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# EVALUATION OF THE SAFETY OF USING COMMERCIALLY AVAILABLE BLUE-BLOCKING LENSES UNDER DIFFERENT BLUE LIGHT EXPOSURES

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**Abstract- Background: A new generation of blue-blocking lenses (BBLs) are now commercially available and marketed under different brand names. They have been designed for everyday wear, particularly in the evening to reduce ocular exposure to blue-light hazard from nascent light-emitting diodes (LEDs) screens and devices that might interfere with physiological processes involved in the regulation of the circadian rhythm and thus sleep patterns.**

**The aims of this study were: 1) to estimate the protective effect of commercially available BBLs against retinal damage by natural and artificial light sources and 2) to evaluate melanopic ratio these BBLs under the different light sources.**

**Methods: Seven different types of BBLs from six manufacturers and an untinted control lens with three different powers (+2.00 D, −2.00 D and Plano) were evaluated. Blue- light irradiance (BLI) and the maximum permissible exposure duration for viewing five different light sources (4100K Fluorescent, daylight "clear sky", 58lux laptop, 45lux smartphone) were calculated based on the guidelines published by the International Commission on Non- Ionizing Radiation Protection (ICNIRP, 2013) and the American Conference of Governmental Industrial Hygienists (TLVs® and BEIs®, 2015). The melanopic irradiance effect of each BBL type was evaluated at all light sources based on CIE 026/E:2018. Finally, a correlation test was conducted to determine if the protective effect of BBLs is associated with the natural circadian cycle.**

**Results: All BBL types significantly reduced the potential photochemical damage to the retina if their use did not exceed the maximum permissible exposure duration. A significant positive correlation was found between the melanopic ratio and hazard ratio among all BBL types (r = 0.876 (+2.00D); r = 0.827 (Plano); r = 0.918 (-2.00D). These results suggest that BBLs offer protection against damage by the artificial blue light, but at the same time, does not adequately allow natural blue light to activate intrinsically photosensitive retinal ganglion cells (ipRGCs) vital in controlling circadian entrainment and melatonin secretion.**

**Conclusion: The attenuation of short blue wavelengths through different BBL types significantly reduce the potential photochemical damage it can cause to the retina. The natural circadian cycle can be potentially altered by the exposure to the artificial blue light of digital devices, but the same lens does not interfere with the natural rhythm of the circadian cycle in the case of natural, solar light exposure.**

**Keywords: Blue-blocking lenses, hazard ration, melanopic ratio**

## 1. INTRODUCTION

Previous research utilising animal models and cell culture experiments have shown that exposure (from seconds to hours), to high irradiance white light above 10 $mW.cm^{-2}$ can result in photochemical damage to retinal cells [1,2]. However, the extent of damage to cells is particularly evident at shorter wavelengths of light and sharply peaks at blue light of approximately 440 nm [1,2]. The action spectrum posing a blue-light photochemical retinal hazard (BLH) is broad and ranging in wavelengths of between 400 and 500 nm,[1,3] and the extent of damage can be serious. For example, previous studies have reported that retinal damage in animal models after 48 hours of exposure to blue light,[1,4] is similar to that caused by directly viewing a solar eclipse over the same length of exposure, and regular exposure to intense sunlight over years is associated with the development of age-related macular degeneration (AMD) in elderly humans [5].

To address the potentially harmful effects of blue light, recent optical technologies in the form of wearable lenses and overlays have been designed to block short wavelengths of light (i.e., blue light) that are known to be hazardous to vision. Most popular are blue-blocking lenses (BBLs) which are now commercially available and marketed under different brand names. They have been designed for everyday wear, particularly in the evening hours to reduce exposure to blue light from artificial sources and frequently used electronic devices (such as laptops, electronic tablets and mobile phones). In our previous work, we demonstrated that a number of commercially available BBLs may offer considerable protection to vision as they have transmittance profiles that selectively attenuates hazardous blue-light (400nm-500nm) compared to a clear lens without blue-light filtering [6,7].

The potential effectiveness of BBLs in protecting vision can be quantified by determining their safety exposure limit to blue light from natural and artificial sources. The safety exposure limit is determined by calculating two parameters: blue-light

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retinal irradiance ($E_{blue}$) values and the corresponding maximum permissible exposure duration per day ($t_{max}$). These parameters were introduced by the International Commission on Non- Ionizing Radiation Protection Guidelines,[8] which estimate the ability of the BBLs to prevent retinal damage caused by different light sources. Previous studies examining older generation BBLs by Comparetto R et al.[9,10] showed that while they can protect retinal cells from the photochemical damages due to blue light, BBLs do not allow enough natural blue-light to reach the intrinsically photosensitive retinal ganglion cells (ipRGCs) [10] which contain the photopigment melanopsin, and is most sensitive to blue light at a wavelength of approximately 480 nm [11]. Such retinal ganglion cells are vital in controlling non-visual physiologic responses in the human body including circadian entrainment and melatonin secretion [12].

Previous studies have investigated the effect of wearing BBLs on regulating the sleep-wake cycle. Evening use of amber lenses (that completely block blue wavelengths less than 550 nm) for 3 hours prior to sleep showed subjective improvements in both sleep quality and mood [13]. Wearing BBLs during evening hours while viewing a LED screen or a bright light prevented light-induced night-time melatonin suppression [14,15]. Short-wavelength blocking glasses (yellow tinted) have also been shown to prevent melatonin suppression from bright light during simulated shift work at night [16]. Wearing Uvex BBLs (yellow-tinted lenses that block 99% of blue light) before sleep, decreases the night-time blue light exposure and helped regulate the circadian rhythm [17]. In contrast, blocking short blue wavelengths in the morning with orange-tinted BBLs delayed circadian phase in young adults [18,19].

While the potential benefits of older BBLs have been investigated, they have been superseded by newer generation lenses that have been designed to be cosmetically transparent. These BBLs are designed to effectively attenuate short wavelengths (400 nm-500 nm) by 6%–43%,[6,7] and have transmittance profiles that are substantially different from older designs. Importantly, the potential protective effect and their effect on circadian entrainment and melatonin secretion of new generation BBLs have not been thoroughly investigated [20,21]. The goals of the present study were to address this paucity in knowledge and to 1) to estimate the protective effect of newer generation commercially available BBLs against retinal damage by natural and artificial light sources and 2) to evaluate the melanopic ratio of newer generation BBLs under the different light sources.

## 2. METHODS AND MATERIALS

### *Samples*

In this study, seven different types of BBLs by six manufacturers with three different powers (+2.00 D, −2.00 D and Plano) were evaluated. These lenses were the Crizal Prevencia and Smart Blue Filter (Essilor), Blu-OLP (GenOp), Blue Control (Hoya), UV++Blue Control (JuzVision), SeeCoat Blue UV (Nikon) and Blue Guardian (Opticare). All lenses function as a blue blocker based on either absorption or reflection of the specific blue wavelengths and are from brands that are commonly available in the market place [6,7].

The spectral transmittance of these BBLs were measured using a Cary 5000 UV-Vis-NIR spectrophotometer (Model: EL04043683) with an integrating sphere and already reported in our previous work [6,7]. The transmittance profiles of these BBLs indicated that they are effective in selectively blocking short wavelengths of light while transmitting longer wavelengths. Our results show a degree of variability between lens types, the Blu-OLP lens was the most effective in blocking more blue light, as shown in Figure 1.

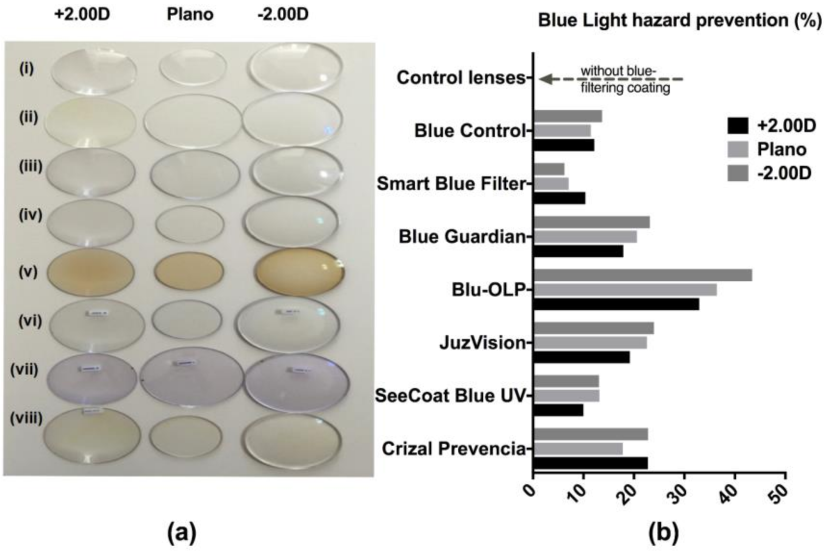


Figure 1: (a) Blue-blocking lenses (BBLs) evaluated in this study: i. Control lenses (without blue filtering coating); ii. Blue Control; iii. Smart Blue Filter; iv. Blue Guardian; v. Blu -OLP; vi. UV++Blue Control; vii. SeeCoat Blue UV; viii. Crizal Prevencia. (b) The blue light hazard prevention (%) of BBLs.

## 3. MEASUREMENTS

### *3.1 Hazard ratio*

Based on the International Commission on Non- Ionizing Radiation Protection Guidelines, the maximum permissible exposures duration per day ($t_{max}$ in seconds) for viewing a light source can be calculated using the following formula [8,25]:

$t_{max} = (100\ J.m^{-2})/E_{blue}$

where $E_{blue}$ is blue-light retinal irradiance. Exposure above this maximum time limit is expected to adversely affect retinal cells. Importantly, $t_{max}$ is useful as a cut-off limit for when the light source becomes hazardous to vision, particularly when the blue-light retinal irradiance value exceeds the safe exposure limit of 1 $W.m^{-2}$.

For a particular light source, the $E_{blue}$ value can be calculated using the following formula:

$E_{blue} = \int E(\lambda)\ B(\lambda)\ d\lambda$

Where $E(\lambda)$ is the spectral power distribution (SPD) of the light source ($W.m^{-2}$), $B(\lambda)$ denotes the blue-light hazard function, which conforms to the action spectrum over which blue-light is hazardous to the photochemical processes of retinal cells (indicated by the dashed line in Figure 2). This action spectrum can be applied as a weighting function to the spectral power distribution (spectral radiance) of a light source to yield a measure of the BLH potential of the source $E(\lambda)$. Importantly, this permits a direct comparison between the different radiation sources to determine the relative effectiveness or the potential hazard of each source.

The blue light retinal irradiance while wearing BBL can be expressed as,

$E_{blue,BBL} = \int E(\lambda)\ T(\lambda)\ B(\lambda)\ d\lambda$

Where $T(\lambda)$ is the spectral transmittance of the BBL. $E(\lambda)$ is the spectral power distribution (SPD) of a selected light source. Natural daylight and four different common light sources that have different proportions of BLH content in their spectral power distributions (SPDs) were evaluated in this study, including:

Daylight “clear sky”
4000K LED
4100K Fluorescent
Laptop, 45lux
Smartphone, 58lux

The potential photochemical injury due to exposure to blue light as given by the retinal hazard ratio, which was calculated for different BBLs and different light sources (different blue light exposures) using the following equation:

Retinal hazard ratio $R_{BLH} = ( \int E(\lambda)\ T(\lambda)\ B(\lambda)\ d\lambda)/( \int E(\lambda)\ B(\lambda)\ d\lambda)$

The retinal hazard ratio value ranges from 0 to 1. If $R_{BLH}= 0$, then the lens offers complete protection against blue- light photochemical retinal damage dt, while $R_{BLH}=1$ indicates no protection to hazardous blue-light by the lens.

### *3.2 Melanopic ratio*

The melanopic metric is a standardized measurement used to predict melanopsin photoactivation responses in the intrinsically photosensitive retinal ganglion cells (ipRGCs). These retinal ganglion cell type has been linked to the regulation of the human circadian system [26]. The melanopic curve is defined as the action spectrum of the spectral sensitivity of the ipRGCs ($S_{mel}(\lambda)$) with an effective wavelength around $\lambda= 480$ nm (indicated with a dashed curve in Figure 4).

The melanopic irradiance ($E_{mel}$) is defined as weighting of the light irradiance to the action spectrum of the spectral sensitivity of the ipRGCs ($S_{mel}(\lambda)$) [26-28].

For a particular light source, the melanopic irradiance can be calculated using the following formula:

$E_{mel} = \int E(\lambda)\ S_{mel}(\lambda)\ d\lambda$

As BBLs are designed to reduce the transmittance of short wavelengths of light (i.e., blue light), it is expected to reduce the melanopic irradiance described in the following formula:

$E_{mel,BBL} = \int E(\lambda)\ T(\lambda)\ S_{mel}(\lambda)\ d\lambda$

Where $E_{mel,BBL}$ denotes the melanopic irradiance when viewing through BBLs. $T(\lambda)$ is the spectral transmittance of the BBL. $E(\lambda)$ is the spectral radiance of light source.

In order to demonstrate how effective each BBL (across different lamps) is in reducing melanopic responses for a given lamp (i.e., the effect of light on the circadian clock), the melanopic ratio ($R_{mel}$) was calculated using the following equation:

Melanopic ratio $R_{mel}= ( \int E(\lambda)\ T(\lambda)\ S_{mel}(\lambda)\ d\lambda)/( \int E(\lambda)\ S_{mel}(\lambda)\ d\lambda)$

The $R_{mel}$ values range from 0 to 1, where a $R_{mel}$= 0, signifies that the BBL completely prevents melanopic action because it effectively blocks blue light that is most effective in driving this system. A $R_{mel}$=1 indicates that the BBL transmits blue light to completely activate the melanopic effect

## 4. RESULTS

Figure 2 shows the relative blue hazard of transmitted light through each BBL type. A one-way repeated measures ANOVA showed that there is a significant difference among different BBL types in terms of their ability to reduce the potential blue-light hazard that can cause damage to the retina ($p < 0.001$). Comparing the relative action spectrum of BLH for each BBL type with the standard action spectrum, Dunnett's multiple comparisons test showed that all BBL types significantly reduced the potential photochemical injuries to the retina due to blue light exposure ($p < 0.0001$ for all comparisons).

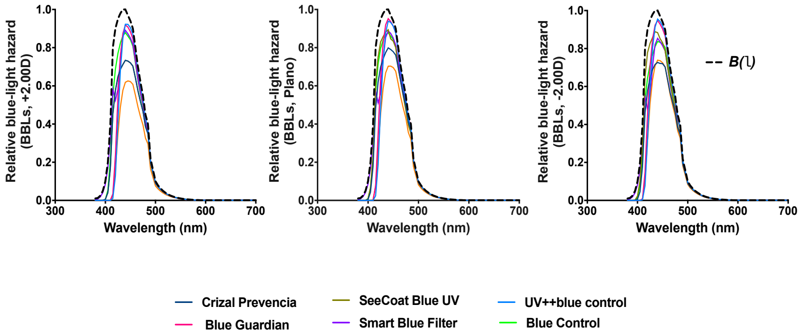


Figure 2: The relative hazard of transmitted light through each BBL type. Dashed lines represent the standard action spectrum for BLH (B(λ)) based on ICNIRP guidelines,[3] while solid coloured lines represent the action spectrum calculated for each BBL.

The International Standard IEC 62471:2006 indicates that there is a difference in the proportion of BLH content in the SPD of different lamp and lamp systems,[29] and the limited safety emission for BLH is $E_{blue,BBL} \leqslant 1.0$ $W.m^{-2}$. This limited exposure level is believed to protect the human eye against retinal photochemical injury from chronic blue-light exposure. Figure 3 shows that blue-light retinal irradiance values ($E_{blue,BBL}$)for different BBLs and light source combinations. For all artificial light sources, the $E_{blue,BBL}$ values were all at least 50 times less than the exposure limit of 1.0 $W.m^{-2}$. The maximum value of $E_{blue,BBL}$= 0.055 $W.m^{-2}$ (20 times less than the exposure limit) is found for SeeCoat Blue UV lenses with light exposure from 4000K LED. According to the International Commission on Non- Ionizing Radiation Protection Guidelines, all $E_{blue,BBL}$ values are below the maximum levels and is not expected to cause adverse effects even with exposure duration that exceeds 100 s. There was no common trend in the $E_{blue,BBL}$ values among the different lens powers.

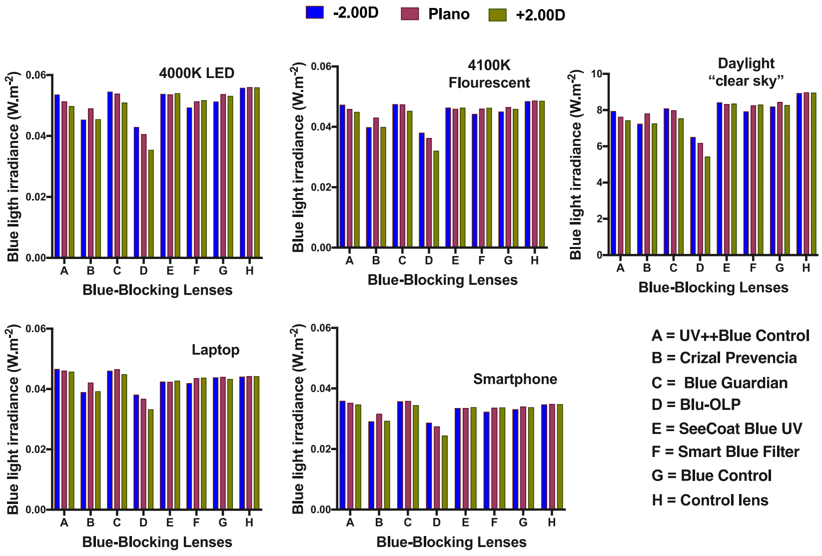


Figure 3: Blue-light irradiance values for different BBLs types ($E_{blue,BBL}$) at different blue light exposures.

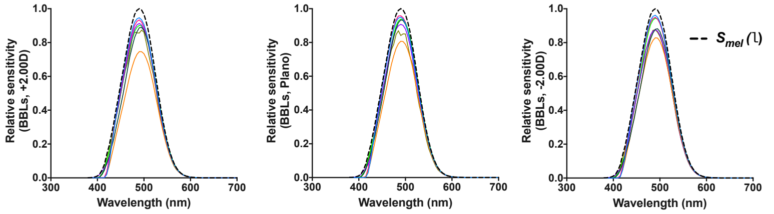
In contrast, the blue-light retinal irradiance values ($E_{blue,BBL}$) when viewing natural daylight exceeded the international exposure limits ($E_{blue,BBL}$= 1.0 W.m$^{-2}$), accordingly the prolonged exposure to this natural blue light can cause retinal damage. Therefore, the maximum permissible exposures durations per day ($t_{max}$ in seconds) for those $E_{blue,BBL}$ values need to be considered and must not exceed 100 s.

Table 1 shows the maximum permissible exposures durations per day ($t_{max}$ in seconds) for all BBL types. The longer durations were recorded for Blu-OLP lenses (15.34s -18.38s) that reduce most blue light and have a higher ability to reduce the adverse effect of blue light hazard (BLH).

Table 1: The hazard ratio ($R_{BLH}$) and maximum permissible exposure duration per day ($t_{max}$ in seconds) for viewing natural daylight while wearing BBLs

| BBL Type | Lens power | Hazard ratio $R_{BLH}$ | Maximum permissible exposure duration per day ($t_{max}$ in seconds) |
|---|---|---|---|
| UV++Blue Control | −2.00 D | 0.81 | 12.58 |
| | Plano | 0.78 | 13.10 |
| | +2.00 D | 0.76 | 13.44 |
| Crizal Prevencia | −2.00 D | 0.74 | 13.79 |
| | Plano | 0.79 | 12.80 |
| | +2.00 D | 0.74 | 13.75 |
| Blue Guardian | −2.00 D | 0.82 | 12.34 |
| | Plano | 0.81 | 12.51 |
| | +2.00 D | 0.77 | 13.24 |
| Blu-OLP | −2.00 D | 0.66 | 15.34 |
| | Plano | 0.63 | 16.17 |
| | +2.00 D | 0.55 | 18.38 |
| SeeCoat Blue UV | −2.00 D | 0.86 | 11.86 |
| | Plano | 0.85 | 12.00 |
| | +2.00 D | 0.85 | 11.96 |
| Smart Blue Filter | −2.00 D | 0.81 | 12.61 |
| | Plano | 0.84 | 12.10 |
| | +2.00 D | 0.84 | 12.03 |
| Blue Control | −2.00 D | 0.83 | 12.19 |
| | Plano | 0.86 | 11.86 |
| | +2.00 D | 0.84 | 12.08 |
| control lens | −2.00 D | 0.91 | 11.19 |
| | Plano | 0.91 | 11.14 |
| | +2.00 D | 0.91 | 11.17 |

Figure 4 shows the relative circadian sensitivity for each BBL type. One-way ANOVA test showed that there is a significant difference among different BBL types in terms of their ability to reduce light needed for melanopsin photoactivation responses ($p < 0.001$). Comparing the relative action spectrum of melanopic sensitivity for each BBL type with the standard action spectrum, Dunnett’s multiple comparisons test showed that all BBL types significantly reduced the melanopic effect of light and then they could have an adverse effect on the natural circadian clock ($p < 0.0001$ for all comparisons).



| | +2.00D | Plano | -2.00D |
|---|---|---|---|
| — UV++Blue Control | 0.01817 | 0.01622 | 0.01272 |
| — Crizal Prevencia | 0.03049 | 0.02091 | 0.03175 |
| — Blue Guardian | 0.01998 | 0.0133 | 0.01398 |
| — Blu-OLP | 0.06003 | 0.04668 | 0.04159 |
| — SeeCoat Blue UV | 0.02819 | 0.03102 | 0.02904 |
| — Smart Blue Filter | 0.02236 | 0.02297 | 0.03025 |
| — Blue Control | 0.0205 | 0.01489 | 0.01647 |

Figure 4: Relative sensitivities of the circadian rhythm for various commercially available blue-blocking lenses (solid lines) with +2.00 D, −2.00 D and Plano in comparison to the standard melanopic response curve $S_{mel}(\lambda)$ (dashed line).The standard melanopic response curve $S_{mel}(\lambda)$ are given in the Commission Internationale de l'Eclairage CIE S 026/E:2018.The mean differences between the standard circadian sensitivity and that for each BBL type are summarized in the table at the bottom.

Table 2 shows the melanopic ratios ($R_{mel}$) values for different BBL types at different light sources. The lower values of $R_{mel}$ (0.72-0.82) were observed for Blu-OLP lenses at all light sources, while $R_{mel}$> 0.85 for other BBLs types. However, it seems that all BBLs types are transparent for melanopic effect of light. In other words, all BBLs types do not prevent the effect of light on the circadian clock.

Table 2: Melanopic ratio ($R_{mel}$) for different BBLs types and for different light sources.

| BBL Type | Lens power (D) | 4000K LED | 4100K Fluorescent | Daylight "Clear sky" | Laptop | Smartphone |
|---|---|---|---|---|---|---|
| UV++Blue Control | −2.00 D | 0.91 | 0.92 | 0.91 | 0.95 | 0.93 |
| | Plano | 0.93 | 0.93 | 0.93 | 0.95 | 0.94 |
| | +2.00 D | 0.94 | 0.95 | 0.93 | 0.96 | 0.96 |
| Crizal Prevencia | −2.00 D | 0.87 | 0.86 | 0.86 | 0.86 | 0.85 |
| | Plano | 0.91 | 0.91 | 0.90 | 0.91 | 0.90 |
| | +2.00 D | 0.86 | 0.86 | 0.85 | 0.85 | 0.85 |
| Blue Guardian | −2.00 D | 0.87 | 0.87 | 0.87 | 0.88 | 0.87 |
| | Plano | 0.85 | 0.85 | 0.86 | 0.86 | 0.86 |
| | +2.00 D | 0.86 | 0.86 | 0.87 | 0.87 | 0.87 |
| Blu-OLP | −2.00 D | 0.74 | 0.74 | 0.72 | 0.73 | 0.73 |
| | Plano | 0.80 | 0.80 | 0.79 | 0.80 | 0.79 |
| | +2.00 D | 0.82 | 0.82 | 0.81 | 0.82 | 0.82 |
| SeeCoat Blue UV | −2.00 D | 0.91 | 0.92 | 0.91 | 0.93 | 0.92 |
| | Plano | 0.94 | 0.95 | 0.94 | 0.96 | 0.95 |
| | +2.00 D | 0.94 | 0.94 | 0.94 | 0.95 | 0.95 |
| Smart Blue Filter | −2.00 D | 0.89 | 0.90 | 0.90 | 0.91 | 0.90 |
| | Plano | 0.89 | 0.89 | 0.90 | 0.90 | 0.90 |
| | +2.00 D | 0.85 | 0.86 | 0.86 | 0.87 | 0.86 |
| Blue Control | −2.00 D | 0.92 | 0.91 | 0.91 | 0.91 | 0.91 |
| | Plano | 0.94 | 0.94 | 0.93 | 0.93 | 0.93 |
| | +2.00 D | 0.93 | 0.93 | 0.93 | 0.93 | 0.92 |

In Figure 5, the melanopic ratio values of all BBL types were plotted against their retinal hazard ratio. The results indicate that melanopic ratio value is related to the degree to which each BBL type is capable of attenuating natural blue light. The Pearsons correlation test showed that a significant positive correlation is observed for BBLs without power (r = 0.827, P =

.022), BBLs with power (+2.00 D) (r = 0.876, P = 0.008) and with power -2.00 D (r = 0.918, P = 0.004), thus implicating that the higher blue light hazard preventions or low transmission contributes to more reduction in the blue light required for melanopsin photoactivations.

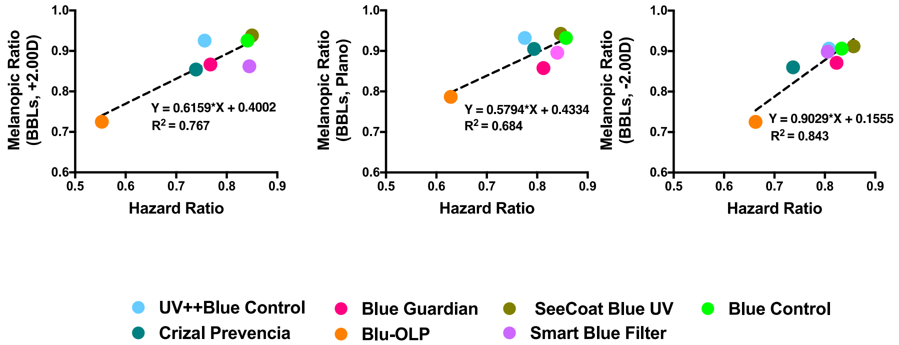


Figure 5: The correlation between melanopic ratio ($R_{mel}$) and hazard ratio ($R_{BLH}$) for all BBLs types when viewing standard daylight illuminant D65 through BBLs.

## 5. DISCUSSION

Based on the standard measurements provided by the International Commission on Non- Ionizing Radiation Protection Guidelines, all BBLs types can significantly reduce the potential photochemical damage caused to the retina if their use did not exceed the maximum permissible exposure duration. Comparing to our previous works,[6,7] blue-light weighted irradiance $E_{blue,BBL}$ values were not affected by lens thickness and they were clearly dependent on the blue light hazard prevention value of each BBL type (i.e., lower $E_{blue,BBL}$ values were observed for the higher the blue light hazard prevention value).

To determine the optimum lens optical spectral transmission properties that protect ocular tissues from photochemical damage and macular degeneration and other pathologies, it is important to also mention the amount of ultraviolet wavelengths transmitted through different BBL types. The danger from ultraviolet light is well known. High-energy violet light is currently being investigated increasingly as a potential hazard to ocular tissues [30,31]. The safe limits regarding of the ultraviolet radiation are given as a cut-off, which is dependent on the region. The European ultraviolet light cutoff is 380 nm, whereas the Canadian, Australian/New Zealand, and Brazilian, the cut-off is 400 nm.[32-34] Based on the transmittance profiles of BBLs,[6,7] all of the BBLs types used in this study met the general standards specification of blocking 100% for ultraviolet a light less than 380 nm, except for “Smart Blue“ lenses that only block 83% of ultraviolet light.

Melanopic ratios values are important to understand the consequences of each type of BBLs on the circadian clock (sleep-weak cycle). Light transmitted from all BBLs types have a greater impact on the control of the circadian cycle, i.e. the set of all the physiological cycles of our body within 24 hours, including the regulation of melatonin production. Thus, BBLs are not recommended to be worn in the evening hours for those individuals who intend to use BBL for regulating sleep-wake cycles. Our studies showed that all BBLs used in this study allowed artificial light from digital devices to alter the natural circadian cycle. The artificial lights have the potential to suppress melatonin over a broad range of intensity levels and at all levels we are exposed to in real-life conditions [35].

Additionally the low melanopic lux content in ambient lighting and LED screens have been shown not only to suppress melatonin but also to induce circadian phase-shifting and impact sleep, alertness,[12,36-41] thermoregulation, cardiac and EEG activity [42].These findings are important to consider since it suggests that blue light exposure disrupts the circadian clock (due to potentially suppressing melatonin) and may cause adverse consequences on mental, physical health,[43-47] and sleep [17].The disruption of circadian rhythm is associated with mood disorders,[43] breast cancer,[45] obesity and chronic diseases,[44] heart disease, high blood pressure, and other cardiovascular problems [46].

recent study on the blue-blocking lenses showed that orange-tinted BBLs (filtered out of short blue wavelengths < 500 nm by approximately 93%) have low circadian index of 0.23 [9]. It has been found that wearing those orange-tinted BBLs during the evening hours while using the LED screen or bright light, prevented light-induced night-time melatonin suppression [14,15]. Thus, compared to BBLs used in this study, orange-tinted BBLs are better and recommended for those individuals who suffer from sleep disorders. However, orange-tinted BBLs are not suitable for daylight use as these lenses block the most blue light required to preserve the natural circadian cycle, health, and well- being. The reduction in blue-enriched light during daytime hours can increase daytime melatonin levels, which may lead to sleepiness, mood and cognitive deficits [47]. However, currently commercially available BBLs used in this study allow the natural rhythm of the circadian cycle in the case of natural, solar light exposure.

In conclusion, BBLs can provide some protection to the human eye from photochemical retinal damage by reducing a portion of blue light that may affect non-visual performances such as those critical to the circadian rhythm. The present findings have obvious implications and are most useful for clinicians who may wish to recommend BBLs as a protective option for individuals who work in environments in which blue light is prevalent.

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