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Closing eyes with artificial tears: A simple and effective strategy to combat screen-related asthenopia and dry eye symptoms

Ning Wang [a,1], Jinjin Min [b,1], Xiaojing Fan [b], Xiuming Jin [a,*]

[a] Eye Center, The Second Affiliated Hospital of Zhejiang University School of Medicine, Zhejiang Provincial Key Laboratory of Ophthalmology, Zhejiang Provincial Clinical Research Center for Eye Diseases, Zhejiang Provincial Engineering Institute on Eye Diseases, Hangzhou, China
[b] Zhejiang University, Hangzhou, China

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ABSTRACT

Background: The widespread use of various video display terminals (VDTs) always had a detrimental impact on ocular health. Prolonged use of smartphones has been one of the leading causes of dry eye (DE) and asthenopia. Therefore, the purpose of this study is to find a simple and effective strategy to combat screen-related DE and asthenopia.

Methods: A group of healthy participants aged 18 and above were randomly assigned to three groups and tasked with a 2 h smartphone reading task. After 1 h of usage, each group adopted different methods of rest: no rest (Group A), a 10 min eye-closed rest (Group B), or a 10 min eye-closed joint artificial tears rest (Group C). Ophthalmological examinations and questionnaires were administered to all participants before and after the 2 h reading task.

Results: 90 qualified volunteers, including 29 males and 61 females, were randomly assigned to three groups. Group A demonstrated a significant increase in the severity of DE and asthenopia as evidenced by all the evaluated indices. On the other hand, Group C did not exhibit any notable change in DE and asthenopia symptoms, with an improvement in corneal fluorescein staining (CFS) results ($P > 0.05$) when compared to the pre-reading values. Group B showed a significant increase in ocular surface disease index (OSDI) ($P \leq 0.05$) and a decrease in critical flicker frequency (CFF) ($P \leq 0.05$).

Conclusions: Close-eye rest with artificial tears may be a convenient and effective prevention strategy for screen-related DE and asthenopia.

1. Introduction

The widespread adoption of smartphones has connected 4.54 billion people to these devices, making them an integral part of daily life.[1] However, the increasing use and dependence on VDTs, including smartphones, has raised concerns about their impact on human health.[2,3] A series of ocular and extraocular symptoms caused by long-time use of VDTs are called video display terminal syndrome (VDTS), the main ocular manifestations are DE and asthenopia.

VDTS was highly prevalent among college students, with young individuals and those who used VDTs for extendedd periods being the most affected.[4–6] The occurrence of VDTS could pose significant challenges to populations' visual acuity, impacting their daily work and learning.[7] Current studies indicated that VDT-induced DE was caused by decreased blink rate,[8] blue light affecting corneal epithelial cell viability,[9] and increased ocular surface inflammatory response.[10] However, it is important to note that these effects could vary depending on the specific type of device and its usage mode.[11] Factors such as screen time, viewing position (including distance and angle), cognitive needs, screen resolution and contrast, image refresh rate, screen size, brightness, as well as spectral and other digital characteristics, could all influence the severity of dry eye symptoms.[11] VDT includes different types of devices such as computer monitors, smartphones, tablets, and televisions. Generally, the screen size of smartphones is much smaller than that of other VDTs, with an average size of approximately 5 inches.[12] Due to visual suppression associated with amplitude saccades, the blink rate under smartphone use may be lower than that under other VDTs.[13] Additionally, the lighting level for VDTs use should ideally be half of the normal classroom lighting

* Corresponding author. Eye Center, The Second Affiliated Hospital of Zhejiang University School of Medicine, Hangzhou, China.
E-mail address: lzyjxm@zju.edu.cn (X. Jin).
[1] These authors contributed equally.

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level, as higher lighting levels may lead to excessive glare and difficulties in visual adaptation.[14,15] The brightness of smartphones can be automatically adjusted or manually controlled, whereas in computers, it is typically fixed and users do not frequently change it.[16] If the brightness setting of a smartphone is too high, it may increase the issue of glare, negatively impacting eye comfort and visual health. The distance between the eyes and the screen can also affect the focusing system of the eyes and may result in adaptation issues, including accommodative spasms.[17] Compared to other VDTs, smartphones are used at a closer working distance, which may more easily induce abnormalities in accommodation and convergence capabilities.[18] Therefore, it is expected that DE would be more severe following smartphone use compared to other VDTs.

However, current treatments for DE and asthenopia caused by VDTs had limited efficacy, making preventative measures the best way to cope with the disease. In our previous studies, we focused on the effect of screen performance and found that circularly polarized screens and eINK screens can minimize subjective discomfort and ocular surface disorders when reading on smartphones.[19,20] However, considering the issue of penetration rate, we aimed to identify a simple, convenient, and effective prevention strategy. Thus, we designed the following experiments to determine a better reading pattern that could reduce the damage caused by long-time smartphone reading. This study provided new ideas for preventing DE and asthenopia during long-time smartphone reading.

2. Materials and methods

2.1. Subjects

This prospective randomized controlled study was carried out at the Eye Center of the Second Affiliated Hospital of Zhejiang University School of Medicine from September 2020 to December 2020. The study protocol adhered to the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the Second Affiliated Hospital of Zhejiang University School of Medicine (No. 2020-11). It was also registered with the Chinese Clinical Trial Register (https://www.chictr.org.cn/, No. ChiCTR2000029342) to ensure transparency and compliance with regulatory requirements.

In the power analysis, we set the significance parameter P to 0.05 and the effect size was ultimately determined to be 0.5. Moreover, aiming for more precise experimental results, we set the power value to 0.9. Under these conditions, the power analysis yielded a minimum sample size of 85. Considering a maximum sample fall off value of 20%, the sample size was finalized to be 90. Participants aged 18 and above with basic reading skills were eligible to participate in this study. Those with eye conditions affecting corneal nerves, a history of ocular surgery within the past 6 months, recent use of contact lenses within the past month, current treatment for DE (excluding artificial tears), such as punctal occlusion or intense pulsed light therapy, as well as pregnant or lactating women, and volunteers with severe systemic diseases were excluded.

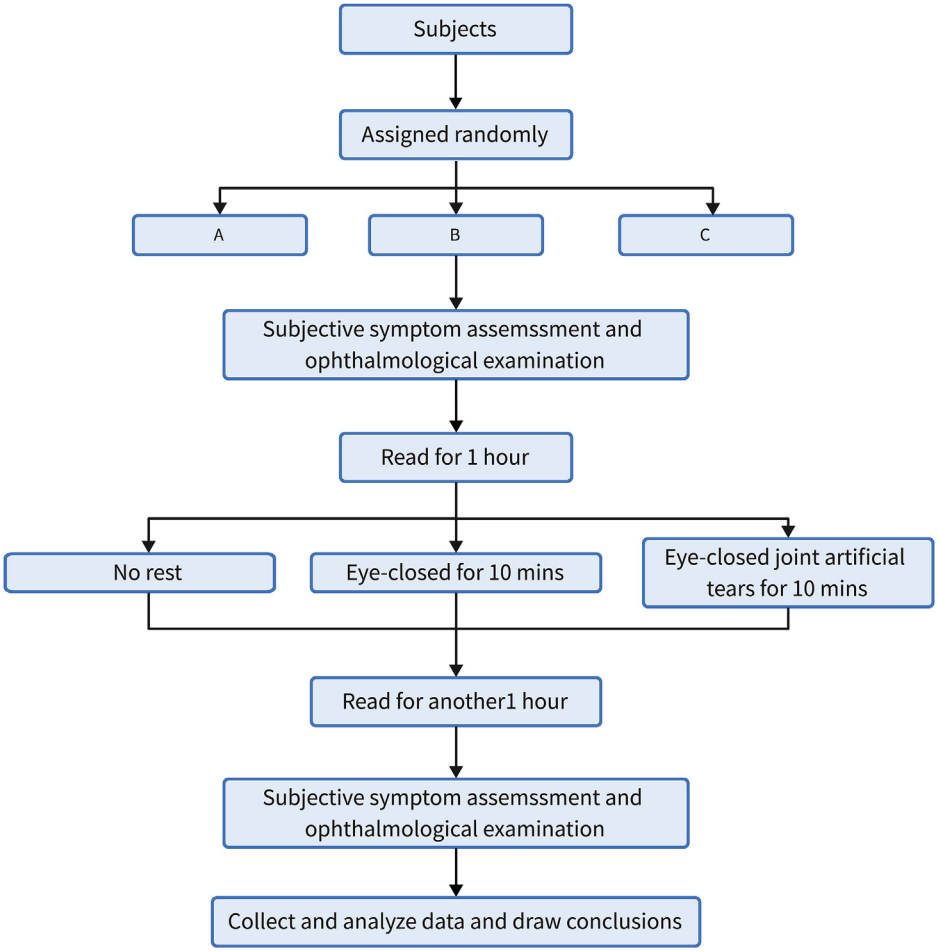

Fig. 1. Experiment flow chart. The flow chart illustrates the sequence of procedures in the study, including participant recruitment, baseline assessments, intervention, and post-intervention measurements.

2.2. Study treatment

The participants were randomly assigned to one of the three groups and were asked to read on their smartphones for 2 h. After reading for 1 h, each group followed a different rest method: no rest (Group A), 10 min eye-closed rest (Group B), or 10-min rest with 0.1% sodium hyaluronate eye drops (URSAPHARM Arzneimittel GmbH, Germany) (Group C). Ophthalmological examinations and questionnaires were administered to all participants before and after the 2 h reading task. The study flowchart was represented in Fig. 1.

The study employed Hisense A6 (see Table 1 for relevant parameters) as the device for reading. The subjects were kept in rooms with similar light, temperature, and humidity levels throughout the experimental period. The brightness of the smartphone screen was set at 80% of the maximum brightness, and the text fonts and sizes were standardized for ease of comparison. The distance between the screen and the subjects' eyes was approximately 40 cm. The reading time for all three groups was from 8:00 to 10:00 in the morning for 2 h. During the reading period, the subjects were instructed not to engage in non-reading activities for extendedd periods (more than 5 min), and they were allowed to adjust their reading posture moderately. After 1 h of reading, the latter two groups rested for 10 min in different ways. The study involved tests for DE and asthenopia in the following order: subjective questionnaire, critical flicker frequency (CFF), non-invasive break-up time (NIBUT), fluorescein tear break-up time (FBUT), corneal fluorescein staining (CFS), and the Schirmer I test (SIT).

2.3. Ocular surface disease index (OSDI)

OSDI questionnaire was used to assess the subjective severity of DE. The questionnaire consisted of 12 questions that were grouped into three subscales: (1) ocular symptoms (OSDI symptoms), (2) vision-related function (OSDI visual function), and (3) environmental triggers (OSDI trigger). Responses were scored on a scale of 0–4, where 0 indicated no symptoms and 4 indicated severe symptoms. The OSDI score was calculated using the following formula: OSDI = [(sum of scores for all questions answered) *100]/[(total number of questions answered) *4].[21]

2.4. Critical flicker frequency (CFF)

CFF was measured by the Digital Flicker (Takei Scientific Instruments Co. Ltd. Tokyo, Japan). The participant assumed a daily reading posture and looked at the red flash fusion point in a darkroom. The flicker frequency was gradually reduced from 60 Hz until the subject could distinguish the flicker of light spots with the naked eye, at which point the STOP button was pressed to record the resolution frequency. The CFF measurement was performed twice and the average was recordedd.

2.5. Non-invasive break-up time (NIBUT)

NIBUT was measured using the Keratograph 5 M (Oculus, Wetzlar, Germany). Participants were positioned in front of the instrument and instructed to focus on the red marker while the examiner calibrated their pupils. The participants were then asked to blink twice, after which the instrument automatically detected the first rupture time of the tear film on the ocular surface. The experiment was repeated three times, and the average value was recordedd.

Table 1
Smartphone parameters.

Smartphone Model	Screen Size	Display Resolution
Hisense A6	6.8 × 13.6 cm (6.01 inches)	2160*1080 pixels

2.6. Fluorescein tear film break-up time (FBUT) and corneal fluorescein staining (CFS)

Fluorescein paper strips (Jinming New Technological Development Co. Ltd., Tianjin, China) were used to measure FBUT and CFS. The test paper was moistened with saline and a drop was placed in the lower conjunctival fornix. The subject was asked to look straight ahead after opening their eyes under the cobalt blue light of a slit lamp. FBUT was determined as the time interval between opening the eyes and the appearance of the first dark spot on the ocular surface. The average value of each eye was measured three times in succession. CFS score was evaluated using the National Eye Institute scoring system, which divided the cornea into five areas and graded each area separately. 0: indicates no staining, 1: isolated staining, 2: fused staining, 3: corneal epithelial defect. The scores of all areas were added up to give a total score ranging from 0 to 15.

2.7. Schirmer I test (SIT)

To conduct the SIT, a tear secretion test strip (5 mm × 30 mm, Jinming New Technological Development Co. Ltd., Tianjin, China) was gently placed in the middle and outer 1/3 of the lower eyelid conjunctival sac of the subject by folding its upper end. The subject was then instructed to close their eyes and remain still for 5 min, after which the length of the strip soaked with tears was recorded.

2.8. Statistics

Statistical analyses were performed by SPSS 23.0 (SPSS, Chicago, IL, USA), and GraphPad Prism 8.0 (GraphPad Software, San Diego, CA, USA). CFF and NIBUT showed normal distributions, and were analyzed using analysis of variance. OSDI, FBUT, CFS, and SIT did not show normal distributions, and were analyzed using nonparametric tests. Intra-group differences between subjective and objective indicators were analyzed using the Wilcoxon signed-rank test. Inter-group differences were analyzed using the Kruskal-Wallis H and Mann-Whitney U tests. All tests were two-tailed, and $P \leq 0.05$ was considered a statistical difference.

3. Results

3.1. General information of the subjects

Ninety qualified volunteers, consisting of 29 males and 61 females between the ages of 22–30, were recruited from the community. This age range represented a population with higher rates of VDTs usage. Additionally, it was also a common period for the occurrence of DE. The general information and grouping of the subjects were shown in Table 2. All examination results were performed on the right eye of the subjects. The pre-reading measurements of three groups, including CFF (P =

Table 2
Participant demographics and grouping information.

	Group A	Group B	Group C		p
Number	30	30	30	/	/
Number of eyes	30	30	30	/	/
Sex (male: female)	0.57	0.42	0.42	χ^2 = 0.407	0.816
Age	25.26 ± 2.24	24.90 ± 1.60	24.90 ± 1.68	F = 1.220	0.300
Years of smartphone use	9.80 ± 2.36	8.80 ± 2.37	9.40 ± 3.46	F = 1.220	0.378

Note: Data are presented as mean ± SD. Differences in sex composition were compared by Chi-square test, and differences in age and years of mobile phone use were analyzed by One-Way Anova. $P \leq 0.05$ was regarded as a statistical difference.

0.915), NIBUT ($P = 0.175$), OSDI ($P = 0.966$), CFS ($P = 0.07$), and SIT ($P = 0.796$), indicated no statistically significant differences among the groups. However, the FBUT test showed $P = 0.003$, indicating a statistical difference, as shown in Tables S1 and S2. The changes in relevant indicators after reading could be found in Table S3.

3.2. Avoiding continuous reading on smartphones can relieve eye discomfort

The OSDI scale was used to assess subjective symptoms of DE. Group C did not show a significant change before and after reading (Fig. 2A, $P > 0.05$). In contrast, OSDI scores were significantly higher in Group A and B compared to baseline statistics (Fig. 2A, $P \leq 0.001$ $P \leq 0.01$). The results of ΔOSDI revealed significant differences among the three groups (Fig. 2B, $P \leq 0.001$ $P \leq 0.01$).

3.3. Long-term reading on smartphones reduces the quality of tears

In Group A, the NIBUT decreased statistically significantly after long-time reading on smartphones compared with the baseline (Fig. 3A, $P \leq 0.05$). FBUT showed the same change trend (Fig. 3C, $P \leq 0.05$). For CFS, a difference was also found in Group A (Fig. 3E, $P \leq 0.05$). Comparing Group B and C, who used different rest methods while reading, no significant differences were observed in NIBUT and FBUT before and after reading (Fig. 3A, $P > 0.05$; Fig. 3C, $P > 0.05$). The inter-group comparison showed no changes in ΔNIBUT, ΔFBUT and ΔCFS between Group B and C (Fig. 3B, $P > 0.05$; Fig. 3D, $P > 0.05$; Fig. 3F, $P > 0.05$). However, significant differences were found in ΔCFS between Group A and the other two groups (Fig. 3F, $P \leq 0.01$; $P \leq 0.05$), while no changes were detected in ΔNIBUT and ΔFBUT (Fig. 3B, $P > 0.05$; Fig. 3D, $P > 0.05$). Tear production measurements showed no significant changes in either SIT or ΔSIT (Fig. 3G, $P > 0.05$; Fig. 3H, $P > 0.05$).

3.4. Eye-closed joint artificial tears rest can significantly alleviate asthenopia caused by long-time reading on smartphones

The impact of different rest methods on asthenopia symptoms was assessed by analyzing the CFF data before and after reading. As illustrated in Fig. 4A, CFF was significantly lower after reading without rest compared to the baseline (Fig. 4A, $P \leq 0.01$). A decrease in CFF was also observed in Group B (Fig. 4A, $P \leq 0.05$), while no significant difference was observed in Group C (Fig. 4A, $P > 0.05$). A comparison of ΔCFF among the groups revealed significant differences (Fig. 4B, $P \leq 0.001$; $P \leq 0.01$).

4. Discussion

The aim of this study was to investigate effective ways of preventing DE and asthenopia resulting from prolonged use of smartphones. The results indicated that prolonged staring at smartphone screens can cause ocular surface damage and subjective discomfort, and closing eyes with artificial tears was an important preventative measure to promote eye health in individuals who frequently use smartphones.

Based on long-standing observations and experiences regarding the effects of prolonged near-distance visual tasks on the eyes, the "twenty-twenty rule" has been proposed. The twenty-twenty rule is a simple and practical recommendation aimed at alleviating visual fatigue caused by prolonged focused viewing of close objects, such as electronic screens. According to this rule, it is suggested to take a brief visual break approximately every 20 min and shift the gaze away from the screen to a distant object for at least 20 s.[22] This short visual rest can help relieve eye strain and contribute to the restoration of normal eye function. However, the requirement of taking a 20-s eye break every 20 min may disrupt workflow or task continuity. For certain tasks that require high levels of concentration, frequent eye breaks may interfere with efficiency and productivity. Therefore, in the context of longer-term work, it would be beneficial to educate the public on the benefits of the closing eyes with artificial tears intervention, and encourage its adoption as part of a healthy digital lifestyle. Nonetheless, individual eye conditions and tolerance to electronic screens may vary. Personal needs may require the adoption of additional eye care measures during the use of VDTs, such as ensuring moderate ambient lighting when using electronic devices and avoiding overly strong or weak illumination. Excessive lighting may lead to visual fatigue, while insufficient lighting may strain the eyes in adapting to the screen.[23] Glare can cause eye fatigue and discomfort, and reducing glare stimulus can be achieved through adjustments in screen angle or wearing anti-glare glasses.[24] Using a humidifier in dry environments can increase indoor air humidity, thereby reducing evaporation from the ocular surface and alleviating dry eye symptoms.[25,26] Adjusting screen contrast, color temperature, and other settings to enhance comfort and meet individual needs may be beneficial, but further research is needed to determine their efficacy. Furthermore, it is important to pay attention to the duration of VDT usage. A cross-sectional study has shown that using VDTs for 2–7 h per day increases the risk of developing DE.[27] Moreover, exceeds 8 h of daily VDT exposure is associated with symptomatic DE.[28] Additionally, an increase in VDT exposure time (by 1 h per day) is also a significant predictive factor for an increased probability of developing DE.[29]

The OSDI questionnaire was used to assess the subjective symptoms of volunteers with DE. The results showed a statistically significant increase in OSDI scores after 2 h of continuous reading. The eye-closed only group also showed a significant increase in symptoms, while the combined use of artificial tears group showed some relief of eye discomfort after reading. Sodium hyaluronate is a natural polymer compound with high lubricity, viscoelasticity, and water-saving performance when combined with fibronectin. Symptoms such as dry sensation, foreign body sensation, and fatigue could be remarkably relieved. Some studies have also indicated that sodium hyaluronate can effectively reduce

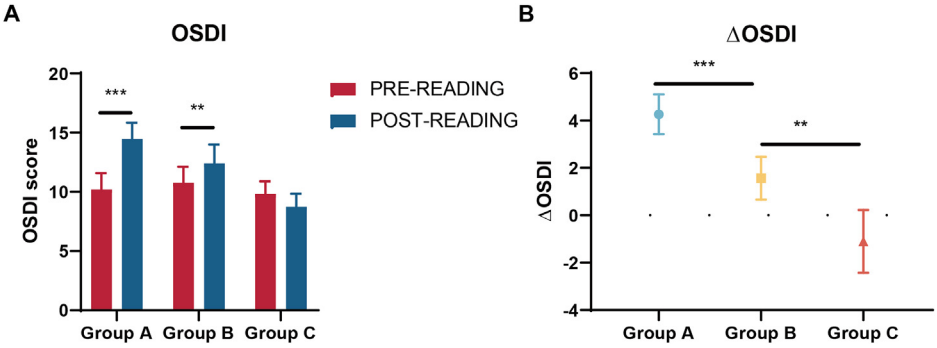

Fig. 2. Subjective assessments of dry eye symptoms. (A) Shows the differences of subjective measurements between post-and pre-reading. (B) Demonstrates the Δdifferences of OSDI between groups (Δ = post–pre). $^{**}P \leq 0.01$, $^{***}P \leq 0.001$. OSDI, Ocular Surface Disease Index.

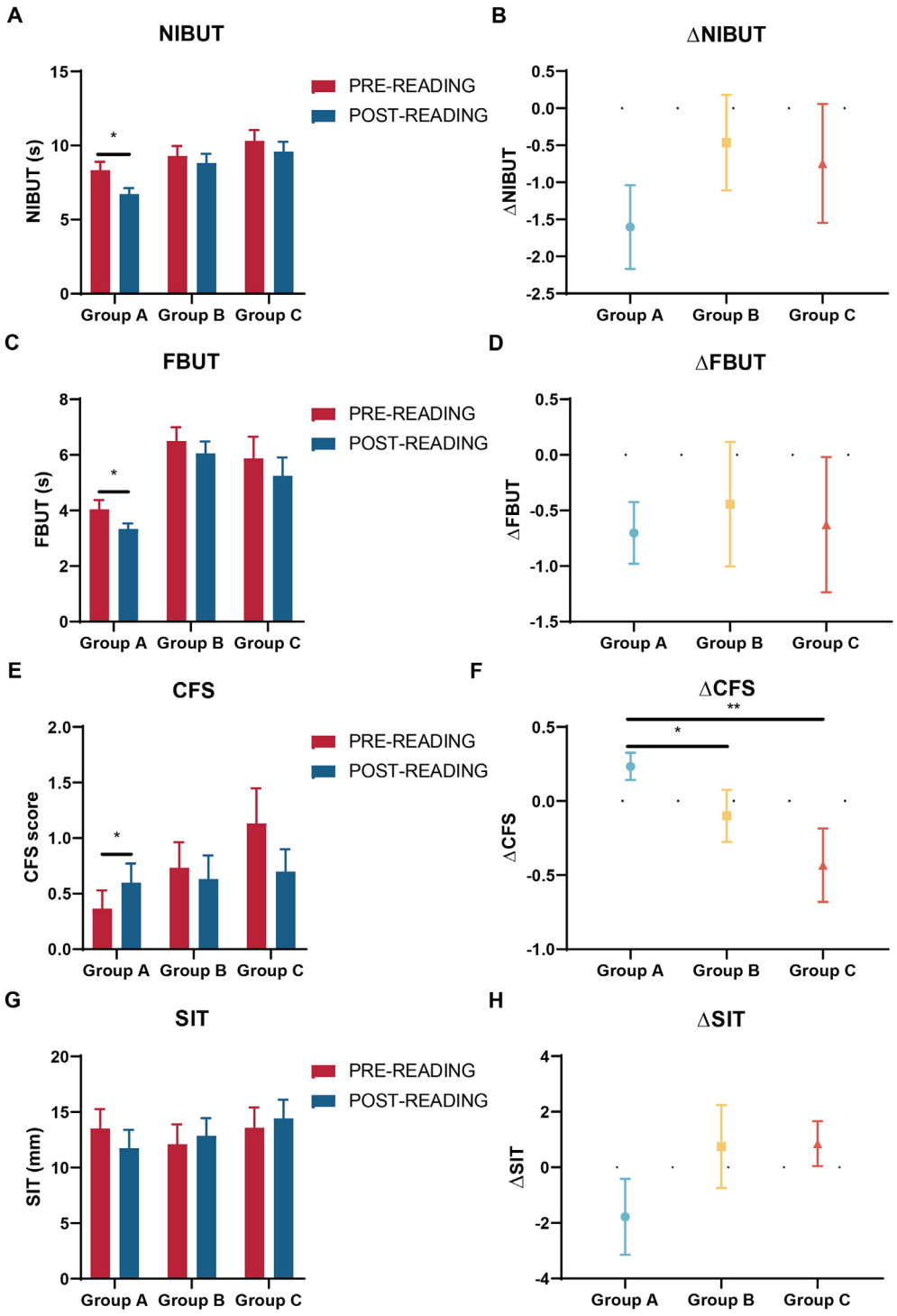

Fig. 3. Influence of different rest ways on tear quality. (A, C, E, G) Shows the differences NIBUT, FBUT, CFS and SIT between post-and pre-reading. (B, D, F, H) Demonstrates the Δdifferences of above indicators between groups (Δ = post–pre). *$P \leq 0.05$, **$P \leq 0.01$. NIBUT, noninvasive break-up time; FBUT, fluorescein tear film break-up time; CFS, corneal fluorescein staining; SIT, Schirmer I test.

subjective symptoms in patients with moderate DE.[30] Based on the OSDI results, closed-eye joint artificial tears during continuous reading on smartphones should be advocated.

Studies have shown that despite having a stable tear film at baseline, symptomatic VDT users exhibited tear film instability after computer work.[31] This supports our experimental findings. The detection results of BUT were commonly used to reflect the stability of the tear film. The decrease in blink frequency and the increase in tear osmotic pressure were significantly correlated with the decrease in BUT. Blinking could affect the distribution of tear film, and during the use of VDTs, the frequency of blinking decreased due to concentration, resulting in uneven distribution of tear film. Compared to other VDTs, smartphones had smaller screen sizes, which might have led to poorer visual images,[12] such as reduced contrast and font size, requiring more focus and longer fixed time to receive visual information, greatly reducing the frequency of spontaneous blinking. Inappropriate viewing angles might have also exposed more of the conjunctiva and cornea to the air, leading to accelerated tear evaporation, increased tear osmotic pressure, and

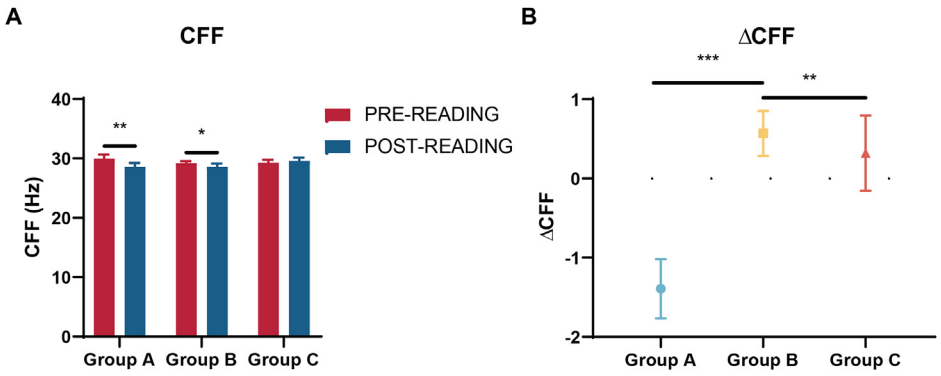

Fig. 4. Influence of different rest ways on asthenopia symptoms. (A) Shows the differences of CFF between post-and pre-reading. (B) Demonstrates the Δdifferences of CFF between groups (Δ = post–pre). *$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$. CFF, Critical flicker frequency.

decreased tear film stability.[32] However, according to the results of the SIT, we did not observe a decrease in tear production, which further confirmed that the abnormal tear film caused by smartphones was due to a decrease in tear film stability.

Smartphones had a higher adoption rate compared to other VDTs, and as a result, smartphone-induced DE became increasingly prevalent. Unfortunately, there was a lack of awareness about the harmful effects of DE, resulting in delayed treatment. Corneal epithelial cells had excellent regenerative and migration abilities, which allowed them to repair slight damage quickly. However, severe DE can lead to corneal epithelial cell dysfunction and repeated damage can cause corneal epithelial defects.[33] Continuous reading on smartphones resulted in increased corneal epithelial staining, as revealed by CFS, which was an indication of epithelial defects. This staining was not observed in the other groups, highlighting the preventable nature of ocular damage caused by smartphones. It is essential to avoid prolonged reading on smartphones to prevent the risk of DE and corneal epithelial defects.

In addition to assessing DE, this study utilized CFF to measure the degree of asthenopia. When the human eye was exposed to intermittent light, it perceived a flashing sensation. As the frequency of the flashing increased, the sensation gradually disappeared, and eventually, the light appeared to be stable. This phenomenon was known as light fusion. The minimum intermittent frequency that could cause continuous flash fusion perception was referred to as the CFF.[34] CFF was a valuable tool for assessing visual function, sensitivity, and fatigue.[35] Research suggested a correlation between the use of smartphones and the onset of asthenopia, with prolonged usage resulting in greater eye discomfort and fatigue.[36] As previously mentioned, extended use of smartphones could lead to tear film instability, resulting in an irregular and rough optical surface on the cornea. This phenomenon increased wavefront aberration.[37] Wavefront aberration assessment can help identify abnormalities in the optical system of the eye. The tear film in front of the cornea, as the foremost refractive surface of the eye, plays a crucial role in the optical quality of the eye. The uniform thinning of the tear film has minimal impact on the optical quality of the surface, while the irregularity of pathological tear film significantly affects the light path, primarily occurring when the blink rate decreases.[38,39] Any local variations in tear film thickness and regularity introduce distortions in the optical system, thereby reducing image quality and potentially increasing visual fatigue.[39] In fact, improvements or reductions in wavefront aberration have been reported in dry eye patients following the use of artificial tear eye drops.[40]

Usually, during the use of VDTs, people were exposed to text and video content. Reading text and watching video content involved different visual loads. Based on previous research and understanding, reading text might have had a greater impact on the ocular surface compared to watching videos.[15] Firstly, reading text involved more eye movements and focusing adjustments, requiring higher levels of visual cognitive processing. This could have increased muscle tension and fatigue in the eyes, exerting pressure and causing discomfort on the ocular surface. Secondly, relative to watching videos, individuals had higher cognitive demands when reading text and tended to be more focused on the screen. As a result, the blink rate may have decreased more noticeably when reading text. Reduced blink rate could have led to increased evaporation of moisture from the ocular surface, resulting in elevated tear film osmolarity. Although reading text might have had a greater impact on the ocular surface, the specific degree of impact could have varied among individuals due to individual differences.

However, some areas required improvement. A 2 h reading task on a smartphone might have been considered a mild stimulus, especially when interventions were conducted after 1 h of reading, at which point the changes in clinical signs and symptoms may not have been adequately observed. We considered extending the duration of the reading task in future studies. Additionally, longer follow-up periods were necessary to investigate smartphones' potential cumulative damage effects on the eyes. Further research was required to determine if increasing the frequency of rest intervals would yield better results. In this experiment, we set a break time of 10 min, This was based on the consistency of experimental design and considerations from clinical practice. It has been shown that the instilled eye drops are rapidly cleared from the ocular surface within a few minutes.[41,42] Studies have indicated that the use of eye drops has no observable impact on central tear film thickness.[43] However, the ocular surface can still remain smooth, which is advantageous. This actually highlighted the benefits of eye-closed joint artificial tears rest compared to eye-closed rest alone. Next, we would investigate whether shorter breaks had the same effect on relieving DE and asthenopia, to meet most people's needs.

Inevitably, people spent a considerable amount of time on smartphones every day for various reasons. Hence, it was crucial to find ways to enhance eye comfort and the quality of life. This article presented a simple and effective strategy to prevent DE and asthenopia caused by prolonged smartphone use.

5. Conclusions

It was crucial to prioritize taking rest breaks with artificial tears while reading on smartphones for extended periods to prevent DE and asthenopia. By adopting this simple and convenient prevention strategy, we could effectively protect our eyes from the harmful effects of prolonged screen use and promote long-term eye health.

Study approval

The authors confirm that any aspect of the work covered in this manuscript that involved human patients or animals was conducted with the ethical approval of all relevant bodies and the study was performed in accordance with the Declaration of Helsinki , and the protocol was approved by the Ethics Committee of the Second Affiliated Hospital of

Zhejiang University School of Medicine (approval number: 2020-11).

Author contributions

The authors confirm contribution to the paper as follows: NW and JM wrote the manuscript. XJ designed the research. NW and XF performed the research. NW and JM analyzed the data. All authors reviewed the results and approved the final version of the manuscript.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aopr.2024.07.001.

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