

Short-Term Blue-Blocking Intervention Improves Photostress Recovery Under Blue- Light Exposure

Sristi Nayak

Manipal Academy of Higher Education

Stelyna Joylin

Manipal Academy of Higher Education

Nagarajan T

nagarajan.t@manipal.edu

Manipal Academy of Higher Education

Research Article

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Abstract

Background

This study aimed to examine the recovery rate of photostress time in healthy participants exposed to blue light and the amelioration achieved with blue-blocking lenses.

Methodology:

The study included 30 eyes from 15 healthy participants 18 to 25 years. For 20 seconds, a smartphone was held 5 cm from the pupil plane and illuminated with high-intensity blue light. After 20 s, baseline photo stress recovery time (PST) was assessed. Similarly, the recovery time following blue light exposure was evaluated with and without a blue-blocking lens.

Results

There were significant differences in the photostress recovery times following blue light exposure when comparing placebo lens (PL), Crizal Prevention (CP), and Dura Vision (DV) lenses ($F_{2,29}=10.44$, $p = 0.0001$ for PL; $p < 0.0001$ for CP; $F_{2,29}=4.264$, $p = 0.0013$ for DV). Compared with the CP group (34.28 ± 8.31 seconds), the PL group (32.56 ± 7.36 seconds) and DV group (29.53 ± 5.45 seconds) showed shorter recovery times.

Conclusion

This study found that blue light exposure prolonged photostress recovery time in healthy young adults, but it does not indicate macular damage or sleep disruption.

Introduction

Light is essential for vision. Inadequate nighttime exposure to artificially produced blue light (visible light with a wavelength of 400–500 nm) has several negative effects, including cancer, sleep difficulties, mood disorders, and many other health issues(1). A wavelength less than 400 nm is harmful to the retina. Light-induced retinal toxicity is well established, and excessive exposure can lead to phototoxicity. Owing to its high energy, blue light highly penetrates and can reduce contrast, which can cause fatigue, dry eyes, aching eyes, difficulty focusing, and digital eye strain(2). Excess exposure to blue light may lead to the

development of AMD or other retinal pathologies(3). Blue light enhances alertness and influences melatonin release, triggering a circadian rhythm(2).

The principles of photomechanical, photothermal, and photochemical injury provide a foundation for comprehending photopic retinal injury(4). High-energy blue light can penetrate the cornea and lens and reach the retina directly, causing severe damage to the retina, which is called a blue light hazard(4). Photochemical damage to rod cells via blue light has long been recognised. Long exposure times and exposure to low-wavelength light are linked to photochemical damage. Photochemical damage results from photodynamic treatment (PDT)(4).

Blue-blocking lenses reduce the transmission of blue light, which harms photoreceptors in the retina without degrading visual performance or sleep quality(5). Blue light transmission can be considerably decreased by using

certain hues, such as orange, red, yellow, pink, and brown. Blue-blocking lenses may serve as a supplementary option for protecting the retina from potential blue light(5). BBLs may impair scotopic vision, which raises concerns for activities requiring visual attention, such as nighttime driving and visual search(6, 7).

A quick clinical test called the photostress test can help distinguish between retinal and postretinal disease(8). Photostress recovery time (PST) is the time taken for visual acuity to return to normal levels after the retina has been breached by a bright light source(8). Age-related macular degeneration (AMD), central serous retinopathy (CSR), retinal detachment (RD), and retinitis pigmentosa (RP) are diseases affecting central vision that may affect recovery time(9). Intense light exposure depletes photopigments, which are then replenished via photopigment regeneration(8), which lengthens the recovery time, and the speed of recovery depends on how quickly photopigment regenerates(9). Therefore, this study examined whether blue light-induced macular damage could be reduced with blue-blocking lenses.

Methodology

Seventeen participants (n = 34 eyes) aged 18–25 years participated in this crossover study. All participants were healthy young adults with normal ocular findings and normal visual acuity. Participants underwent a comprehensive ocular examination, which included distance and near visual acuity using a log MAR chart and N-notation chart, slit lamp examination (Zeiss and Haag-Streit, USA), stereo acuity via Frisby, intraocular pressure (IOP) with an I-care tonometer (I-care Finland Oy, Centervue S.p.A., I-care USA Inc.) and retinal examination (Direct Ophthalmoscope). The included participants had a best-corrected visual acuity (BCVA) of 0.00 logMAR in both eyes and stereopsis of ≤ 40 seconds of arc without any ocular abnormalities. Individuals with a history of refractive surgery, ocular abnormalities or conditions that could be triggered or worsened by exposure to high-intensity light were excluded. The standardised protocol was maintained, and eligible subjects provided written informed consent. The study adhered to the tenets of the Declaration of Helsinki. Ethics approval was granted by the Institutional Ethics Committee (IEC137/2023).

Light Exposure Protocol

The eligible subjects were lightly adapted for 20 minutes prior to the testing procedure. The photostress recovery time (PST) was measured using a visual acuity chart at a distance of 3 meters after 20 seconds of retinal stress, aided by a smartphone. The device used was a Samsung M12 smartphone (display: Super AMOLED, 6.5 inches, 720 × 1600 pixels, 20:9 ratio, 270 ppi; GPU: Mali-G52, running Android 11 with One UI Core 3.1). To stabilise the output, the device was turned on for 1 minute before bleaching. These are photometric measurements at the source level.

Blue-Blocking Lenses

Type I - Placebo lens (clear lens with no blue light filtering), Type II - Crizal Previncia lens (blue light filtering approximately 50% of blue wavelengths), or Type III - DuraVision Blue Protect lens (blue light filtering approximately 65% of blue wavelengths).

Procedure

Two blue LED lights were positioned at 45 degrees to the subject's eye and 80 centimetres away from the participant for approximately 10 minutes during the reading task. Subjects were instructed not to look directly at the lights. Following exposure to blue light, recovery time was measured. A washout period of at least 48 hours was provided between study conditions per protocol. After the washout period, blue light exposure was repeated while subjects

wore one of three randomised lenses. These lenses were randomised using a double-blind methodology. Following exposure, photostress recovery time was measured to compare recovery rates across lens types.

Statistical Analysis

GraphPad Prism software (version 7.00; ©2023 GraphPad Software) was used for all statistical analyses. The Kolmogorov–Smirnov test was used to assess the normality of the data. The chi-square test was used to analyse demographic variables across the three groups. A repeated-measures analysis of variance (RM-ANOVA) was performed to compare PST measurements across the three lens conditions (baseline, placebo lens, blue-blocking lens). Tukey’s post hoc test was conducted for pairwise comparisons.

Results

Participant Characteristics

A total of 17 participants (n = 34 eyes) were enrolled in the study. Two participants (4 eyes) were excluded from the study due to adverse events that occurred during the initial phase of blue light exposure. One participant reported photophobia with accompanying headache during the initial 20-second blue light exposure, and one participant reported migraine symptoms approximately 10 minutes into the reading task with blue light exposure. Both participants’ symptoms were resolved completely within 30 minutes of cessation of light exposure. These participants were excluded per protocol because the symptoms appeared directly attributable to the study light exposure. Therefore, 15 participants (30 eyes) completed the full study protocol. The mean age of the 15 participants who completed the study was 20.93 ± 2.01 years. The cohort included 4 males (8 eyes) and 11 females (22 eyes) with a mean spherical equivalent refractive error of < ± 0.50 D (normal or near-normal vision).

Table 1: Demographic data of the study participants, where n represents the number of participants in a group; PL represents the placebo lens; CP represents Crizal Prevencia; DV represents Dura Vision; M indicates the male sex; F indicates the female sex; BCVA represents the best corrected visual acuity; and IOP indicates the intraocular pressure.

Groups	n	Gender		Age (Years)	BCVA	IOP
		M	F			
PL	5	3	2	21±2.54	0.00	14.2±1.48
CP	5	1	4	20.2±2.28	0.00	15.5±2.60
DV	5	0	5	21.2±1.92	0.00	13.7±2.0
χ ²	4.773			1.020	-0.0072	0.03594
df	2			1	1	1
p value	0.0920			0.3126	<0.0001	0.8496

Photostress Recovery Time Results

PST was assessed at three timepoints at baseline (with no prior light exposure), immediately after 20-second blue light exposure without lens protection, and immediately after 20-second blue light exposure while wearing each of the three lens types (placebo, CP, or DV). A one-way repeated-measures ANOVA was used to compare PST across conditions.

The results revealed statistically significant differences in PST across the Placebo lens group ($F_{2,29}=10.44$, $p = 0.0001$), the Crizal Prevention group ($p < 0.0001$) and the DuraVision group ($F_{2,29}=4.264$, $p = 0.0013$). Both the PL group (32.56 ± 7.360 seconds) and the DV group (29.53 ± 5.449 seconds) demonstrated shorter photostress recovery times compared to the CP group (34.28 ± 8.310 seconds). During Post hoc comparison, the Placebo lens revealed a significant difference between baseline vs PST-after blue light exposure ($p < 0.0001$) and between PST-after blue light exposure vs PST-with placebo lens ($p < 0.05$). Crizal Prevencia showed Significant differences between baseline vs PST-after blue light exposure ($p < 0.0001$) and baseline vs PST-with CP lens ($p < 0.0001$). The Dura Vision group showed significant differences between baseline and PST-after blue light exposure ($p < 0.001$) and between PST-after blue light exposure and PST-with DV lens ($p < 0.05$).

Discussion

In this study, the effects of blue-blocking lenses on photostress recovery time were measured following acute exposure to blue light in healthy young adults. PST prolongation was observed after 20-second exposure to high-intensity blue light emitted from a smartphone display. Photostress recovery time is a functional measure reflecting the rate of photopigment regeneration and dark adaptation in the retina(10). Our study found that PSTs were longer when participants were exposed to blue light. Prolongation of PST does not directly indicate structural macular damage or morphological changes in retinal tissues (11). The observation of PST prolongation after acute blue light exposure suggests transiently altered photopigment regeneration kinetics but cannot be equated with retinal damage or pathology(12).

Based on established in vitro and animal model evidence, short-term exposure to high-intensity blue light can theoretically lead to an overproduction of reactive oxygen species (ROS) and oxidative stress within photoreceptor cells (13). This has been proposed to result in disruption of photoreceptor outer segments and potential photoreceptor dysfunction. However, these mechanistic pathways have been demonstrated primarily in laboratory settings and animal models, not in human clinical studies(13). The clinical relevance of acute PST prolongation in healthy young eyes remains unknown. Animal studies employing prolonged light exposure (90 days cumulative) have documented retinal changes, including apoptosis and mitochondrial dysfunction(13); however, these findings cannot be directly extrapolated to the single acute 20-second exposure in the current study.

Commercially available blue-blocking lenses exhibit transmission profiles comparable to those of adult natural crystalline lenses (14,15). Our results showed that Crizal Prevention lenses maintained longer PST than both placebo and DuraVision lenses, suggesting differential efficacy among commercially available blue-blocking products. However, the clinical significance of these PST differences (2–5-second intervals) in healthy young adults remains unclear.

The current generation uses a variety of gadgets that use LED technology for domestic and other purposes. These LEDs emit an excessive amount of short-wavelength light(2). Some symptoms and retinal problems worsen due to the depletion of retinal layers caused by this high-energy light(13). The slower response to light stimuli exposed to bright lights for a brief period might pose a danger, especially during the night(13). A slow reaction time might result in delayed object detection and an increase in the time required for vision restoration(13), which might lead to increased road traffic accidents and occupational hazards.

Limitation:

This preliminary exploratory study lacked formal power calculations and treated eyes as independent observations, failing to account for within-subject correlation. Future research should utilise multilevel mixed-effects models to address this limitation. Retinal irradiance conversion ($\mu\text{W}/\text{cm}^2$) was not precisely calculated due to factors such as corneal transmission and lens density, underscoring another methodological constraint. The study was limited to healthy young adults (18–25 years) with normal vision, limiting generalizability to older individuals or those with ocular conditions such as age-related macular degeneration, diabetic retinopathy, or prior ocular surgery. Additionally, the study's short duration (20-second exposure) does not reflect chronic blue light exposure from regular screen use.

Future Recommendation:

Larger sample sizes with formal a priori power calculations, extended observation periods beyond acute single exposures, validated sleep assessment parameters if evaluating circadian effects, retinal imaging (OCT, autofluorescence) to correlate functional PST changes with structural retinal changes, studies in clinical populations including older individuals and those with existing macular disease, longitudinal designs to evaluate long-term effects of cumulative blue light exposure, precise retinal irradiance quantification using direct measurement or validated optical modeling.

This exploratory study provides preliminary evidence that acute exposure to blue light transiently affects photopigment regeneration kinetics in healthy young adults. Appropriately powered and designed studies with longer follow-up and relevant outcome measures are essential before clinical recommendations regarding blue light exposure or blue-blocking lens use can be established.

Conclusion

This preliminary study examined photostress recovery time (PST), a functional measure of retinal photopigment regeneration, in healthy young adults following acute exposure to blue light from a smartphone display. PST prolongation was observed following 20 seconds of blue light exposure in healthy eyes. Blue-blocking lens efficacy varied among the three lens types tested, with Crizal Prevention showing the longest PST preservation, followed by placebo and DuraVision. The clinical significance of these PST changes in healthy young eyes remains unknown. PST is a functional measure and does NOT indicate structural macular damage. These findings cannot support conclusions regarding sleep pattern disruption, long-term retinal damage or maculopathy, or the development of age-related macular degeneration.

Declarations

Competing Interest:

The authors declare that they have no competing interests.

Human Ethics and Consent to Participate declarations

The study adhered to the tenets of the Declaration of Helsinki. Ethics approval was granted by the Institutional Ethics Committee (IEC137/2023). Written informed consent was obtained from all the participants.

Clinical trial number

Not applicable.

Consent to Publish declaration: Not applicable.

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Author Contribution

SN contributed to the conceptualization and design of the study, conducted experimental procedures, and was involved in data collection and analysis. SJ assisted with the literature review, provided critical insights during the development of the methodology, and contributed to the interpretation of results. NT supervised the entire study, ensured adherence to ethical standards, and was responsible for manuscript preparation, including writing, editing, and finalizing the text for publication. All authors reviewed and approved the final manuscript, ensuring the integrity and accuracy of the reported findings.

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Nil

Data availability statement:

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

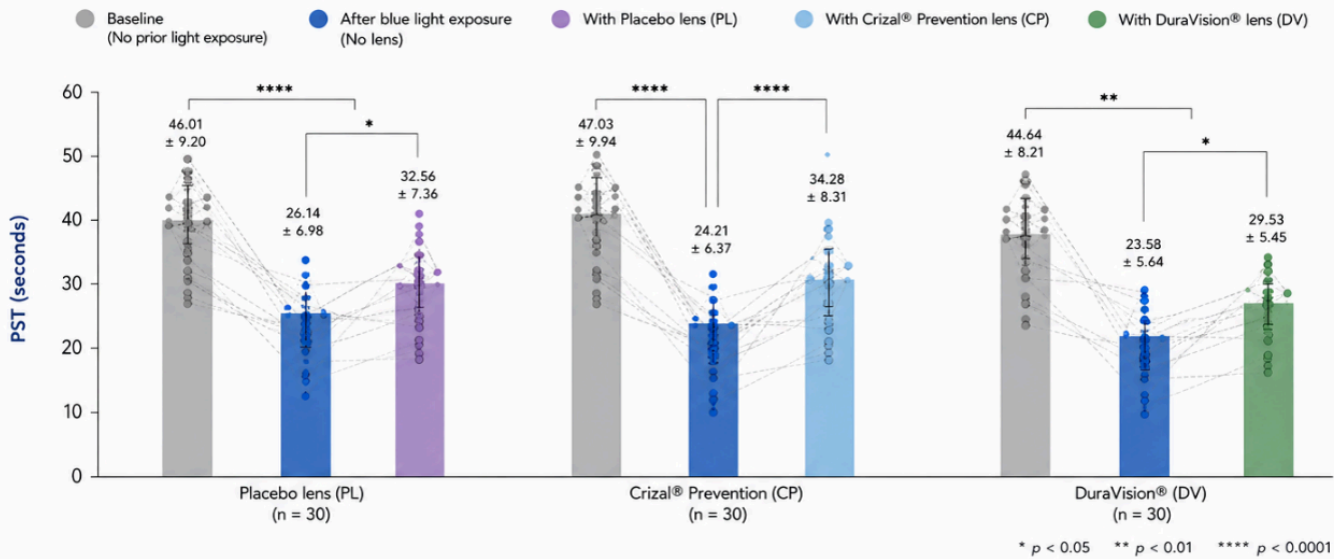


Figure 1

illustrates the experimental setup, which consists of three components. Panel A shows the blue-light source used for exposure, panel B shows the wrap-around frame fitted with the blue-blocking lenses (BBL), and panel C shows the light arrangement employed in the experiment

Photostress Recovery Time (PST)

Mean $\pm$ SD (seconds)



STATISTICAL ANALYSIS

Lens Group	ANOVA Result (One-way repeated-measures)	Post hoc Significant Differences		
		Baseline vs. After blue light exposure (No lens)	Baseline vs. With lens	After blue light exposure (No lens) vs. With lens
Placebo lens (PL)	$F_{2,29} = 10.44$, $p = 0.0001$	$p < 0.0001$	NS	$p < 0.05$
Crizal® Prevention (CP)	$F_{2,29} = 11.79$, $p < 0.0001$	$p < 0.0001$	$p < 0.0001$	NS
DuraVision® (DV)	$F_{2,29} = 4.264$, $p = 0.0013$	$p < 0.001$	NS	$p < 0.05$

PST: Photostress Recovery Time; PL: Placebo; CP: Crizal® Prevention; DV: DuraVision®; NS: Not significant

Figure 2

Study design and effects of blue-blocking lenses on photostress recovery time. The upper panel illustrates the experimental design, in which photostress recovery time (PST) was measured at three time points: baseline (no prior light exposure), immediately after a 20-second blue-light exposure without lens protection, and immediately after a 20-second blue-light exposure while wearing each of the three lens types (placebo lens, Crizal Prevention lens, and DuraVision lens). The lower left panel shows mean $\pm$ SD PST values for each condition and lens type, and the lower right panel summarises the results of one-way repeated-measures ANOVA with post-hoc pairwise comparisons, indicating significant differences in PST between baseline, post-blue-light exposure without lenses, and post-blue-light exposure with each lens condition. Key findings highlight that all three lenses altered PST relative to the no-lens condition, with placebo and DuraVision lenses demonstrating shorter PST than Crizal Prevention in this sample.