ORIGINAL ARTICLE

Blue-light transmittance in sunglasses over long-term irradiation within a solar simulator

Mauro Masili[1] · Fernanda O. Duarte[1] · Liliane Ventura[1] (ORCID)

Abstract

Purpose High-energy visible light (commonly referred to as blue light) transmittance in sunglasses plays an important role in eye safety. Current standards do not have specific requirements for blue light ocular protection, as in the past. However, the literature has warned against potential harm to the eye caused by blue light. The limits imposed in the past state that the average spectral transmission in the 380–500 nm range should not be 20% in excess of the luminous transmittance in the 380–780 nm range. The literature on transmittance evaluations of blue-blocker sunglasses and their aging processes is scarce. Thus, in addition to the transmittance of blue light in sunglasses, this study investigates the limits of these transmittances before and after artificial aging of lenses in a solar simulator.

Methods Twelve sunglasses samples were artificially aged within a solar simulator for a period of 2500 h, which is compatible with a user wearing them for 2 h a day for 2 years. The spectral transmittances of the lenses were measured every 25 h to assess the time evolution of the blue-blocking protection of the lenses, as evaluated by current and old standards.

Results The results showed that there were relevant changes in the lenses over time; that is, they considerably weakened their blue light attenuation capabilities. Thus, during the aging process, some lenses exhibited increased blue light transmittance compared to the visible one, exceeding the 120% criterion established by a superseded standard.

Conclusion The results suggest that aging tests should be performed on sunglasses not only for ultraviolet radiation, as required by most standards, but also for blue light. Furthermore, the standards should include constraints on blue light attenuation. In the context of public health and preventive medicine, evaluation of blue blockers from various perspectives is of ongoing interest.

Keywords Aging test of sunglasses · Blue light transmittance · Sunglasses standards · Solar simulator

Introduction

The harmful cumulative effects of ultraviolet (UV) radiation and consequent health care are widely publicized by the strenuous work that medical societies constantly perform to fight skin cancer. Sunglasses wearers are usually concerned with fashionable models and protection against UV rays. However, the public is unaware that other elements and wavelengths are also important for eye safety. Potential hazardous wavelengths are on the sidelines of the public, for instance, the so-called "blue light" (380–500 nm), which is more appropriately termed as high energy visible (HEV) light. HEV light can be harmful to the eye if cumulative exposure exceeds safe limits, for which studies have been carried out over the years (Dain 2003; Wong and Bahmani 2022).

The blue light hazard (Sliney 1997), also known as type II photochemically induced retinal damage (Mellerio 1994), is associated with the absorption of the ocular system, the retinal pigment epithelium and the choroid, from exposure to 380 to 520 nm short-wavelength light for periods of approximately 10 s to 1–2 h. Retinal damage has been validated, under selected conditions, by the photochemical injuries observed in laboratory studies (Hamet al. 1976). However, investigations on HEV light emitted from digital gadgets (computer screens, tablets, laptops, smartphones, etc.) have found that HEV hazards are well below the safe limits (ICNIRP 2020), even with extended exposure

✉ Liliane Ventura
lilianeventura@usp.br

1 Department of Electrical Engineering, São Carlos School of Engineering / University of São Paulo (EESC-USP), Av. Trabalhador Sãocarlense 400, São Carlos, SP CEP: 13566-590, Brazil

(O'Hagan et al. 2016). Although it is generally believed that the blue light from digital devices does not cause acute harm to the retina (Clark et al. 2018; O'Hagan et al. 2016; Scheer 2019), whether chronic exposure causes a long-term degenerative impact remains to be determined. Nonetheless, HEV light can affect the circadian cycle and processes mediated by photosensitive retinal cells, which calls for some sort of HEV light filtering. The reader is referred to a comprehensive review of the current state of this field, which is an excellent reading (Wong and Bahmani 2022), although the standards and regulations are beyond the scope of that review. Hence, the present investigation inserts itself in the field of industry standards, aiming at improving regulations and promoting the body of knowledge for scientists, board members, professionals, and the general public.

Currently, the industry has envisioned a blue-blocking lens market based on the possible association between short-wavelength light and maculopathies. These lenses absorb HEV light and therefore do not transmit blue light, failing in the Australian (AS/NZ-1067 2009) and American coloring requirements (ANSI Z80.3 2001). They also failed in the coloring requirements of the British BS and DIN standards when enforced before the adoption of the European Standard EN 1836 (BS EN-1836 1997).

The new European standard EN 12,312–1, which is a mirror of ISO 12312–1 (2013), has established the value of the relative visual attenuation quotient for traffic signal blue light recognition, which allows the "blue blocker" certification by the old EN 1836 and current ISO 12312–1 standards. Hence, this compliance for traffic light recognition (blue in some countries) means that these glasses do not block blue light, turning ineffective the requirement. Dain (2003) proposed that it is more logical to set upper limits for blue light transmittance than for total light transmittance. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has also recommended guidelines to limit exposure to HEV light (ICNIRP 2013).

To the best of our knowledge, the only effort to enforce blue light protection in sunglasses was accomplished in the past by the British standard BS-2724 (1956). According to this standard, the average spectral transmission in the 380–500 nm region should not exceed 120% of the luminous transmittance. Although Barker (1990) supported this concept, it was not adopted by BS EN 1836 (1997) or subsequent standards.

Efforts of our group have been progressively made toward an improved eye-safe standard for sunglasses for tropical countries (Masili et al. 2015; Masili and Ventura 2016; Masili et al. 2019) and worldwide, as in 2013, as a member of the committee for revising the Brazilian standard ABNT NBR-15111 (2013). In 2015, the Brazilian standard was updated to become an ISO 12312–1 mirror. Moreover, research by this group has been conducted to contribute to the standard requirements of sunglasses and to develop systems (Mello et al. 2014; Magri et al. 2017; Loureiro and Ventura 2020a, b; Ventura and Masili 2020; Gomes et al. 2022) to bridge the gap in the lack of instrumentation available in the industry for sunglasses research and certification.

This work is a part of this continuing effort. It aims to investigate whether unbranded sunglasses sold on the streets meet the requirements of past standards for blue light, given that there is no requirement for this wavelength range in the current standards. The highlight of this investigation is not only to perform the test for HEV light transmission in sunglasses but mainly to perform a long-term aging test aiming to verify whether there is any degradation of the material of the lenses over time, posing a potential hazard to the eyes. As far as we are concerned, there are no reports in the literature on aging tests of sunglasses in the blue region, even for short periods. In this sense, this pioneering study may contribute to the advancement of this field.

Methods

Twelve random unbranded sunglasses lenses, donated by the Brazilian association of manufacturers of sunglasses (ABIÓPTICA), were selected. Only 12 lenses were selected because of constraints on the solar simulator capacity. The sunglasses had no prior information regarding their specifications. Of the 12 lenses, six were in category 2 (lighter), two were in category 3, and four were in category 4 (darker). All the lenses were made of synthetic materials (CR-39, polyamide, polycarbonate, and polymethyl methacrylate). The chosen lenses belong to these categories (2–4) because they are most commonly used by sunglasses wearers. Lighter sunglasses (categories 0 and 1) are seldom marketed; therefore, this was an exclusion criterion. This set of chosen lenses replicates the consumer market and a sample calculation is not required. Thus, the results can be fairly extrapolated without a loss of generality. An alternative setup could test 12 lenses for each category. However, as will be discussed further, this is impractical.

Regular transmission spectroscopy of all the samples was performed at first as required by the ISO 12312–1 standard. After the transmission spectroscopy, the lenses were subjected to the aging process required by the ISO 12312–1 standard. The aging process consisted of artificial irradiation using a solar simulator (LEMA Xenon Suntest) with an ozone-free xenon arc lamp (450 W). The samples were placed 300 mm from the lamp and irradiated for 50 h, as established by the ISO 12312–1 (2013) standard. However, an earlier investigation on UV protection found that the 50-h cycle required by the standard was ineffective in assessing even a slight degradation in the lenses (Masili et al. 2019). The solar simulator is 0.46 suns, as already shown (Masili

and Ventura 2016). Thus, we extended the required aging test by exposing the lenses within the solar simulator at intervals of 25 h for up to 2500 h. The 2500-h cycle yields a radiant exposure equivalent to wearing sunglasses in a tropical country for 2 years, 2 h a day, following a survey on the Brazilian population (Masili and Ventura 2016). Therefore, this investigation was conducted on aging sunglasses consistent with these statistics. Transmission spectroscopy was performed on all the lenses to measure their luminous transmittance and blue light attenuation every 25 h of irradiation. This procedure allowed for the monitoring and estimation of the possible ongoing deterioration of filters during the artificial aging process. We stress here that the xenon arc lamp within the solar simulator lasts only 2000 h, and that a new lamp should be burned for at least 250 h in the empty simulator before the first essay. In the present approach, two lamps must be used to achieve the desired radiant exposure of 2500 h. Because these lamps are not readily available owing to budget restrictions, additional sets of lenses were not analyzed. Other than that, calibration was unnecessary whatsoever. Moreover, because only 12 lenses fit within the solar simulator, descriptive statistics were hampered.

All transmittance spectra were measured in the 200–800 nm range using a double-beam UV–VIS-NIR CARY 5000 (VARIAN) spectrophotometer and double-checked using a scanning spectrophotometer model, UV-1800 (SHIMADZU), both with a 1-nm spectral resolution. Measurements were taken at the geometric center of each lens using a circular mask with a diameter of 5 mm. The total mean transmittance is the average of the spectral transmittance weighted by an illuminant and a proper action function in accordance with the standard (ISO 12312–1 2013). Thus, the mean luminous transmittance, τ_V, of the sunglasses lenses for the CIE standard daylight illuminant D65 is expressed as a percentage as follows:

$$\tau_V = 100 \times \frac{\int_{380}^{780} \tau(\lambda) \cdot S_{D65}(\lambda) \cdot V(\lambda) \, d\lambda}{\int_{380}^{780} S_{D65}(\lambda) \cdot V(\lambda) \, d\lambda}, \tag{1}$$

in which $\tau(\lambda)$ is the measured spectral transmittance of the lens, $S_{D65}(\lambda)$ is the spectral distribution of radiation of CIE D65 standard illuminant, and $V(\lambda)$ is the spectral luminous efficiency for daylight (photopic) vision. Similarly, the total blue light transmittance for sunglasses, τ_B, is calculated in percentage as follows:

$$\tau_B = 100 \times \frac{\int_{380}^{500} \tau(\lambda) \cdot E_S(\lambda) \cdot B(\lambda) \, d\lambda}{\int_{380}^{500} E_S(\lambda) \cdot B(\lambda) \, d\lambda}, \tag{2}$$

in which $B(\lambda)$ is the blue light hazard function (ISO 12312–1 2013) and $E_S(\lambda)$ is the standard solar spectrum (ISO 12312–1 2013) at sea level for air mass 2 (solar

spectrum at ground level when the position vector of the sun is 60.11° from the zenith).

According to the BS-2724 (1956) standard, the blue light transmittance is calculated using a simple, unweighted arithmetic mean as follows:

$$\tau_B = 100 \times \frac{\sum_{380}^{500} \tau(\lambda)}{13}, \tag{3}$$

for which the spectral resolution is taken as 10 nm. It is noteworthy that by the period the BS-2724 (1956) standard was in force, the blue light hazard function was still undiscovered, and only years later (the 1970s), pioneering works (Ham et al. 1976; Harwerth and Sperling 1971) raised concerns about retinal damage caused by short-wavelength visible light.

In what follows, the HEV light to visible light ratio is given by

$$\rho = \frac{\tau_B}{\tau_V}. \tag{4}$$

The integrals in Eqs. (1) and (2) were calculated using the 5-point Gauss–Legendre quadrature with a cubic Lagrange polynomial interpolation of the integrand. These methods ensure results with numerical roundoff errors way below the measurement accuracy.

Results

This section presents the lens transmittance results during the resistance-to-radiation test, which is an artificial aging test in a solar simulator.

Figure 1 shows an overview of the spectral transmittances of the 12 selected sunglasses lenses in the visible range (380–780 nm) before the artificial aging test in a solar simulator, that is, at 0 h. These transmittance profiles were used as the control group.

These lenses were submitted to a solar simulator specified by the current ISO 12312–1 (2013) standard. Figure 2 illustrates the spectral transmittances of one typical polycarbonate lens at intervals of 500 h of exposure in the solar simulator, up to 2500 h. The left panel shows the luminous (380–780 nm) transmittance, and the right panel highlights the respective HEV light (380–500 nm) transmittance.

The time evolution of the overall blue light attenuation calculated using Eq. (2) is shown in Fig. 3 for all the lenses. In these samples, blue light protection decreased as a function of the exposure period in the solar simulator. In Fig. 3, the trend lines (solid and dashed lines) are displayed for some lenses to emphasize the temporal evolution. The changes from solid to dashed lines indicate a slight change in the angular coefficient of the regression lines around 1000 h
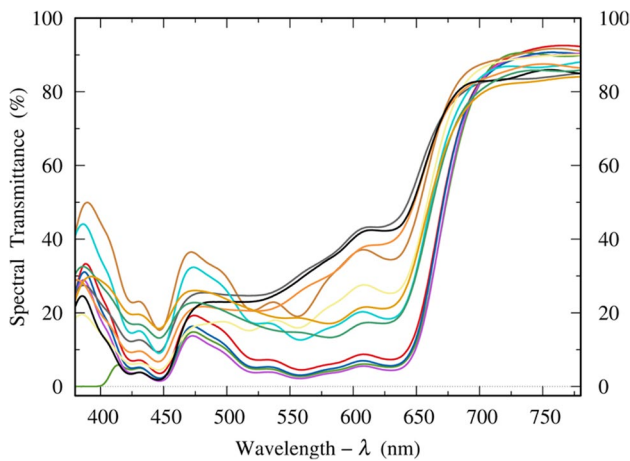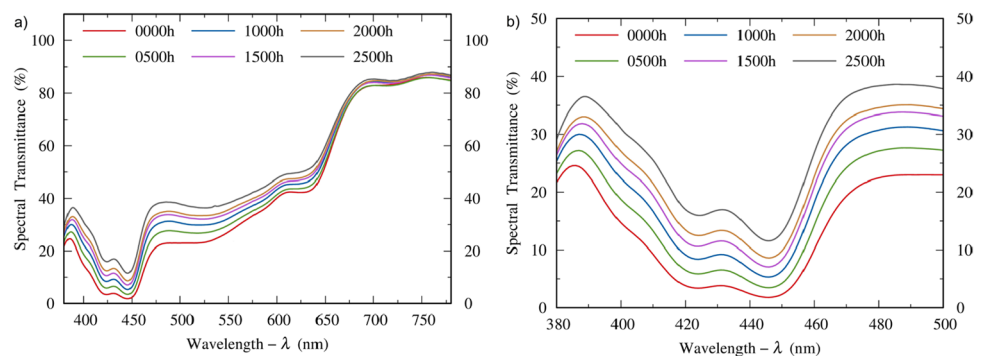
Fig. 1 Luminous (380–780 nm) spectral transmittance of the 12 sunglasses lenses before exposure to a solar simulator

of exposure, suggesting some sort of saturation effect on the materials. In Fig. 3, the top horizontal axis represents the equivalence between the exposure period in the solar simulator and the number of days of use of sunglasses in the sun, as depicted in a previous study (Masili et al. 2016, 2019).

Table 1 presents the results of the blue light transmittance of the lenses before and after the aging test. The blue light transmittances were computed as required by both the ISO 12312–1 standard [Eq. (2)] and the BS-2724 standard [Eq. (3)]. In both standards, the mean visible transmittance is computed using Eq. (1). The square brackets show the blue light to luminous transmittance ratios ρ [Eq. (4)]. Ratios over 1.2 are marked in boldface. Before the aging test (0 h), 4 lenses did not meet the criterion of $\rho < 1.2$ when using the ISO standard definition of τ_B [Eq. (2)]. Similarly, 6 lenses failed as BS standards were used to compute τ_B [Eq. (3)]. Recall that current standards do not enforce or even suggest any type of HEV light filtering. Hence, the lenses actually did not fail a compliance test. Thus, because one of the objectives was the aging process, those lenses were aligned with the inclusion criterion. After 2500 h of exposure in the solar simulator, all the lenses diminished their blue and visible light attenuation capabilities, i.e., the average

transmission of light through the lenses increased. Table 1 shows this behavior for the blue light transmittance. In the last two columns, a star highlights the specimens originally with $\rho < 1.2$ that evolved to surpass $\rho > 1.2$ during the aging test.

Figure 4 illustrates the time evolution of the ratio of blue light to visible light transmittances (ρ), according to both ISO 121312–1 (left panel) and BS-2724 (right panel) standards.

Discussion

In an extensive review, Wong and Bahmani (2022) pointed out the lack of consensus regarding the adverse effects of HEV light on age-related macular degeneration owing to the many difficulties in this research field. Consequently, they emphasized that further research is required to establish how blue light might affect visual functioning in the long term. In terms of public health and preventive medicine, to
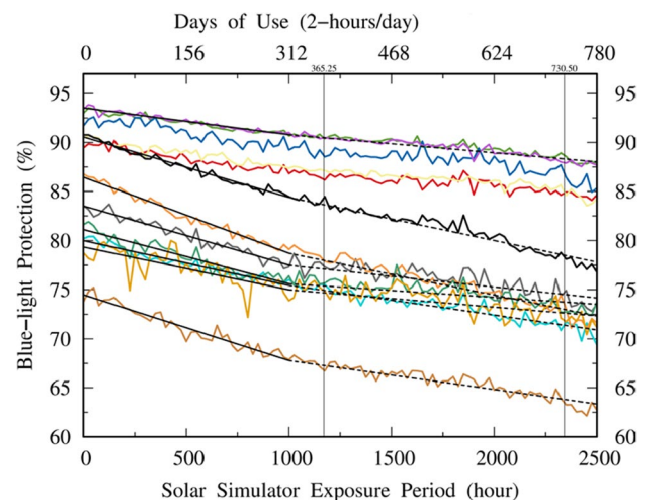

Fig. 3 Time evolution of the blue light (380–500 nm) protection. The vertical lines denote the time (in days of use in the sun for 2 h), in the top axis, equivalent to 1- and 2-year exposures in a sun simulator

Fig. 2 (**a**) Luminous (380–780 nm) and (**b**) blue light (380–500 nm) spectral transmittances of a typical polycarbonate sunglasses lens up to 2500 h of exposure in a solar simulator at 500-h intervals

Table 1 Blue light transmittance before and after exposure of the lenses in a solar simulator. Blue light transmittance was calculated as required by ISO 12312–1 [Eq. (2)] and by BS-2724 [Eq. (3)] standards. The square brackets show the blue to luminous transmittance ratios ρ [Eq. (4)]. Ratios greater than 1.2 are marked in boldface. The stars highlight the samples that turned from $\rho < 1.2$ to $\rho > 1.2$ during the test

Lens label	Lens category*	Initial (0 h) Blue light transmittance (%)		50 h in the solar simulator Blue light transmittance (%)		2500 h in the solar simulator Blue light transmittance (%)	
		ISO 12312–1	BS-2724	ISO 12312–1	BS-2724	ISO 12312–1	BS-2724
033	4	10.56 [**1.34**]	15.65 [**1.99**]	10.26 [**1.35**]	15.16 [**2.00**]	15.36 [**1.61**]	19.25 [**2.02**]
061	4	8.31 [**1.37**]	13.21 [**2.19**]	7.39 [**1.40**]	11.95 [**2.27**]	14.65 [**1.78**]	18.78 [**2.28**]
040	4	7.01[**1.29**]	6.07 [1.12]	6.58 [**1.31**]	5.69 [1.14]	12.23 [**1.66**]	*6.64 [**1.31**]
120	4	6.59 [**1.41**]	11.26 [**2.41**]	6.31 [**1.44**]	10.87 [**2.47**]	12.32 [**1.75**]	16.63 [**2.36**]
195	3	19.82 [1.10]	26.02 [**1.45**]	19.60 [1.11]	25.65 [**1.46**]	*30.63 [**1.38**]	34.99 [**1.58**]
343	3	18.38 [1.11]	21.76 [**1.32**]	18.49 [1.13]	21.85 [**1.34**]	*26.18 [**1.28**]	28.66 [**1.40**]
161	2	26.24 [0.98]	32.04[**1.20**]	24.79 [0.99]	30.49 [**1.22**]	*37.28 [**1.22**]	40.83 [**1.34**]
346	2	21.24 [1.05]	23.39 [1.15]	22.05 [1.06]	24.10 [1.15]	*28.87 [**1.20**]	*29.86 [**1.24**]
183	2	16.47 [0.52]	19.86 [0.63]	17.60 [0.54]	21.02 [0.64]	26.47 [0.70]	28.68 [0.76]
196	2	13.23 [0.49]	17.25 [0.64]	13.59 [0.50]	17.61 [0.65]	28.39 [0.70]	31.41 [0.78]
193	2	9.48 [0.48]	12.54 [0.64]	9.42 [0.49]	12.38 [0.65]	15.76 [0.73]	18.06 [0.84]
267	2	9.23 [0.31]	13.73 [0.46]	9.50 [0.32]	13.98 [0.47]	23.22 [0.57]	27.76 [0.68]

* The higher the category, the darker the lens

Fig. 4 Time evolution of the blue light-to-luminous transmittance ratio for all the 12 lenses. The horizontal line at 1.2 shows the limit required by the standard BS-2724. Left panel (**a**): blue light transmittance computed as required by the ISO 12312–1 standard [Eq. (2)]. Right panel (**b**): same calculation using the BS-2724 standard [Eq. (3)]
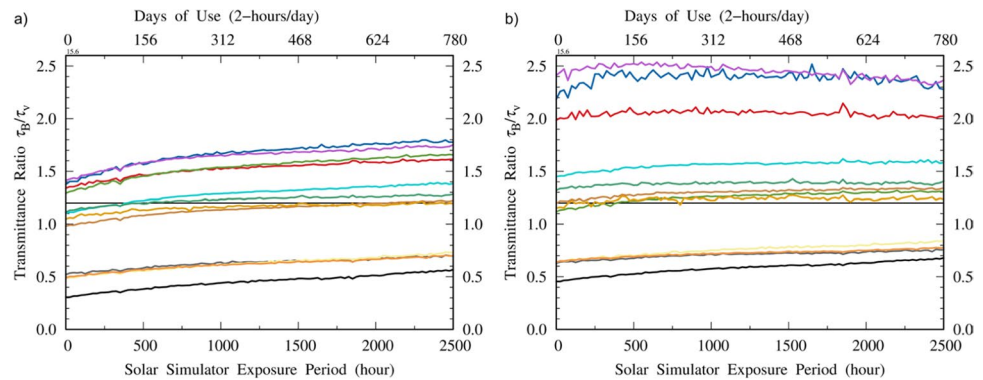
stand on the safe side, evaluations of blue blockers in varied standpoints are of continuing interest.

The current standards do not require specific parameters for eye protection against HEV light. However, an old superseded standard (BS-2724 1956) established a safe limit for the overall transmittance of blue light of sunglasses, which should not exceed 120% of the total luminous transmittance.

The current ISO aging test requires 50 h of exposure in a solar simulator. Note that the values in Table 1 corresponding to the 50-h test do not show significant changes in the transmittances compared with the control (0 h). Indeed, as pointed out in previous works on UV protection (Masili et al. 2016, 2019), the resistance to radiation testing is ineffective as required by the ISO 12312–1 (2013) standard.

Figure 2 demonstrates that a long-term artificial aging test degrades both the blue and luminous transmittances, which means that the lens color is bleaching. It can be observed that the degradation of the blue light transmittance over time is more prominent than that of the respective luminous transmittance. Hence, the blue light to luminous transmittance ratio ρ [Eq. (4)] increases over time, i.e., as sunglasses age, the blue light attenuation degrades faster than the bleaching effect (visible light attenuation) on the lenses (cf. Figure 4). This behavior is evident in all the 12 analyzed lenses.

The results in Fig. 3 show that the rate of deterioration of the blue light protection is greater than the corresponding deterioration rate found in a previous study regarding UV protection (Masili et al. 2019).

As listed in Table 1, during the aging test, some lenses turned from $\rho < 1.2$ to $\rho > 1.2$, assuming that the $1.2 \times$ criterion was enforced. It can be seen in Fig. 4 in what way the ratios ρ for each of the 12 lenses changed over time. The left panel shows ρ using the ISO definition of τ_B, whereas the right panel shows the BS calculation for τ_B. All the lenses exhibited an increase in ρ over time. However, in the long term, ρ appears to approach a constant value. This means that the bleaching effect was stabilized. Notice that four lenses (left panel) turned from $\rho < 1.2$ to $\rho > 1.2$ when ISO was considered and that two lenses (right panel) turned when BS was in effect. Despite the depreciation of their blocking properties over time, the four lenses sustained the suggested criterion of $\rho < 1.2$.

As mentioned in Introduction, the lack of similar investigations reported in the literature precludes a straightforward comparison with the present results.

Conclusion

The results showed that the filtering properties of sunglasses degraded over time when exposed to solar radiation. In this investigation, a set of 12 typical lenses was artificially aged in a solar simulator, and the blue-to-visible light transmittance ratio was determined during the aging process. The blue light transmittances were computed under superseded and current standards for comparison.

Because HEV light protection has come to the potential eye hazard scenario, one may suggest that standards include requirements for these particular wavelengths in addition to the requirement for blue light traffic light. Furthermore, the standards should consider revising the parameters for the artificial aging process of lenses in the solar simulator. An exposure of 2500 h is recommended as a period quite compatible with regular sunglasses users. Nevertheless, if impractical for certification routine, a shorter period could be used by placing the lenses closer to the xenon arc lamp bulb. Suggestions for new setups have already been made (Masili and Ventura 2016).

The present results are compelling and suggest a course of action to broaden the analysis, including a larger sample size, to overcome a supposed bias in the present approach.

Declarations

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