Adolescents

Sharma Srishti¹, Singh Anupam¹, Mishra Shreya¹,
Narang Kirti¹, Agrawal Ajai¹, Kumari Ranjeeta³, Barun Kumar⁴

¹Department of Ophthalmology, All India Institute of Medical Sciences, Rishikesh, India

²Department of Ophthalmology, AIIMS Rishikesh, Uttarakhand, India

³Department of Community and Family Medicine, All India Institute of Medical Sciences, Rishikesh, India

⁴Department of Cardiology, All India Institute of Medical Sciences, Rishikesh, India

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First author:
Dr. Srishti Sharma, MBBS

Corresponding author:
Prof. Dr. Anupam Singh
Ophthalmology Department
AIIMS Rishikesh
Uttarakhand
India
E-mail dr.anupamsingh@gmail.com

SUMMARY

Aim: The study aimed to explore the association between duration of smartphone usage and tear film parameters in adolescents through a hospital-based cross-sectional study.

Material and methods: A detailed history regarding smartphone usage was obtained, followed by tear film assessment for all the study participants. Tear meniscus height (TMH), Tear film break up time (TBUT), and Schirmer's I test were done for all participants. Then they were classified into four groups, based on daily smartphone usage: < 2 hours/day, 2–4 hours/day, 4–6 hours/day, and > 6 hours/day.

Results: 123 smartphone users of the adolescent age group aged 10–19 years (mean age: 16.6 ± 2.8 years) were included. The mean values of tear film parameters were as follows: TMH was 0.25 ± 0.1 mm, Schirmer's I was 17.7 ± 9.2 mm, and TBUT was 10.5 ± 5.7 seconds. Participants using smartphones for > 6 hours/day had a significantly higher prevalence of reduced TMH (< 0.25 mm) compared to those with lower usage durations ($p < 0.0001$). Similar trends were observed for Schirmer's I and TBUT values, indicating a statistically significant association between prolonged smartphone use and tear film dysfunction ($p < 0.0001$). Notably, 72.7% of eyes in the > 6 hours/day group exhibited tear film dysfunction, significantly higher than in other groups.

Conclusion: Prolonged smartphone use adversely affects tear film stability and ocular surface health in adolescents. Awareness and appropriate measures to limit excessive screen time are essential to prevent tear film dysfunction and associated ocular discomfort.

Key words: tear film dysfunction, TBUT, adolescents, smartphone usage.

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INTRODUCTION

Smartphones have become an indispensable part of modern life, with their usage growing exponentially among youth worldwide [1,2]. The widespread adoption of smartphones among adolescents has led to a marked increase in screen time, compared to traditional mobile phones, as these devices offer diverse functionalities beyond mere communication [3]. Activities such as reading, watching videos, social networking, and attending virtual classes demand prolonged visual engagement, contributing to extended digital exposure. While the COVID-19 pandemic initially drove a surge in digital device use, this pattern has continued post-pandemic, with screen time among youth steadily increasing as digital devices remain integral to education, communication, and en-

tertainment. These patterns are especially worrisome for adolescents (aged 10–19 years), as numerous studies suggest that behaviors established during this critical developmental stage tend to persist into later life [4]. Therefore, contemporary adolescents are anticipated to experience greater lifetime exposure to smartphones in the future, and there exists a deficiency in awareness concerning prudent smartphone usage among the youth.

Notably, a recent meta-analysis reported that 19.7% of children experienced asthenopic symptoms, reflecting a significant burden of visual fatigue in this age group [5,6]. Binocular functions, including near point of convergence, accommodative convergence /accommodation (AC/A) ratio, and binocular accommodative facility, are more likely to exhibit abnormalities with prolonged smartphone use, particularly when usage exceeds six

hours per day [6]. Prolonged smartphone engagement may lead to Acute Acquired Concomitant Esotropia, as sustained near work can disturb the balance between accommodation and vergence, particularly in younger individuals [7]. A study investigated the relationship between smartphone-based video gaming and strabismus in children aged 4 to 10 years. The study found that 40% of the participants used smartphones for video gaming more than 2 hours daily. Among these, 59.5% had exotropia, 27% had esotropia, and 13.5% exhibited combined deviations. Statistical analysis revealed a significant association between over 2 hours of daily smartphone gaming and the occurrence of exotropia in these children [8]. Prolonged screen exposure in children has also been significantly linked to reduced tear break-up time (TBUT) and decreased blink rate, which are key contributors to tear film dysfunction and the development of dry eye disease (DED) [9].

DED is a complex, multifactorial condition that occurs when the natural balance of tear film production, distribution, and drainage is disrupted. It is associated with various symptoms and clinical signs, including tear film instability, ocular surface inflammation, and neurosensory abnormalities [10]. While DED can occur across all age groups, it is considerably less common in children than in adults [11]. However, with the steady rise in screen time, this trend is shifting, and the younger population is increasingly being recognized as an at-risk group for developing DED [12]. Unlike conventional mobile phones, smartphones require sustained visual attention, leading to prolonged near-work and reduced blink rates. Excessive smartphone use has been shown to negatively impact tear film dynamics by decreasing blink rate, causing incomplete eye closure, and increasing ocular surface exposure [1,13]. Studies have linked excessive screen time to digital eye strain and DED, with growing evidence suggesting that children and adolescents who frequently use smartphones are at a heightened risk of developing tear film dysfunction [14].

Adolescents (aged 10–19 years) are particularly vulnerable to DED due to their increasing reliance on digital screens for education, communication, and recreation. This age group is in a critical phase of visual development, and sustained near work on screens, often without regular breaks, can significantly reduce blink rate and promote incomplete blinking, both accelerating tear film evaporation. The early onset of DED in this age group can have long-lasting implications. Studies have shown that visual disturbances caused by DED, such as blurred vision, light sensitivity, and difficulty in concentrating can severely affect school performance, self-esteem, and overall quality of life [15]. Given the formative nature of this developmental window, unaddressed dry eye symptoms could contribute to persistent ocular surface dysfunction and chronic visual strain well into adulthood.

The impact of digital device usage on dry eye symptoms is well-documented in adults. However, the specific effects on younger populations, particularly concerning

tear film dynamics, remain inadequately explored [16]. Therefore, this hospital-based cross-sectional study explored the association between duration of smartphone usage and tear film function in adolescents aged 10–19 years. By assessing key tear film parameters, this study aims to provide insights into the ocular health implications of prolonged smartphone use in this age group and to highlight the need for preventive strategies and increased awareness to mitigate potential risks.

MATERIAL AND METHODS

The study followed the Guidelines of the Indian Council of Medical Research for ethical biomedical research on human subjects. This hospital-based cross-sectional study was conducted between May 2021 and November 2022, using a cross-sectional approach, in a tertiary care hospital of North India. The target population comprised adolescents (aged 10–19 years), attending the ophthalmic outpatient department, and having a history of smartphone use (for more than 6 months, but less than 2 years). Eligibility criteria included adolescents aged 10–19 years with a history of regular smartphone use, with best-corrected visual acuity (BCVA) of 6/6 or better, and near vision of N6 or better. Adolescents with a history of exposure to other digital screens (such as computers, tablets, and laptops), clinical evidence of strabismus, previous ocular surgery, amblyopia therapy, history of contact lens use, using tear substitutes, refractive error beyond the range of ± 6 D or any other ocular co-morbidity that could independently affect tear film stability were excluded from the study. The study adhered to the tenets of the Declaration of Helsinki and approval from the Institutional Ethics Committee was obtained (letter number AIIMS/IEC/21/ 247 dated 15/05/2021). Written informed consent was obtained from participants aged 18 years and older. Assent was obtained from those below 18 years of age, along with consent from their parents/guardians.

All patients underwent basic ophthalmic work-up, including visual acuity assessment with best refractive correction and anterior and posterior segment examination. A detailed history was obtained from all the participants, including the type of smartphone use, duration of smartphone use, and average number of hours spent on the smartphone. Based on self-reported screen time over the past six months, participants were categorized into four groups: < 2 hours/day, 2–4 hours/day, 4–6 hours/day, and > 6 hours/day.

Tear Film Meniscus Height (TMH) was measured, using a slit-lamp biomicroscope with an illuminated horizontal slit beam aligned with the lower lid margin. The beam width was adjusted to match the height of the tear prism. A TMH value of < 0.25 mm was considered abnormal.

Tear Film Breakup Time (TBUT) was performed, using fluorescein strip paper moistened with one drop of balanced salt solution and applied to the lower conjunctival

sac, using the cobalt blue filter of a slit-lamp biomicroscope. The time interval between the last blink and the appearance of the first dry spot on the cornea was recorded. The measurement was repeated three times for eye testing, and the mean value of the three measurements was taken as the final. A value of less than 10 seconds was considered abnormal.

Schirmer's I was performed simultaneously for both eyes with standard Whattman no 41 filter paper strips, by placing it on the inferior fornix at the junction of the medial two-thirds and the lateral one-third of the lower lid margin for 5 minutes. A value of less than 10 mm was considered abnormal.

STATISTICAL ANALYSIS

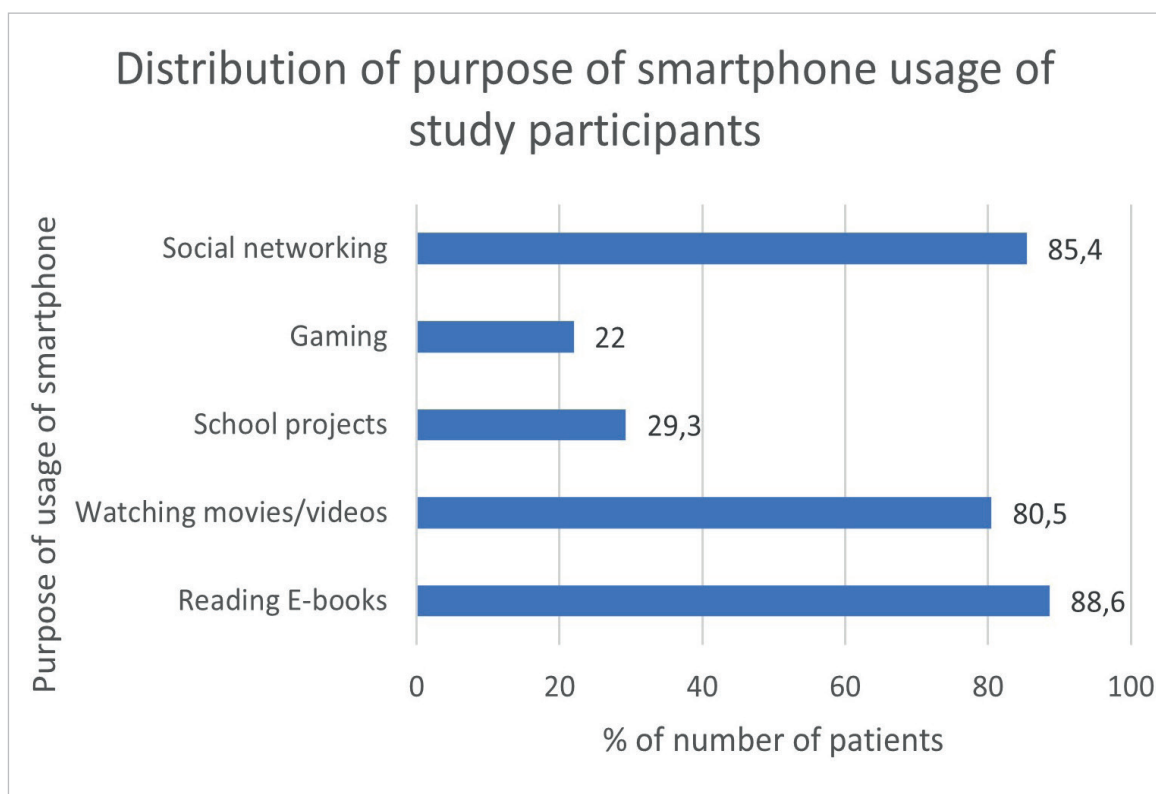
Statistical Package for Social Sciences (SPSS) software, IBM manufacturer, Chicago, USA, version 25.0, was used for the statistical analysis. The Kolmogorov-Smirnov test was used to check the normal distribution of data. Categorical variables were presented as numbers and percentages (%). Quantitative data were presented as mean \pm SD and median with 25th and 75th percentiles (interquartile range). Non-parametric tests were applied where the data was not normally distributed. The Kruskal-Wallis test (for more than two groups) was used to assess the association of quantitative variables that were not normally distributed. Fisher's exact test was used for an expected

value of < 5 . Any p-value less than 0.05 was considered statistically significant.

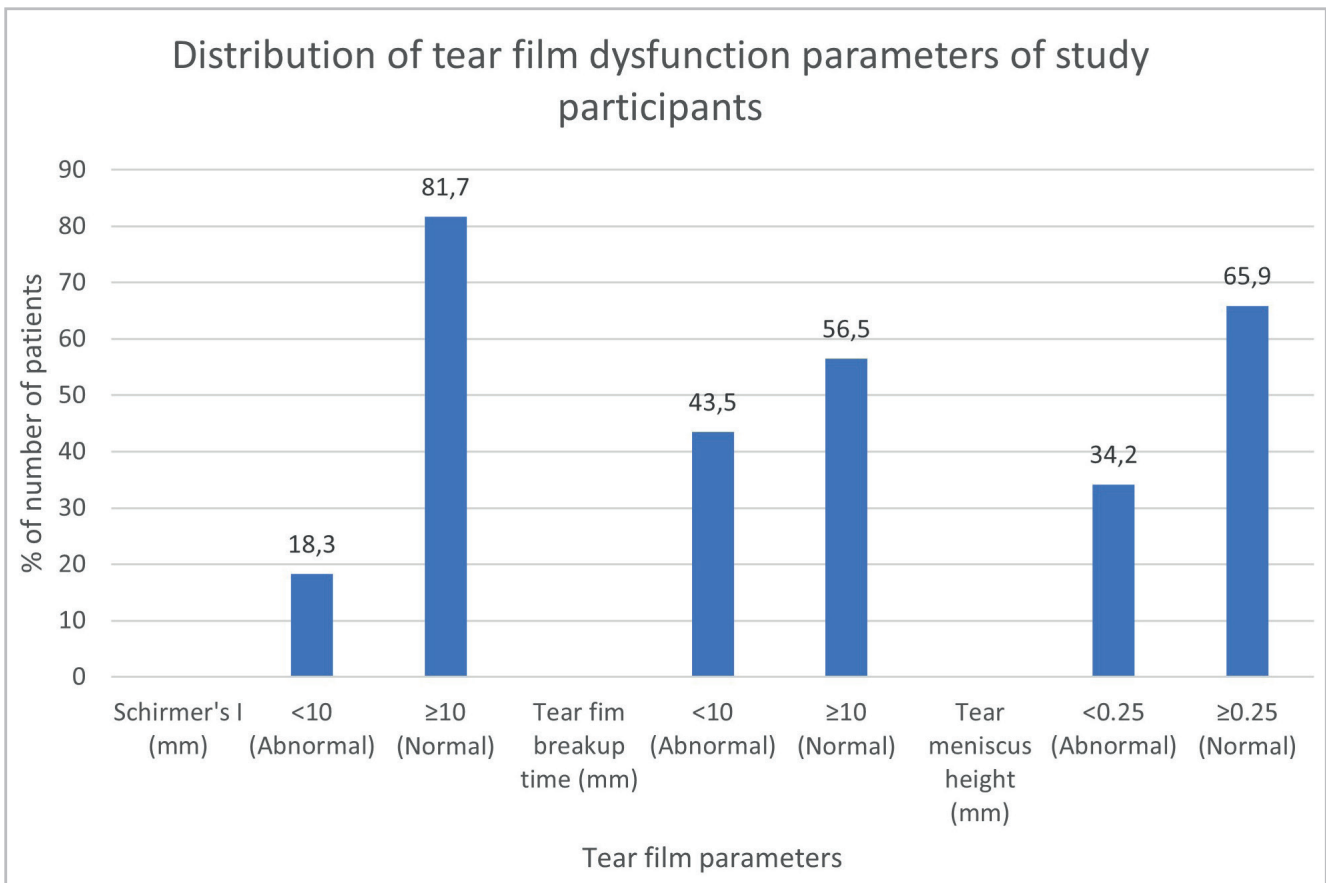
RESULTS

The study included 123 participants, comprising 52% males and 48% females, with a mean age of 16.9 ± 2.8 years, ranging from 10 to 19 years. The mean spherical equivalent of the study population was $+0.5 \pm 6.6$ DS, and patients were compliant with their best refractive correction. The distribution of smartphone usage among participants was maximum for more than 6 hours/day (60.98%, $n = 75$), followed by 2–4 hours/day (17.1%, $n = 21$), 4–6 hours/day (15.5%, $n = 19$), and ≤ 2 hours/day (6.5%, $n = 8$), depicting increased screen time for long hours in most of the participants.

The most common purpose for smartphone use among participants was for reading e-books and social media, followed by watching videos, gaming, and other uses, such as school projects, reflecting the dominance of educational and social interaction-related smartphone usage in this adolescent age group (Graph 1). Graph 2 shows the graphical representation of the tear film parameters in the study participants, depicting that TBUT was the most common deranged parameter (43.5%). Approximately 34% of participants had a TMH of < 0.25 mm; abnormal TBUT (< 10 seconds) was seen in 43.5% of the population, whereas Schirmer's I of < 10 mm was present in 18.3%.



Graph 1. Bar graph depicting the distribution of the purpose of smartphone usage among participants, with the percentage of participants being depicted on the y axis and study participants being denoted on the x axis



Graph 2. Bar graph representing distribution of tear film dysfunction parameters denoting % of participants (on y axis) versus tear film parameters including tear meniscus height, Schirmer's I, and tear film breakup time (on x axis)

The mean value of TMH among participants was 0.25 ± 0.1 mm, Schirmer's I was 17.7 ± 9.2 mm, and TBUT was 10.5 ± 5.7 seconds. The TMH was > 0.25 mm in 65.9% of eyes and < 0.25 mm in 34.2%, while Schirmer's I was > 10 mm in 81.7% of eyes and < 10 mm in 18.3%. TBUT was > 10 seconds in 56.5% of eyes and < 10 seconds in 43.5%.

The association of deranged tear film parameters with the duration of smartphone usage is shown in Table 1. A significant association was found between smartphone use duration and derangement of tear film parameters. TMH in participants using smartphones for > 6 hours/day had a value < 0.25 mm in a much higher number, when compared to those using smartphones for < 2 , 2–4, or 4–6 hours/day ($p < 0.0001$). Similarly, for Schirmer's I, those with values < 10 mm was significantly higher in the > 6 hours/day group, compared to the lower usage categories ($p < 0.0001$). For TBUT, the proportion of participants with values < 10 seconds was also significantly higher in the > 6 hours/day group, compared to the other groups ($p < 0.0001$). (Table 1).

In terms of tear film dysfunction, the proportion of participants with dysfunction was significantly higher in the > 6 hours/day group, with 72.7% of eyes showing abnormal parameters compared to other groups ($p < 0.0001$).

Thus, these results indicate a significant association between longer smartphone usage and increased tear film dysfunction, as evidenced by decreased TMH, Schirmer's I, and TBUT values, and a higher incidence of tear film dysfunction in participants using smartphones for > 6 hours/day.

DISCUSSION

Since their introduction in the late 2000s, smartphones have seen a rapid and widespread increase in usage. Smartphones have become an essential part of daily life, but the increasing time spent on these devices, particularly among adolescents, has raised concerns about their potential impact on ocular health [1].

With the widespread adoption of smartphones, newer research has identified connections between smartphone use and ocular health. Excessive smartphone use has been implicated in the development of acute acquired comitant esotropia among children and adolescents [7]. Binocular visual dysfunctions are more common with extended smartphone use, especially when daily usage exceeds six hours [6]. In a study on pediatric DED, children with DED spent significantly more time on smartphones than those without DED [12]. A study examining the link

Table 1. Association of tear film dysfunction parameters with duration of smartphone usage (hours/day)

Tear film dysfunction parameters	Daily duration of usage of smartphone (hours/day)					p-value
	< 2 (n = 16)	2 to 4 (n = 42)	4 to 6 (n = 38)	> 6 (n = 150)	Total	
Tear meniscus height (mm) {Abnormal/Normal}						
< 0.25 mm {Abnormal}	0 (0%)	1 (2.4%)	0 (0%)	83 (55.3%)	84 (34.2%)	<.0001†
≥ 0.25 mm {Normal}	16 (100%)	41 (97.6%)	38 (100%)	67 (44.7%)	162 (65.9%)	
Mean ±SD	0.32 ±0.07	0.32 ±0.06	0.32 ±0.05	0.2 ±0.07	0.25 ±0.08	<.0001§
Median (25 th –75 th percentile)	0.3 (0.25–0.36)	0.3 (0.3–0.35)	0.3 (0.3–0.35)	0.2 (0.15–0.25)	0.25 (0.2–0.3)	
Range	0.25–0.45	0.2–0.45	0.25–0.4	0.1–0.4	0.1–0.45	
Schirmer's I (mm) {Abnormal/Normal}						
< 10 mm {Abnormal}	0 (0%)	0 (0%)	0 (0%)	45 (30%)	45 (18.3%)	<.0001*
≥ 10 mm {Normal}	16 (100%)	42 (100%)	38 (100%)	105 (70%)	201 (81.7%)	
Mean ±SD	26.7 ±7.1	24.9 ±5.1	26.3 ±4.1	12.6 ±7.4	17.7 ±9.2	<.0001§
Median (25 th –75 th percentile)	29.5 (21.5–32.3)	25 (22.3–27.8)	26.5 (23.3–30)	12 (7–16)	17.5 (11–25)	
Range	13–34	11–33	15–32	1–35	1–35	
Tear film break up time (seconds){Abnormal/Normal}						
< 10 sec {Abnormal}	4 (25%)	3 (7.2%)	4 (10.5%)	96 (64%)	107 (43.5%)	<.0001†
≥ 10 sec {Normal}	12 (75%)	39 (92.9%)	34 (89.5%)	54 (36%)	139 (56.5%)	
Mean ±SD	14.9 ±5.5	14.2 ±4.0	15.3 ±4.2	7.8 ±4.7	10.5 ±5.7	<.0001§
Median (25 th –75 th percentile)	15.5 (11.3–20)	15 (11.3–17)	16 (12–18)	8 (4–10)	10 (6–15)	
Range	6–22	3–22	6–22	1–18	1–22	

*Fisher's exact test, † Chi square test, § Kruskal Wallis test

between smartphone-based video gaming and strabismus in children aged 4 to 10 years demonstrated a significant correlation between excessive smartphone gaming (over 2 hours daily) and the development of exotropia in this age group [8]. The significant increase in screen time over recent years has raised questions about its effects on tear film function. To date, limited studies have specifically examined this association in adolescents.

In our study, 93.5% of participants used smartphones for more than 2 hours per day, with the majority (61.0%) using smartphones for over 6 hours daily. This finding is consistent with the increasing trend of prolonged smartphone use seen in studies by J. Kim et al., Golebiowski et al., Moon et al., Long et al., where digital device usage has been associated with various ocular problems, including DED [1,12,17,18]. Furthermore, Moon et al. reported that the prevalence of DED was higher in older children from the urban region, and that the symptoms and signs of DED improved after cessation of smartphone use for 4 weeks [12].

Similarly, we found a significant association between longer smartphone use and worsening of all three tear film parameters, including TMH, Schirmer's I, and TBUT. Specifically, participants using smartphones for more than 6 hours per day had significantly lower values of TMH (< 0.25 mm), Schirmer's I (< 10 mm), and TBUT (< 10 seconds), compared to those using smartphones for shorter durations. These findings align with previous

studies, such as those by Jung Han Choi et al., Moon et al., and S. Khezrzade et al., which reported a decrease in TBUT as the duration of smartphone and screen time use increased [12,13,19]. However, these results contrast with a study by Golebiowski et al., that found no significant change in TBUT after 60 minutes of smartphone reading [17]. The discrepancy may be attributed to differences in study design, device type, or shorter duration of smartphone usage (60 minutes).

Cardona et al. found a statistically significant reduction in spontaneous blink rate, TMH and TBUT after just 20 minutes of computer use, suggesting that even relatively short durations of screen exposure can impact tear film function [20]. They assumed that the combined effect of a reduced blink rate and an increase in the incomplete blink rate may result in excessive evaporation of tears from the ocular surface and a reduced expression of tear film components, thus negatively affecting both the quality and volume of the tear film. Furthermore, the study suggested that the dynamic visual tasks on a visual display terminal may have a more pronounced effect on tear quality (as measured with BUT and NIBUT tests) than tear volume.

Similarly, we observed that among all three tear film parameters, there was a more pronounced reduction of TBUT than the other two parameters, TMH and Schirmer's I. This finding contradicts the results of Golebiowski et al. and Choi et al., where no significant TMH changes were reported [14,17].

In terms of tear film dysfunction, we observed that the proportion of participants with tear film dysfunction was significantly higher in those using smartphones for > 6 hours/day, with 72.7% of eyes showing dysfunction compared to just 25%, 7.1%, and 10.5% in the < 2, 2–4, and 4–6 hours/day groups, respectively. These results are consistent with previous studies that have highlighted the role of excessive screen time in the development of dry eye symptoms, particularly in younger individuals. The high prevalence of tear film dysfunction in heavy smartphone users underscores the need for preventive measures, including screen-time moderation, frequent blinking, and ocular surface hydration strategies to mitigate the risk of developing DED-like symptoms. One of the strategies that can be used to mitigate the effects, such as eye strain, due to excessive smartphone use, can be to follow the 20-20-20 rule, which advises users to take a 20-second break every 20 minutes by looking at an object at least 20 feet away. This practice helps to relax the ciliary muscles and reduces accommodative stress. This method is an effective, low-cost behavioral intervention for preventing digital eye strain [21]. Recent literature also emphasizes its role in maintaining tear film stability and reducing blink rate-associated dryness among smartphone users [22].

Our findings suggest that excessive smartphone usage is strongly associated with tear film dysfunction in adolescents, as evidenced by significant alterations in TMH, Schirmer's I, and TBUT values. Prolonged screen time, particularly in excess of 6 hours per day, appears to be a significant risk factor for ocular surface instability and dry eye symptoms in this age group.

Nevertheless, further large-scale, community-based studies are required to validate these results and to explore additional contributing factors, such as lighting conditions, smartphone viewing distance, and posture. Future research should also investigate longitudinal effects to determine whether early-onset tear film changes may predispose adolescents to chronic dry eye disease in adulthood.

CONCLUSION

Our study demonstrates that prolonged smartphone usage has a significantly negative impact on ocular health in adolescents, particularly in terms of tear film dysfunction. Adolescents who use smartphones for more than 6 hours per day exhibit notable reductions in TBUT, TMH, and Schirmer's I scores, indicating compromised tear film stability and increased risk of DED.

To mitigate these adverse effects, it is recommended that smartphone usage be limited to less than 2 hours per day to help preserve tear film integrity and maintain a healthy ocular surface. Adopting screen hygiene practices – such as taking regular breaks, increasing blink frequency, and optimizing screen brightness and ambient lighting – may reduce the risk of digital eye strain and tear film dysfunction.

Given the increasing reliance on digital devices in the future, further long-term, community-based studies are needed to establish causal relationships and to develop more specific guidelines for safe and sustainable smartphone usage among adolescents.

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