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The Impact of a Blue-blocking Filter Over One Eye on Health and Performance Outcomes and its Implications for Night Workers

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Abstract

The higher risk for cancer documented among night-shift nurses compared to the day-shift nurses possibly results from lower melatonin levels associated with exposure to light at night in the work environment. Research demonstrates that eliminating spectral power <530 nm to both eyes prevents light-induced nocturnal melatonin suppression, and complete occlusion of one eye reduces melatonin suppression relative to that when both eyes are open. This study investigated whether filtering short wavelengths from one eye using a blue-blocking filter, rather than occluding one eye, would maintain high melatonin levels, alertness, and visual performance. This crossover, within-subjects study ran for six nights. Subjects experienced one of six light conditions involving combinations of binocular versus monocular and filtered versus unfiltered vision per night. Normalized melatonin concentration area under the curve (AUC_n) served as the primary outcome and the numerical verification (NVT) and go/no-go (GNG) performance tasks, pupil area, and subjective sleepiness (Karolinska Sleepiness Scale [KSS]) served as secondary outcomes. Both filtered and unfiltered monocular light conditions resulted in significantly greater melatonin AUC_n than the unfiltered binocular light condition. Performance at the NVT and at the GNG was not affected by filtering one eye compared to the unfiltered binocular light condition, nor did it affect KSS ratings. Melatonin AUC_n positively correlated with pupil area for corresponding light conditions. In conclusion, filtering one eye can help preserve melatonin levels

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Declaration of Conflicting Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Considerations

Ethical approval for this study/case/case series was obtained from The Mount Sinai Health System Institutional Review Board (STUDY-23-00816).

Consent to Participate

Written informed consent was obtained from all participants in this study.

Trial Registration

ClinicalTrials.gov, <https://www.ClinicalTrials.gov>, Registration Number: NCT06310135.

in night workers while maintaining alertness and visual performance, which could be a simple and effective solution for improving health in night-shift nurses.

Keywords

binocular and monocular vision; melatonin suppression; spectral filtering; subjective sleepiness; task performance

Introduction

The master biological clock located in the suprachiasmatic nucleus (SCN) generates and regulates circadian rhythms. In mammals, the effects of light on circadian activity are mediated by retinal photoreceptors, which send electrical signals to the SCN via two different anatomical routes: (1) a direct pathway from the retino-hypothalamic tract, originating in the retina, and (2) an indirect pathway from the geniculo-hypothalamic tract, which arises from the intergeniculate leaflet (Pickard et al., 1987), a retino-recipient nucleus. Signals from the SCN are conveyed to the pineal gland, which controls melatonin production. Melatonin, a hormone produced at night and in darkness, is believed to serve as a timing messenger for the body and facilitates sleep. Retinal light exposures during the night, with short-wavelength (“blue”) light being the most efficient (Brainard et al., 2001; Thapan et al., 2001), will suppress melatonin production in a dose-dependent manner (Brainard et al., 1988; Cajochen et al., 2000; Laakso et al., 1993).

Melatonin may protect against cancer growth and development (Blask et al., 2005; Di Bella et al., 2013; Zamfir Chiru et al., 2014). Night-shift nurses, who are at higher risk for cancer, have some 30% lower levels of melatonin at night compared to the day-shift nurses (Papantoniou et al., 2014), possibly because of exposure to light at night (LAN) in the work environment. Decreased melatonin production due to LAN has been proposed as one of the physiological mechanisms associated with night-shift work and high risk for chronic diseases such as breast cancer (Hunter & Figueiro, 2017; Stevens et al., 2014). Thus, to create a safer nighttime work environment, it is important to develop and field-test the impact of novel, practical interventions that minimize melatonin suppression without compromising workers’ alertness and performance. Several studies lay the foundation for the present study.

Kayumov et al. (2005) and Rahman et al. (2013) used filters that removed transmission at short wavelengths (between 460 and 480 nm), where melatonin suppression by light is shown to be most effective, and were able to maintain high levels of melatonin during simulated shift work.

Van de Werken et al. (2013) exposed participants to three light conditions: (1) dim light control (3 lx at the eye), (2) short-wavelength attenuated polychromatic light (spectrally filtered light, 193 lx at the eye), and (3) unfiltered polychromatic light (256 lx at the eye). Saliva samples for melatonin assays were collected hourly (from 23:30 to 06:30) and from that, overnight area under the curve (AUC) melatonin levels were calculated. The percentage of melatonin suppression was calculated by comparing the melatonin AUC in

the dim light condition with the melatonin AUC in the filtered light and non-filtered light conditions. They showed that spectrally filtered light suppressed salivary melatonin by 6% while under the unfiltered light melatonin was suppressed by 45%. Interestingly, under spectrally filtered light compared with the unfiltered (bright) light, participants performed equally well on a performance test (addition task) and reported similar subjective sleepiness, as measured using the Karolinska Sleepiness Scale (KSS). However, in the spectrally filtered light condition, alertness, as defined by distal-to-proximal skin temperature gradient, was similar to that under the dim-light control condition.

In another study, Souman et al. (2018) compared melatonin suppression by two light spectra with similar correlated color temperatures and photopic illuminance levels but very different spectral power distributions (SIDs). The authors were particularly focused on the difference between the two spectra near 480 nm, the peak spectral sensitivity of the intrinsically photosensitive retinal ganglion cells. Both light sources were compared to a dim-light control (< 5 lx). Three-hour exposures to the light source with lower spectral power near 480 nm did not suppress melatonin relative to the dim-light control. Even at the same photopic illuminance (175 lx), exposure to the source with higher energy near 480 nm suppressed melatonin by nearly 50%, showing that spectral power near 480 nm is important for modulating light-induced melatonin suppression. Also, there were no significant differences in self-reported sleepiness between the three conditions.

Another technique that could be used to minimize melatonin suppression by LAN is occluding one eye. Studies have shown that monocular light exposures at the same irradiance and exposure duration are disproportionately ineffective for suppressing melatonin at night (Brainard et al., 1997; Spitschan & Cajochen, 2019; Wang et al., 1999). Rather than reducing melatonin suppression by 50% relative to binocular conditions, as might be expected, the efficacy of monocular light exposures for suppressing nocturnal melatonin could be as low as about 10% (i.e., 90% melatonin is preserved).

Integrating previous findings, the present study was designed to determine whether melatonin levels, visual performance, and alertness would be preserved at night by filtering short wavelengths of just one eye using a blue-blocking filter. A blue-blocking filter over both eyes is known to preserve melatonin synthesis at night because the retinal neural circuit that stimulates the SCN is much less sensitive to wavelengths greater than about 540 nm (Sasseville et al., 2006). Thus, we would expect that “blinding” the retinal circuit responsible for nocturnal melatonin suppression in one eye with a blue-blocking filter, melatonin levels could remain high under lighting conditions that would otherwise suppress nocturnal melatonin for unattenuated binocular vision.

In terms of performance, binocular vision is almost always better than monocular vision (Sheedy et al., 1986), even though some studies have shown that occlusion of the non-dominant eye does not seem to affect reading speed or any visual task that does not require depth perception (Coull et al., 2000; Johansson et al., 2014; Olivier et al., 1998). Further, lower levels of nocturnal melatonin (as can occur under LAN) are not always associated with lower levels of alertness (Kayumov et al., 2005; Rahman et al., 2013) or greater sleepiness (Van de Werken et al., 2013).

Here, we hypothesize that by spectrally filtering one eye (1) melatonin levels will be preserved to levels similar to those under dim conditions and similar to those when both eyes are spectrally filtered, (2) subjective sleepiness will not be higher than that for unfiltered binocular vision, and (3) visual performance will be similar to that for unfiltered binocular vision. These results would have significant implications for night-shift nurses, as it could protect them from suppression of melatonin by LAN and still maintain visual performance and alertness. Finally, since pupil constriction following prolonged viewing of a luminous field has been used as a correlate to light-induced nocturnal melatonin suppression (Bonmati-Carrion et al., 2016; Markwell et al., 2010), pupil area was also measured under the different light conditions. Here, we hypothesize that larger pupil area will be associated with greater melatonin AUC.

Methods

Subjects

Subjects were recruited via word of mouth, social media, and an information table at a community farmer's market. To qualify for the study, subjects were required to be between the ages of 18 and 60 years, speak English, and maintain a regular sleep schedule with bedtimes before 24:00 and wake times before 08:00. Through interviews, subjects were excluded if they had major health issues (e.g., diabetes, cardiovascular disease, bipolar disorder, and/or seasonal depression) or were keeping an irregular sleep schedule that commenced after 24:00 and ended later than 08:00. Subjects were not eligible if they took beta blockers, antidepressants, or sleep aids, including melatonin. They could only participate if their vision was not compromised by diseases or conditions like glaucoma, macular degeneration, cataract, or color blindness. All eligibility criteria were self-reported, though the participants' sleep schedules were monitored via actigraphy and they were issued reminders to be in bed before 24:00 and wake before 08:00. Subjects were not required to maintain any particular lighting regimen other than their usual daily lifestyles.

Prior to commencement of the experiment, participants were (1) reminded of the study's sleep schedule requirements, (2) instructed to refrain from taking melatonin, (3) instructed to abstain from caffeine after 14:00, (4) advised to eat a meal before arriving at the lab (as the consumption of food of any kind was not permitted during the sessions), (5) advised to take a daytime nap if needed, but only on the day of the session, and (6) instructed to avoid taking daytime naps at all other times for the duration of the experiment.

Twenty-nine eligible subjects were scheduled to participate in the study, composed of six Friday nights. A total of 26 subjects (22 females, four males; mean [SD] age of 38 [12.8] years; median age of 35 years) completed all six nighttime sessions; three subjects who did not complete all six nighttime sessions were excluded (two participants completed three sessions, and one participant completed one session). It was not possible to analyze saliva samples from one subject for one session, so data from 25 subjects were included in the melatonin analyses. Ethical approval for this study/case/case series was obtained from the Mount Sinai Health System Institutional Review Board (STUDY-23-00816). Written informed consent was obtained from all participants in this study.

Laboratory Setup

The laboratory setup for the study is shown in Supplemental Figure S1. Eye-level radiometric measurements (Gigahertz, Model MSC15, Turkenfeld, DE; calibrated by the manufacturer November 2023) from the general illumination in the lab were measured at every seating position. Illumination was provided by light emitting diode (LED) ceiling-mounted diffuse troffer-style luminaires (model RDD-XZPK-030-A0700-Y, RAB Lighting, Inc., Cranbury, NJ, USA) located 2.6 m above floor level. The average vertical photopic illuminance was 503 lx (SEM = 8 lx), which for the spectral power distribution (SID) of the general illumination (Figure 1) produced an average circadian-effective light level (CL_A) = 419 and a corresponding circadian stimulus (CS) level = 0.38. The dim lab lighting used for the study's two control conditions provided a vertical photopic illuminance of ≤ 3 lx at the cornea.

Briefly, CL_A is spectrally weighted irradiance based upon the spectral sensitivity of the human circadian system and comparable to photopic illuminance, and CS represents the magnitude of the retinal response to CL_A (Rea et al., 2005; Rea et al., 2021a, 2021b). To determine CS levels, the average photopic illuminance level and SID measured at all seat locations served as input to a publicly available online CS Calculator 2.0 (Light and Health Research Center, 2021). The CL_A , CS, α -opic quantities (Commission Internationale de l'Éclairage, 2018) and other radiometric and colorimetric quantities for the average illuminance recorded in the laboratory are provided in Table 1.

Protocol and Light Conditions

A crossover, within-subjects design was employed for six nights, starting at 22:30 and ending at 04:00 the next day. Small groups of two or three participants were rotated in a counterbalanced order through all six light conditions after a 30-minute dim light adaptation period (same illuminance as the dim lab lighting described above), one light condition per night: (1) unfiltered binocular vision (BB); (2) unfiltered monocular vision (BM) using an opaque eyepatch (Medline Industries, Northfield, IL USA or Grafcop, Atlanta, GA USA) over the non-dominant eye; (3) a blue-blocking (orange) filter (NoCry, Las Vegas, NV, USA) over both eyes (FB, Figure 2A); (4) the same blue-blocking filter over the non-dominant eye (FM, see Figure 2B); (5) binocular dim control (DB); and (6) monocular dim control (DM) using an opaque eyepatch over the non-dominant eye. Figure 1 shows the SID of the filtered room illumination (alongside the unfiltered illumination); the filter absorbs nearly all spectral power shorter than 530 nm. Figure 3 shows the light conditions and the sampling times for the dependent measures.

Participants were allowed to access their personal electronic devices during the session but were first provided with orange filter media (Roscolux Supergel, R20 medium amber, Rosco Laboratories, Stamford, CT) to cover the devices' display before the session began. Devices were inspected by the study coordinators to ensure the displays were completely covered and that brightness settings were dimmed. Participants were permitted and encouraged to interact with one another during intervals between the study tasks. Naps and exercise were not permitted. Participants were not permitted to eat or drink fluids other than water during

the session and were instructed to refrain from drinking 15 minutes prior to each saliva melatonin sample.

All participants left the lab within 5–20 minutes of the session's conclusion. All participants were offered rideshare transport to and from the lab, which was paid for by the research team and did not affect their compensation of USD \$150 per session (total possible compensation of USD \$900 for all six sessions). As requested by the Institutional Review Board, those who declined the rideshare signed a release waiver acknowledging they had been advised against driving at night and opted out of free transportation. No testing was carried out to determine whether participants were capable of driving safely.

Study Outcomes

The study employed normalized melatonin area under the curve [AUC_n] values based on the raw saliva sample concentrations as the primary outcome. To calculate AUC_n , we first scaled all melatonin concentrations (pg mL^{-1}) for each light condition at time S2 (the last measurement during the dim light adaptation period) to be equal to unity. This provided a unique normalization ratio for each light condition. These normalization ratios were then applied to the melatonin concentrations at each hourly time point (S2 through S12) to obtain normalized concentration values [$(\text{pg mL}^{-1})_n$] for that light condition. AUC_n values [$(\text{pg mL}^{-1} \text{ h})_n$] were computed using the trapezoidal rule, which approximates the integral of the normalized concentration values by summing the areas of the trapezoids formed between pairs of consecutive time points.

AUC_n values were selected as the primary outcome measure because the average raw melatonin concentration values at S2 were not the same for all light conditions. To minimize compromising statistical inferences about the light conditions, it was necessary to normalize concentrations to those at S2 to help mitigate potential confounding session differences with light condition differences before calculating the integrated values (AUC_n) for each light condition.

The numerical verification (NVT) and go/no-go (GNG) performance tasks, pupil area, and subjective sleepiness (Karolinska Sleepiness Scale [KSS]) were secondary outcomes.

Salivary Melatonin: Twelve saliva samples were collected from every subject over the course of the night. The first two samples were collected 2 minutes apart in dim light at the start of the study to help ensure sample reliability under identical (dim) conditions and to provide a basis for normalization across sessions. Ten additional samples were collected every 30 minutes while participants were experiencing each of the six light conditions. Samples were collected and frozen for subsequent melatonin assay using a commercially available ELISA assay kit (Eagle Biosciences, Amherst, NH, USA). The assay's limit of detection specified by the manufacturer was 0.62 pg/mL, with intra- and inter-assay coefficients of variability of 5.1% and 9.8%, respectively.

NVT Performance: Three scheduled times each night, participants performed the NVT (Rea, 1981) on their designated laptop computers (ThinkPad E14 [355 mm screen], Lenovo, Morrisville, NC, USA). On a given trial, participants were required to compare two columns

of 20 five-digit numbers on a page displayed on the computer screen. The two columns of numbers were the same except for randomly located digits. Mismatched digits varied in frequency from zero to six (a mean of three) per page. If a mismatch was identified, participants were instructed to double-click on the five-digit number in the right column, after which the cell containing the number would be shaded red. Upon completing each page, participants double-clicked a button near the bottom of the screen and advanced the display to the next page. Each column of 20 numbers subtended 100 mm vertically and 15 mm horizontally. The columns were separated horizontally (center-to-center) by 60 mm, approximately 7.5° apart. The numbers were displayed in negative polarity with white digits against a black background. The contrast (C) between the luminance of the digits (L_d) and the luminance of the background (L_b) under each lighting condition was always ≥ 0.99 using the formula: $C = (L_d - L_b)/L_d$.

The number text size varied on alternating pages between 11-point Lucida Console (large; each digit subtending a solid angle of 5.8 microsteradians from a viewing distance of 450 mm) and 6.5-point Lucida Console (small; each digit subtending 2.0 microsteradians) typeface. Participants were asked to complete as many pages as possible within a 10-minute period. The NVT software was developed by the experimenters using Excel (Office 2007, Microsoft Inc., Redmond, WA, USA), recording the time taken to complete each page as well as the number of “hits” (correctly identified mismatches), “misses” (mismatches not identified), “correct rejections” (matches correctly ignored), and “false positives” (matched numbers that were nonetheless marked as mismatched) for each page.

GNG Performance: Following completion of the NVT, participants performed the GNG performance task on their designated laptop computer, as described in Figueiro et al. (2016). Briefly, the participants were required to respond by pressing the keyboard space bar as quickly as they could when the word “GO” was displayed in the middle of the computer screen and not to press the space bar when “NO GO” was displayed and to wait for the next prompt to appear without pressing any keys. Each prompt would appear on the screen for a maximum of 2 seconds (if the space bar was not pressed) before proceeding to the next display. If a participant committed any errors (e.g. missed pressing the spacebar on a GO or pressed the spacebar on a NO GO), an error message would appear for 2 seconds. When the space bar was pressed for a GO, the text would disappear immediately. The screen would turn blank for 0.5 seconds between each change in event to indicate a new prompt. For a given block of trials, both GO and NO GO were randomly displayed a total of 150 times each.

The background was black with white text (Segoe UI font, with the same contrast as the NVT task) that was 25 mm tall (subtending 3° of visual angle from 450 mm) on full-screen mode. Response times, false positives (pressing the space bar after NO GO), and misses (not pressing the space bar after GO) were recorded. The version of the GNG performance task used in the first study section was developed by the experimenters using online software (PsyToolkit 3.4.0; University of Glasgow, Glasgow, UK). Because some experimental data were lost via the online platform for this task, an identical GNG task was developed by the experimenters using QB64 (R. Galleon/QB64Team, Open Source). The functionality for this task was the same for both study sections.

Subjective Sleepiness: At the appointed times, participants rated their feelings of sleepiness on a scale from 1 (extremely alert) to 9 (very sleepy, great effort to keep awake, fighting sleep) following the KSS (Åkerstedt & Gillberg, 1990; Kaida et al., 2006).

Pupil Area: Pupil area (natural) was measured at two time points throughout each session only for the BB, BM, FB, and FM conditions. Twice each night, a stand-mounted video camera (Minolta, Model MN4K30NV, New York, NY) was used to capture images of each participant's dominant eye (Supplemental Figure S2). The participant order for collecting images of the eye was arbitrary. While the image was being collected, the participant held a small ruler below the eye and was asked to fixate an array of three dimmed white LEDs that was positioned behind the camera (see Supplemental Figure S1). The array had an SID similar to the illumination in the laboratory and produced a vertical illuminance of 0.5 lx at participants' eyes, less than 0.1% of the total illuminance at the eyes. Two images were captured from every participant at each pupil measurement time (P1 and P2; see Figure 3), for a total of four images per session, to help ensure adequate image quality for the pupil area calculation.

Each image of the participant's dominant-eye pupil, including the ruler they held, was evaluated by first determining the pixel length of 10 mm along the ruler's edge. Next, the diameter (in pixels) of the visible pupil was calculated. From these measurements it was possible to estimate the pupil area (in square millimeters, assuming a circular pupil aperture) for each image.

Data and Statistical Analysis

A one-way ANOVA was conducted using the normalized melatonin AUC_n to determine if there were significant differences between the light conditions. For the other outcomes (NVT speed, proportion of NVT error responses, GNG response time, proportion of GNG error responses, pupil area, and subjective sleepiness ratings), two-way, within-subjects ANOVAs were carried out to assess the main effects of light condition, time of night and the interaction between them. Due to data loss from technical difficulties, missing data from 17 participants were imputed to provide complete data sets for the ANOVAs for the GNG task. Although not the primary purpose of this study, to assess the impact of text size on NVT speed, a paired Student's t-test was performed on the speed for each participant and text size. Finally, the correlation between the mean pupil areas for each of the non-dim conditions and the mean melatonin AUC_n values for the four corresponding conditions and the 25 subjects with complete melatonin data was computed.

We also conducted five planned pairwise comparisons. By limiting the number of planned comparisons to five, the probability of a Type I error ($p < 0.05$) does not need to be adjusted (McGuigan, 1997).

1. BB vs FM. The primary purpose of the present study was to determine if the filtered monocular (FM) light condition had higher melatonin levels than the unfiltered bright binocular (BB) light condition while still maintaining the same performance and subjective sleepiness levels.

2. FM vs DM. As corollary to the first comparison, it was important to determine if the filtered monocular (FM) light condition was the same for the dim monocular (DM) control condition for all outcome measures.
3. FB vs DB. To confirm a previous study (Sasseville et al., 2006), we sought to determine if all outcome measures were the same for the filtered binocular (FB) light condition as for the dim binocular (DB) control condition.
4. BB vs BM. To confirm previous studies (Brainard et al., 1997; Wang et al., 1999), we sought to determine if all outcome measures for the unfiltered bright binocular (BB) light condition were different from the unfiltered bright monocular (BM) light condition.
5. FM vs BM. Since previous studies (Brainard et al., 1997; Wang et al., 1999) showed that melatonin could be preserved for the unfiltered bright monocular (BM) light condition, it was important to compare this condition to the filtered monocular (FM) light condition for melatonin and for the other outcome measures.

Results

The inferential statistics for all outcomes are summarized in Table 2. The only statistically significant effect of time of night was on subjective sleepiness as evidenced in the KSS ratings (see Subjective Sleepiness), which increased gradually and consistently over the course of the night as would be expected, irrespective of light condition. No statistically significant interactions between time of night and light condition were identified. Given these considerations, time of night is not discussed further.

Salivary Melatonin

As shown in Table 2, there was a significant main effect of light condition on AUC_n . From the planned paired comparisons, melatonin AUC_n was significantly higher for FM than for BB. In addition, there was no significant difference between FM and its control condition, DM, nor between FM and BM. Melatonin AUC_n was significantly higher for the BM condition than for the BB condition. Figure 4 shows the mean melatonin AUC_n values for each light condition, and the planned comparisons that yielded statistically significant differences. Supplemental Figure S3 shows the raw, mean melatonin concentrations for each time under each light condition.

NVT Performance

Text sizes, large versus small, were used in the study to show that the NVT is sensitive to factors that affect visual performance. As expected, visual performance was worse for the small size than for the large size text. This difference was highly statistically significant ($t_{482} = 12.5$, $p = 2 \times 10^{-31}$) with the large text providing a 9.5% faster performance speed. In comparison, a model of relative visual performance to predict speed and accuracy of visual processing as a function of light level, task contrast and size (Rea & Ouellette, 1991) yielded a similar difference of 8.8% in task speed when reading text differing in sizes as they did in the present study.

There was not a statistically significant main effect of light condition on NVT speed (see Table 2). For the proportion of errors, there was a statistically significant main effect of light condition (see Table 2). Subsequent pairwise comparisons revealed that the BB condition had a lower proportion of errors than BM while the FM and BB conditions were not statistically different. Finally, the FM condition had lower proportion of errors than the DM condition.

GNG Performance

There was not a statistically significant main effect of light condition for the response times and for proportion of errors (see Table 2).

Subjective Sleepiness

There was not a statistically significant main effect of light condition for KSS scores (see Table 2).

Pupil Area

There was a statistically significant effect of light condition for pupil area (see Table 2). Mirroring the melatonin AUC_n results, pupil areas (Figure 5) were significantly smaller for the BB condition than for the FM or BM conditions. Also, there was no significant difference between the FM and BM conditions in terms of pupil area.

To compare pupil areas under each of the non-dim conditions to nocturnal melatonin AUC_n values for the corresponding measured conditions, mean pupil areas were plotted as a function of mean melatonin AUC_n values for the 25 subjects who had complete sets of data for both outcomes (Figure 6). The goodness of fit (r^2) for the best fitting linear function relating the two outcome measures was 0.83, which was statistically significant ($p = 0.002$).

Discussion

The present study set out to investigate the impact of a blue-blocking filter worn over participants' non-dominant eye on melatonin levels, subjective sleepiness, and performance in healthy adults. Previous research has shown that by occluding one eye, melatonin levels after exposure to the similar irradiance and duration of light were only reduced by about 10%, not by 50% as one might expect (Brainard et al., 1997; Spitschan & Cajochen, 2019; Wang et al., 1999). The present results replicated these earlier studies by demonstrating that occlusion of one eye during light exposure (BM) preserved melatonin concentrations as if the participants had remained in dim light, indicating that monocular vision has reduced ability to affect the biological clock as measured by nocturnal melatonin suppression.

However, the disadvantage of occluding one eye is that visual performance—especially depth perception—may be compromised. This is particularly relevant for night-shift nurses, who require good visual performance to ensure patient safety and high-quality care. Therefore, we set out to test whether filtering short-wavelength light in one eye would preserve visual performance and melatonin concentrations. As hypothesized, we showed that melatonin AUC_n for the FM (orange filter over one eye) condition was not significantly

different than DM (one eye occluded under dim light) light conditions, which means that melatonin levels were preserved with the orange filter over one eye. Consistently, melatonin AUC_n for FM was also significantly higher than for the unfiltered binocular (BB) condition, which is similar to many nighttime working environments (Berkalieva et al., 2025; Razavi et al., 2019). These findings suggest that filtering one eye with an orange filter may help maintain melatonin levels in those working at night.

In terms of both performance and subjective sleepiness, there was no difference between FM and BB conditions, suggesting that covering one eye with an orange filter maintains visual performance. More importantly, orange-filtering one eye (FM) was better for visual performance (accuracy) than occluding one eye (BM). Because occluding one eye to preserve nocturnal melatonin concentrations can compromise visual performance, it would seem preferable to use an orange filter covering one eye so that melatonin can be preserved without compromising performance.

As shown in previous studies, subjective sleepiness increased over the course of the night, but there was no significant effect of light condition on KSS scores, even though melatonin concentrations were significantly reduced in the BB (i.e., unfiltered binocular vision) condition compared to other conditions. Consistent with previous studies, these results suggest lower levels of melatonin are not always associated with lower levels of alertness or of greater sleepiness (Kayumov et al., 2005; Rahman et al., 2013). Indeed, previous work showed that narrowband long-wavelength, red light (peak close to 630 nm), which did not suppress melatonin, had alerting effects and preserved performance in those awake at night (Figueiro et al., 2009; Figueiro & Pedler, 2023; Figueiro et al., 2019). The use of a blue-blocking filter over the non-dominant eye, alone or in combination with red light during break periods, may be a practical method to maintain performance while reducing melatonin suppression by bright ambient lights in night-shift nurses.

The present results are consistent with those of Higuchi et al. (2008), who reported that melatonin suppression values were correlated with pupil area measurements. These results are also consistent with studies (Noe, 2024; ten Doesschate & Alpern, 1967) which, as with melatonin suppression, suggest that a maximum pupil (constriction) response requires binocular vision.

In summary, and perhaps most importantly, the melatonin AUC_n values in the FM condition were significantly higher than in the BB condition, the latter of which would be normal in the nurses' work environment. Further, albeit lower, melatonin AUC_n values in the FM condition were not statistically different than DM, the dim control condition. Equally important, there was no statistical difference between BB and the FM conditions in terms of subjective sleepiness or performance.

A potential limitation of the present study is that the experiment was performed in the laboratory employing performance tasks that may not adequately mirror those performed in real-life field situations. The female participants outnumbered the male participants, reflecting the night-shift nurses population in the United States. Half of the female participants were pre-menopausal, and their menstrual phase was not controlled. Although it

has been shown that cognitive performance at night may vary across menstrual phase (Grant et al., 2020), the impact of the menstrual phase on melatonin levels has been debated in the literature (Berga & Yen, 1990; Parry et al., 1997; Wright & Badia, 1999). Nevertheless, we cannot rule out a possible confound between menstrual cycle and light condition for some subjects. Additionally, although reflecting the composition of the night-shift nurses population, the participants' age range was large and could have introduced variation in the light response due to age-related changes in the eye. The within-subjects nature of our study, however, should minimize these individual differences when comparing the various light conditions. Finally, acceptance of the intervention was not assessed.

Future studies should investigate the intervention's acceptability in the field and how it might impact tasks typically performed by shift workers, such as nurses in hospitals, including investigations of impacts over longer durations (e.g., weeks or months of shift work). As part of next steps in our research, we are beginning to assess such questions in a hospital setting.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability statement

Data from this study will be made available by the corresponding author to any qualified researcher(s) upon reasonable request.

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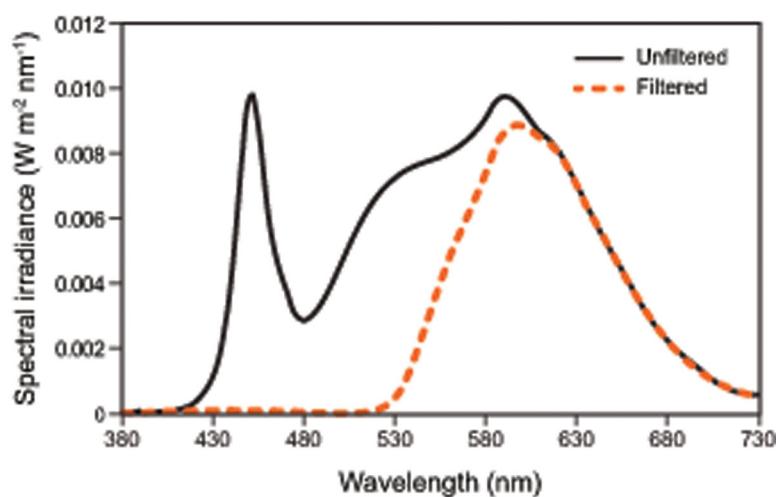


Figure 1. Spectral irradiance of the laboratory lighting, both unfiltered and filtered through the eyewear employed in two of the light conditions (see Protocol and Light Conditions).

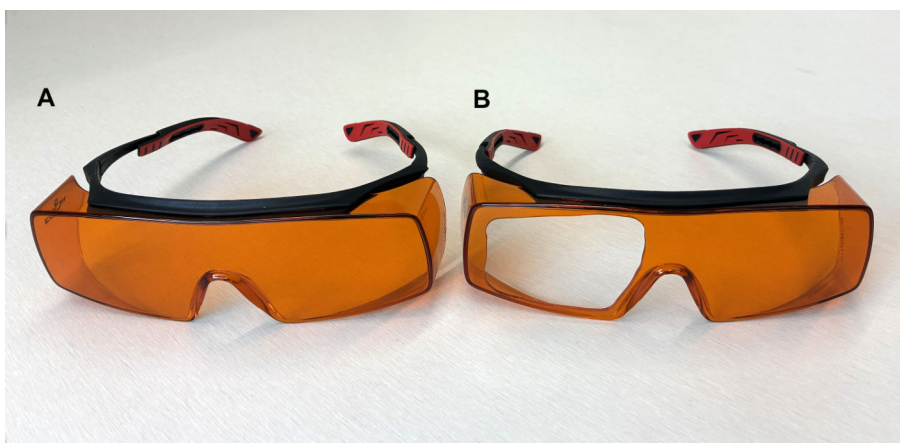


Figure 2. Blue-blocking filters employed in the FB (A) and FM (B) filtered eyewear conditions. The filter labelled B is configured for a left-eye-dominant individual; right-eye-dominant individuals were assigned a filter in a reverse configuration.

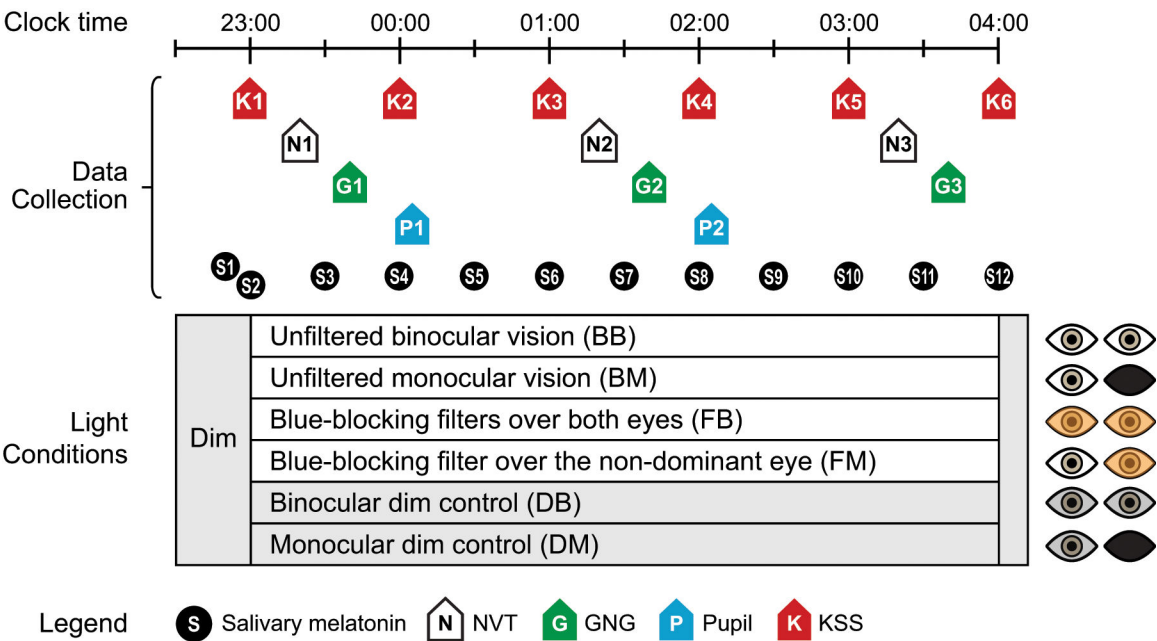


Figure 3. The study protocol, showing the schedule for data collection (top half) and the light conditions (bottom half). The schematics on the lower right represent the filtering (or lack thereof) and eye covering employed in each light condition.

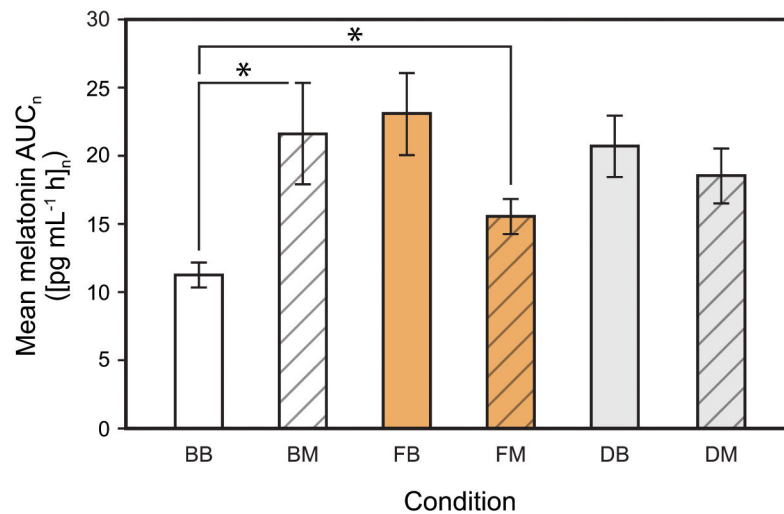


Figure 4.

Mean melatonin AUC_n values for each light condition, showing the significant differences among light conditions for the planned comparisons. The asterisks represent $p < 0.05$.

The error bars represent standard error of the mean. Abbreviations: BB = unfiltered bright binocular, BM = unfiltered bright monocular, FB = blue-blocking filter over both eyes, FM = blue-blocking filter over the non-dominant eye, DB = dim binocular control, DM = dim monocular control.

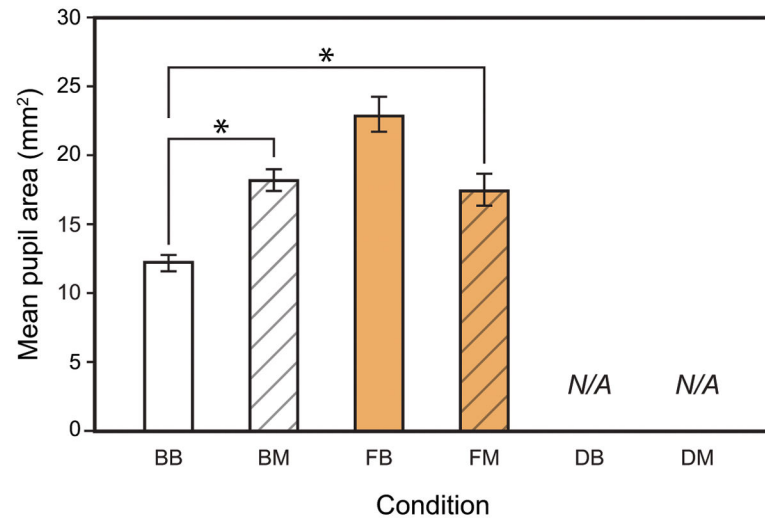


Figure 5.

Mean pupil areas for each light condition, showing the significant differences among conditions for the planned comparisons. The asterisks represent $p < 0.05$. The error bars represent standard error of the mean. Abbreviations: BB = unfiltered bright binocular, BM = unfiltered bright monocular, FB = blue-blocking filter over both eyes, FM = blue-blocking filter over the non-dominant eye, DB = dim binocular control, DM = dim monocular control.

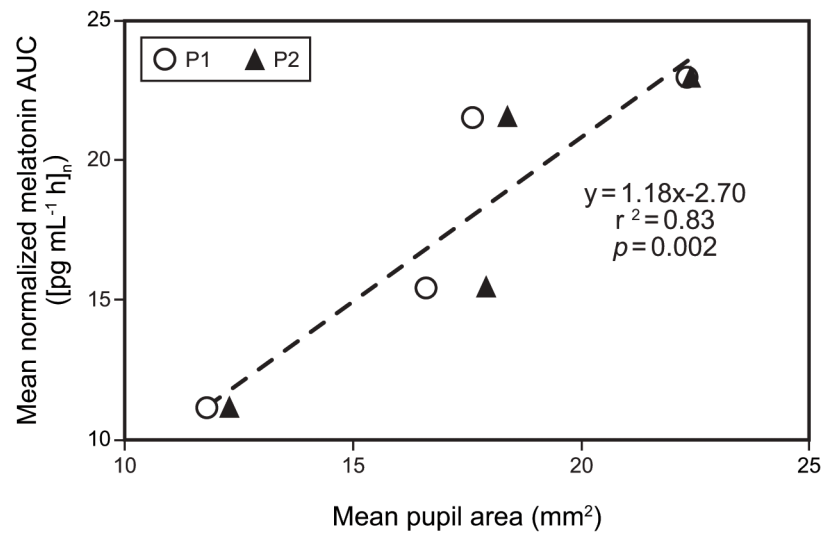


Figure 6.

Mean melatonin AUCn values for each non-dim light condition, plotted as a function of the mean pupil area for the corresponding light conditions at both times of the night. The data collection times (P1, P2) are shown in Figure 3.

Table 1

Mean radiometric and colorimetric values for the laboratory illumination

Characteristic	Value
Vertical photopic illuminance	503 lx
Vertical irradiance	1.49 W m ⁻²
Correlated color temperature	4050 K
Color rendering index	83
Gamut area index	69
CL _A	419
CS	0.38
Melanopic equivalent daylight illuminance	310 lx
CIE S-cone irradiance	0.22 W m ⁻²
CIE M-cone irradiance	0.65 W m ⁻²
CIE L-cone irradiance	0.82 W m ⁻²
CIE rhodopic irradiance	0.50 W m ⁻²
CIE melanopic irradiance	0.41 W m ⁻²

Note: CIE characteristics after Commission Internationale de l'Éclairage (2018). CL_A and CS metrics after Rea et al. (2021a), and Rea et al. (2021b).

Table 2.

Summary of omnibus statistical tests and planned comparisons among light conditions for each outcome measure

Outcome	Subjects (n)	Omnibus test	Planned comparisons among light conditions				
			BB v FM	FM v DM	FB v DB	BB v BM	FM v BM
Melatonin AUC _n	25	Condition: $F_{5,120} = 4.86, p < 0.001^*$	$p = 0.01^*$	n.s.	n.s.	$p = 0.007^*$	n.s.
NVT speed	26	Condition: $F_{5,125} = 2.22, p = 0.06$	n.s.	n.s.	n.s.	n.s.	n.s.
		Time: $F_{2,50} = 0.35, p = 0.706$					
		Interaction: $F_{10,250} = 1.03, p = 0.422$					
NVT error proportion	26	Condition: $F_{5,125} = 3.58, p = 0.005^*$	n.s.	$p = 0.0003^*$	n.s.	$p = 0.009^*$	n.s.
		Time: $F_{2,50} = 2.25, p = 0.116$					
		Interaction: $F_{10,250} = 0.48, p = 0.905$					
GNG RT	26	Condition: $F_{3,35,73.8} = 0.96, p = 0.424$	n.s.	n.s.	n.s.	n.s.	n.s.
		Time: $F_{1,1,24,1} = 2.68, p = 0.112$					
		Interaction: $F_{3,1,68,2} = 1.36, p = 0.263$					
GNG error proportion	26	Condition: $F_{2,96,56.3} = 0.94, p = 0.424$	n.s.	n.s.	n.s.	n.s.	n.s.
		Time: $F_{1,29,24,6} = 3.31, p = 0.07$					
		Interaction: $F_{3,79,71,9} = 0.83, p = 0.506$					
KSS ratings	26	Condition: $F_{5,125} = 1.29, p = 0.272$	n.s.	n.s.	n.s.	n.s.	n.s.
		Time: $F_{5,125} = 91.0, p < 0.001^*$					
		Interaction: $F_{25,625} = 0.94, p = 0.549$					
Pupil area	26	Condition: $F_{3,75} = 23.9, p < 0.001^*$	$p = 4e-13^*$	N/A	N/A	$p = 5e-20^*$	n.s.
		Time: $F_{1,25} = 2.47, p = 0.128$					
		Interaction: $F_{3,75} = 0.29, p = 0.832$					

Abbreviations: BB = unfiltered bright binocular, BM = unfiltered bright monocular, FB = blue-blocking filter over both eyes, FM = blue-blocking filter over the non-dominant eye, DB = dim binocular control, DM = dim monocular control, N/A = not applicable, n.s. = not statistically significant ($p \geq 0.05$).