Degradation of sunglasses filters after long-term irradiation within solar simulator

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ABSTRACT

In our previous investigations on sunglasses standards, limits and insertion of missing requirements have been suggested for ocular safety. In this paper, we evaluate the degradation of the lenses (category and ultraviolet protection) as sunglasses are exposed to solar radiation for periods considered still within its lifetime. Our study includes 44 unbranded sunglasses: 12 were submitted to a solar simulator (0.46 suns) for 2500 h and spectroscopy was performed every 25 h. The remaining 32 were submitted to a 10-sun solar simulator for 962 h of exposure, and transmittance spectroscopy and UV protection evaluation have been done. These exposure conditions are equivalent to wearing sunglasses for a period over 2 years, for 2 h daily. Standards require 50 h exposure as the aging test. Under this condition, only one lens failed the requirement. However, our longer-term irradiation (sunglasses desired lifetime period exposure) experiment in solar simulator shows that the majority of lenses will eventually fail the standard requirement, suggesting the revision of such aging test. Additionally, there has not been any significant alteration on UV protection. Summarizing, current parameters, for the resistance to radiation test for sunglasses on standards, is ineffective for ocular safety within its lifetime. In summary, current parameters for the resistance to radiation test for sunglasses, required by ISO 12312-1 standard, are ineffective for sunglasses average lifetime required by population.

1. Introduction

Ideally, sunglasses should absorb ultraviolet (UV) light ranging from 280 to 400 nm [1]. However, most standards [2–4], with the exception of the Australian, Canadian, and South African standards [5,6], are ISO 12312-1 mirrored [7], which requires 380 nm UVA radiation protection as an upper limit.

Exposing sunglasses to the sun may alter the optical properties of the lenses. Lenses of fixed tint are graded according to the optical density of the tint. As established by the standards, sunglasses must be labeled and show the filter category number. Lenses with visible transmission < 75% are unsuitable for night driving. Lenses with visible transmission < 8% (category 4) are unsuitable for driving at any time and should be labeled "Not suitable for driving and road use". One of the concerns of the standards is the change of lenses' transmittances, which eventually may cause change on category (see Table 1) as they are overexposed to the sun [7]. This means that the lenses may become lighter, harming the consumer in the aspect of the acquisition of a pair of sunglasses of some degree of shade and in the near future such sunglasses become lighter.

Considering the requirement of exposing sunglasses to an appropriate solar simulator for 50 continuous hours as described by ISO

Table 1

Categories of lens filters according to standard ISO 12312-1 [7].

Filter category	Description of filter categories
0	Fashion spectacles; not sunglasses; very low sun glare reduction; some UV protection; clear or very light tint
1	Fashion spectacles; not sunglasses; limited sun glare reduction; some UV protection; light tint
2	Sunglasses; medium sun glare reduction; good UV protection; medium tint
3	Sunglasses; high sun glare reduction; good UV protection; dark tint
4	Sunglasses; special purpose; very high sun glare reduction; good UV protection; must not be used when driving; very dark tint

12311 [8], sunglasses should not change, in an acceptable degree, their visible transmittances after exposure. Even in the in-appropriate event of a category change, to lighter spectacles, the original UV protection should remain.

The initial reason for considering investigating degradation of the material and further loss of UV protection of the lenses was based on some educated guess and intriguing observation of some unbranded sunglasses that one of the authors had purchased in the past in some specific, but the typical condition in tropical countries: sunglasses sold at the seashore. UV protection did not comply [9] with the requirements of the standards for several (10 out of 30 pairs of sunglasses) of those tested randomly chosen sunglasses sold at the seashore, in Brazil. The way sellers display unbranded sunglasses for the public (see Fig. 1) results in intensive exposure of the lenses directly to the sun. It is a very usual way of selling sunglasses in that continental-sized country.

It is worth noting that countries in Southern Hemisphere, such as Brazil and Australia, have features that lead to non-negligible higher levels of solar UV radiation than in Northern Hemisphere [10–12]. For instance, aside from the geographic location, a large number of sunny days yearly and the fact that Earth is 3.4% closer to the Sun in the Southern Hemisphere summer than in the Northern Hemisphere summer. This proximity adds 7% to the UV radiation intensity [11]. Moreover, on average, there is less air pollution in the Southern atmosphere than in the Northern, which results in greater solar UV radiation reaching the ground. Overall, the combination of all these effects can result in 15% more solar UV radiation in Southern latitudes than in corresponding Northern ones [11], not to mention that people in tropical countries have an outdoor-driven lifestyle. For those reasons, the standards should

Fig. 1. Sunglasses being sold by the sea in João Pessoa, PB ($-7°9'28''$ S, $-34°47'38''$ W), northeast of Brazil.

Table 2
Transmittance requirements for sunglasses lenses for general use [7].

Filter category	Requirements			
	Ultraviolet spectral range			Visible spectral range
	Maximum value of solar UV-B transmittance	Maximum value of solar UV-A transmittance		Range of luminous transmittance
	τ_{SUVB}	τ_{SUVA}		τ_V
	280 nm to 315 nm	315 nm to 380 nm		380 nm to 780 nm
0	$0.05\tau_V$	τ_V		$\tau_V > 80\%$
1	$0.05\tau_V$	τ_V		$43\% < \tau_V \leq 80\%$
2	1.0% absolute or $0.05\tau_V$, whichever is greater	$0.5\tau_V$		$18\% < \tau_V \leq 43\%$
3	1.0% absolute	$0.5\tau_V$		$8\% < \tau_V \leq 18\%$
4	1.0% absolute	1.0% absolute or $0.25\tau_V$, whichever is greater		$3\% < \tau_V \leq 8\%$

emphasize stringent UV protection for sunglasses and perhaps have the benefit of law enforcement.

Another aspect is that a requirement regarding UV protection fading is not part of the standards yet and we have been pointing out the need for further studies in conferences worldwide. Therefore, specific limits should still be discussed.

As described in a previous work [13], most Brazilians wear sunglasses for a period of 2 years, in an average of 2 h a day, all year long. Not only people in tropical countries usually wear sunglasses, as a daily routine, but also this is a practice all world around and therefore eye safety must be assured. This primarily means that sunglasses should be exposed to sun simulator for a period that delivers a radiant exposure equivalent to 2 h daily for 2 years in the sunshine (730.5 days or 1461 h). This was extensively investigated in a previous work [13], in which the calculations pointed out a simulator time of 2423.3 h to match the desired equivalence for the exposition of lenses to the sun, i.e., 2 h daily during 2 years. This period of 2423.3 h within solar simulator using the current parameters is noticeably impractical.

1.1. Current material for sunglasses lenses

Most sunglasses lenses are made of polycarbonate, polymethyl methacrylate (PMMA), CR-39 (with polarizing film inside), polyamide, and glass [14].

The 280 nm–400 nm range of UV radiation is partially absorbed in these materials, with the exception of glass [15].

However, the resistance to radiation test requirement in ISO 121312-1 is essential, given that sunglasses consumers should be protected from sun glare and harmful radiation.

Thus, the aim of the study is to carry out a comprehensive analysis of the stress test required by standard ISO 12312-1. Furthermore, we investigate the period for which exposure of lenses within a solar simulator emerges a meaningful variation in UV and visible light transmittances, as listed in Table 2.

The standard establishes that for the resistance to radiation test, at first, one must perform spectrophotometric measurement of UV–Vis transmittances at the center of the lens and submit it to a 450 W solar simulator for a 50 h period. Subsequently, the same spectrophotometric measurement is carried out to further compare with previous data.

2. Methods

2.1. Theoretical models

Transmittance is the ratio of the intensity of the electromagnetic radiation that has passed through a sample to the intensity of the incident radiation upon the sample. It depends on the radiation's wavelength (spectral transmittance). The luminous transmittance, τ_V, of the sunglasses lenses for CIE standard illuminant D65 [7,8] is expressed as a percentage by:

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

in which $\tau(\lambda)$ is the spectral transmittance of the filter, $S_{D65}(\lambda)$ is the spectral distribution of radiation of CIE standard illuminant D65, and $V(\lambda)$ is the spectral luminous efficiency for daylight (photopic) vision [8].

Solar UV-A transmittance, τ_{SUVA}, is given as a percentage by:

$$\tau_{SUVA} = 100 \times \frac{\int_{315}^{380} \tau(\lambda) \cdot E_S(\lambda) \cdot S(\lambda) \, d\lambda}{\int_{315}^{380} E_S(\lambda) \cdot S(\lambda) \, d\lambda} \tag{2}$$

Similarly, solar UV-B transmittance, τ_{SUVB}, is given by:

Table 3
Relative change in the luminous transmittance τ_V after the resistance to radiation test in a solar simulator. Luminous transmittance after irradiation is given by τ_V'. Ref. [7].

Filter category	Relative change in the luminous transmittance
	$\Delta\tau_V / \tau_V = 100\% \times (\tau_V' - \tau_V)/\tau_V$
0	± 3%
1	± 5%
2	± 8%
3	± 10%
4	

$$\tau_{SUVB} = 100 \times \frac{\int_{280}^{315} \tau(\lambda) \cdot E_S(\lambda) \cdot S(\lambda) \, d\lambda}{\int_{280}^{315} E_S(\lambda) \cdot S(\lambda) \, d\lambda} \tag{3}$$

Solar UV transmittance τ_{SUV} is the mean of the spectral transmittance between 280 nm and 380 nm weighted with the solar radiation $E_S(\lambda)$ at sea level for air mass 2 (terrestrial solar spectrum occurring when the sun's position vector has 60.11° from zenith) and the relative spectral effectiveness function for UV radiation $S(\lambda)$ [7], i.e.,

$$\tau_{SUV} = 100 \times \frac{\int_{280}^{380} \tau(\lambda) \cdot E_S(\lambda) \cdot S(\lambda) \, d\lambda}{\int_{280}^{380} E_S(\lambda) \cdot S(\lambda) \, d\lambda} \tag{4}$$

The relative spectral effectiveness function $S(\lambda)$ for UV radiation allows estimating the relative risk of exposure to a variety of UV sources, which delivers different UV irradiation distribution. Although $S(\lambda)$ has been described for skin exposure, the corneal tissue has a similar response to the UV exposure [5].

Using Eqs. (2)–(4), we can define protection as $(100\% - \tau)$ respectively, that is, a lens with average UV transmittance of 1% would have a UV protection of 99%.

The extent to which the UV filters deteriorate in the course of the aging process in the solar simulator is also subject of the ISO standard. Indeed, after the test, the change in luminous transmittance (τ_V') relative to the initial value (τ_V), according to the filter category, must be less than or equal to the values listed in Table 3 [7].

Moreover, the UV requirements for the initial luminous transmittance, τ_V, given in Table 2, must continue to be observed. However, there is no mention in the standard dealing with changes in the UV protection. Hence, for the sake of completeness, we investigate not only the relative changes in the luminous transmittance but also the changes in the UV protection of the filters.

2.2. Experimental procedure

The experiment design was based on the standard ISO 12312-1, which requirements are to perform a stress test where sunglasses are irradiated by a solar simulator for a period of 50 h for further analysis of the UV–Vis transmittances after exposure. Therefore, this test aims to establish the sunglasses lenses resistance to solar irradiation by detecting any change in the UV protection and lenses transmittances after solar simulator exposure. In this study, we extended the irradiation period of the lenses in accordance with theoretical analysis carried out in a previous work [9] in order to simulate long-term sunglasses wearing.

According to a survey among Brazilian population about how often sunglasses are worn [13], it resulted that sunglasses should be exposed to sun simulator for a period equivalent to an individual who wears sunglasses for 2 h daily, for 2 years – period that users usually purchase a new pair of sunglasses, i.e., 730.5 days or 1461 h in the sun. For this purpose, we have considered the sunglasses-wearing period coincident with the solar irradiance peak for the eyes, which happens roughly in the middle of the morning and in the middle of the afternoon, depending on the day of the year (see Ref. [1] for details). Bearing in mind this scenario, the total solar radiant exposure delivered to the sunglasses lenses is 188.7 MJ/m². Hence, the delivered radiant exposure from solar simulator should be 188.7 MJ/m², which equivalent to 2423.3 h of exposure in the simulator.

We have selected and labeled 12 unbranded sunglasses, all lenses made of synthetic plastic materials, donated by ABIÓPTICA (a Brazilian association of manufacturers of sunglasses). The sunglasses had no prior information about their specifications. Out of the 12 lenses, 4 were in category 4, 2 in category 3 and 6 in category 2. All 12 lenses (7 were made of polycarbonate; 4 of polyamide; and 1 of CR-39) were exposed to artificial solar radiation by the solar simulator (LEMA PARMA) with an ozone-free xenon arc lamp (450 W) placed 300 mm away from the lamp. The lenses were exposed in the solar simulator every 25 h to complete a 2500 h cycle, which is equivalent of wearing sunglasses for the period of > 2 years, in an average of 2 h daily, as established in our study as a result from the survey among Brazilian population. Subsequently to every 25 h of exposure to radiation, spectroscopy was performed in all lenses to determine the sunglasses transmittance of radiation in the UV-A, UV-B and visible ranges to determine whether there had been any noticeable changes in lens UV–Vis transmittances, which are related to UV protection. These measurements were compared with data previously to the stress test. The transmittance spectrum of the sunglasses was measured in the 200 nm – 800 nm range, using a double-beam UV–Vis scanning spectrophotometer CARY 5000 (AGILENT, former VARIAN) and double-checked using UV-1800 SHIMADZU spectrophotometer with a 1 nm spectral step. Previously to each measurement, the lenses were gently cleaned to

avoid any interference in the spectroscopic analysis. Spectroscopy was performed within a central circular area of 5 mm.

Another experimental setup, akin to the depicted above, was devised to accelerate even further the artificial aging test. For that matter, an additional set of 32 lenses was submitted to the National Institute of Standards and Technology (NIST) solar simulator (10 suns) for 962 h of exposure, and similar analysis has been done, i.e., the before-and-after spectroscopy measurements with respective transmittances and UV protection calculations. Thus, we have also investigated an accelerated, non-standard aging test other than the ISO standard's slower aging process on sunglasses.

The NIST SPHERE (Simulated Photodegradation via High Energy Radiant Exposure) solar simulator is a 2 m integrating sphere used for accelerated weathering. The SPHERE system provides intense, uniform UV light, as well as controlled temperature, relative humidity, and wavelength (via filters) exposure. A heating, ventilation and air conditioning unit cools the lamps and SPHERE, with the conditioned space separated from the environmental chambers by a quartz window. Each bulb is located inside a reflector assembly that minimizes the visible and infrared radiation of the UV source. A WG295 (SCHOTT Germany) glass window is installed in the optical path between the UV lamp system and the integrating SPHERE to remove radiation below 290 nm. The exterior shell of the SPHERE is aluminum while the interior surface is lined with Spectrolon, a commercial polytetrafluoroethylene (PTFE) that is diffusely reflective in the UV regions.

3. Results and discussion

3.1. Standard solar simulator

A previous work [13], regarding the resistance of the lenses to the exposure to UV radiation, pointed out the inadequacy of the parameters of the resistance to radiation test in international standards for the sunglasses industry, i.e., the ISO 12312-1 standard. In particular, it has been found that exposure of the lenses for 50 h within a solar simulator is virtually harmless to the lenses, not achieving the purpose of real stress (or accelerated aging) test. With each spectral transmittance data, the average transmittance [Eq. (1)] and corresponding UV protection [Eq. (4)] were calculated, thus showing time evolution of those lens properties. In each calculation, the integrals were evaluated using a 5-point Gauss-Legendre quadrature with a cubic Lagrange polynomial interpolation of the integrand.

The starting point is the measurement of all lens spectral transmittances prior to irradiation. Fig. 2 displays these initial transmittances for the 12 lenses examined in this work. The vertical lines indicate the UV spectral band limits, i.e., 315 nm for UV-B upper limit and 380 nm/400 nm for UV-A upper limit.

Fig. 3 shows the UV–Vis spectral transmittances of two selected typical lenses, made of a very common polymeric synthetic material (polycarbonate), taken at intervals of 500 h of exposure in the solar simulator, up to 2500 h of exposure. The figure highlights a consistent increase in spectral transmittances. Consequently, there is an increase in the average luminous transmittance, which can be visually perceived by the bleaching of the lens, and eventually changing the lens category. In addition, a slight increase of transmittance in the UV waveband implies a decrease in UV protection, resulting in higher UV incidence in the ocular media.

Fig. 4 shows the time evolution of the mean luminous transmittance, calculated for all 12 lenses at 25 h intervals in the solar simulator. The integration limits are taken according to the standard, i.e., from 380 nm to 780 nm.

The top horizontal axis refers to the equivalence between the period of hours of exposure in the solar simulator and the period of days of use of sunglasses in the Sun. In this equivalence, one takes into account that the spectacles are used for 2 h a day, in an upright position, and during the solar incidence peak at the sunglasses, which occurs at mid-morning and mid-afternoon [1]. Fig. 4 shows a tendency to increase the average transmittance, showing the effects of radiation stress on the lenses. Depending on the quality of the lens material, some lenses exhibit a more pronounced tendency, while others are more stable. In the graph, it has been added trend
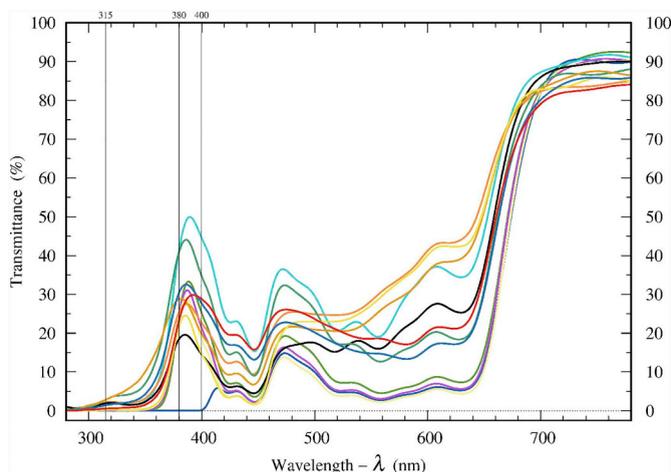

Fig. 2. Initial measurements (0 h) of UV–Vis spectral transmittances for 12 selected lenses. Vertical lines delimit the UV subdivisions.
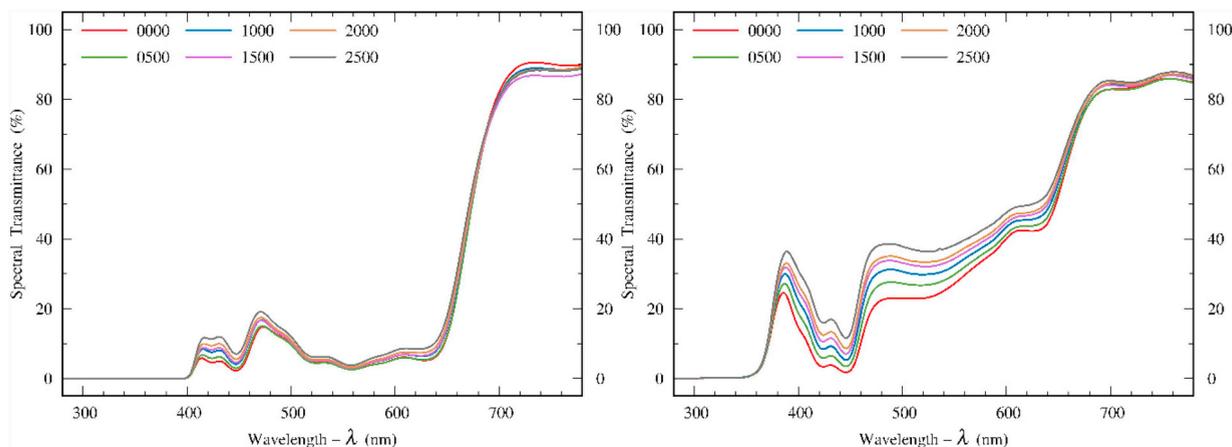
Fig. 3. Ultraviolet and visible spectral transmittances for two selected sunglasses lenses with 500 h intervals of exposure in a 450 W solar simulator required by ISO 12312-1 standard.
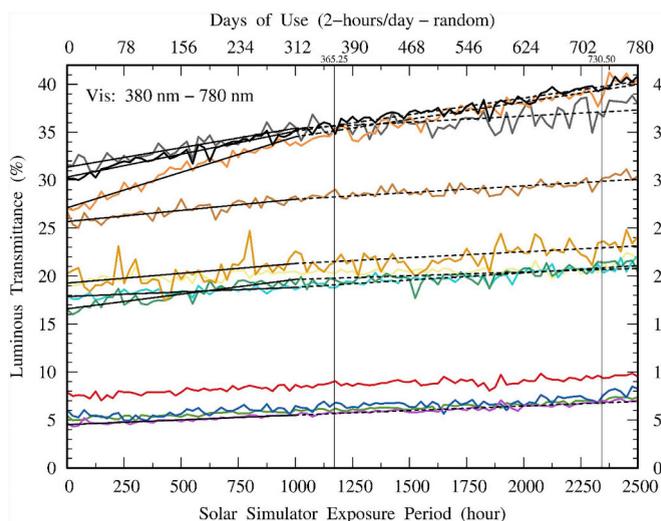

Fig. 4. Time evolution of mean luminous transmittance of 12 sample lenses.

lines (solid and dashed) to make clear the time evolution. These are the least square regression lines of the corresponding data. It appears that, for some specimens, there is a slight change in the trend lines after roughly 1000 h of exposition. The respective dashed lines after 1000 h reveal this effect. This behavior suggests that a saturation effect might occur on some materials.

Similarly, Fig. 5 shows the time evolution of the UV protection of the respective lenses. One can observe the gradual loss of the UV protection for some lenses, evidencing the quality of each filter.

These results consistently show that the standard's exposure requirement in the simulator for 50 h does not yield a measurable effect on the lenses, requiring long-time exposure to attest the quality and durability of the UV ocular safety properties of the lenses. Moreover, these data corroborate the theoretical predictions attained in Masili and Ventura (2016) [13], that is, in order to simulate the use of sunglasses for at least two years, with daily use of 2 h, it takes > 2300 h in the simulator using the standard requirements such as lamp power and lens distance from the lamp. Indeed, after 50 h within the solar simulator, none of the lenses presented any noticeable change in all properties considered in this work, except one lens of category 4 in which only the luminous transmittance decreased by 13%, holding unaltered the remaining protections.

For further contribution on the study of eyes safety, we have investigated up to the 400 nm UVA limit. Fig. 6 shows typical cases of UV protection behavior for some lenses. The solid lines refer to measurements up to 380 nm, while dashed lines refers to values up to for 400 nm. These results show that the definition of the limits of UV plays an important role with respect to eye protection provided by sunglasses.

After 2500 h in the solar simulator, all 12 lenses made of polymers (polycarbonate and polyamide) and CR-39 have failed at least one of the compliance tests required by the ISO 12312-1. Considering all of the alterations on the sunglasses, the best case, presented an increase of 9.6% of luminous transmittance, while for the worst case it increased by as much as 50.7%. In these 12 samples, the lenses became visually lighter than initially. Tables 4 and 5 show a summary of the tests for each lens and display the exposure time
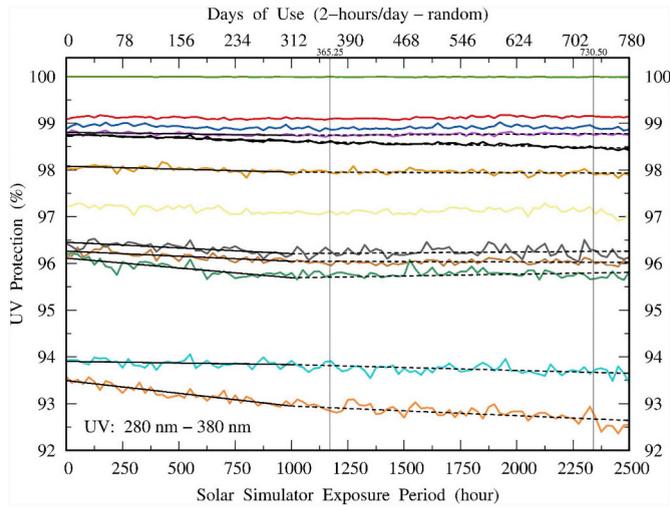
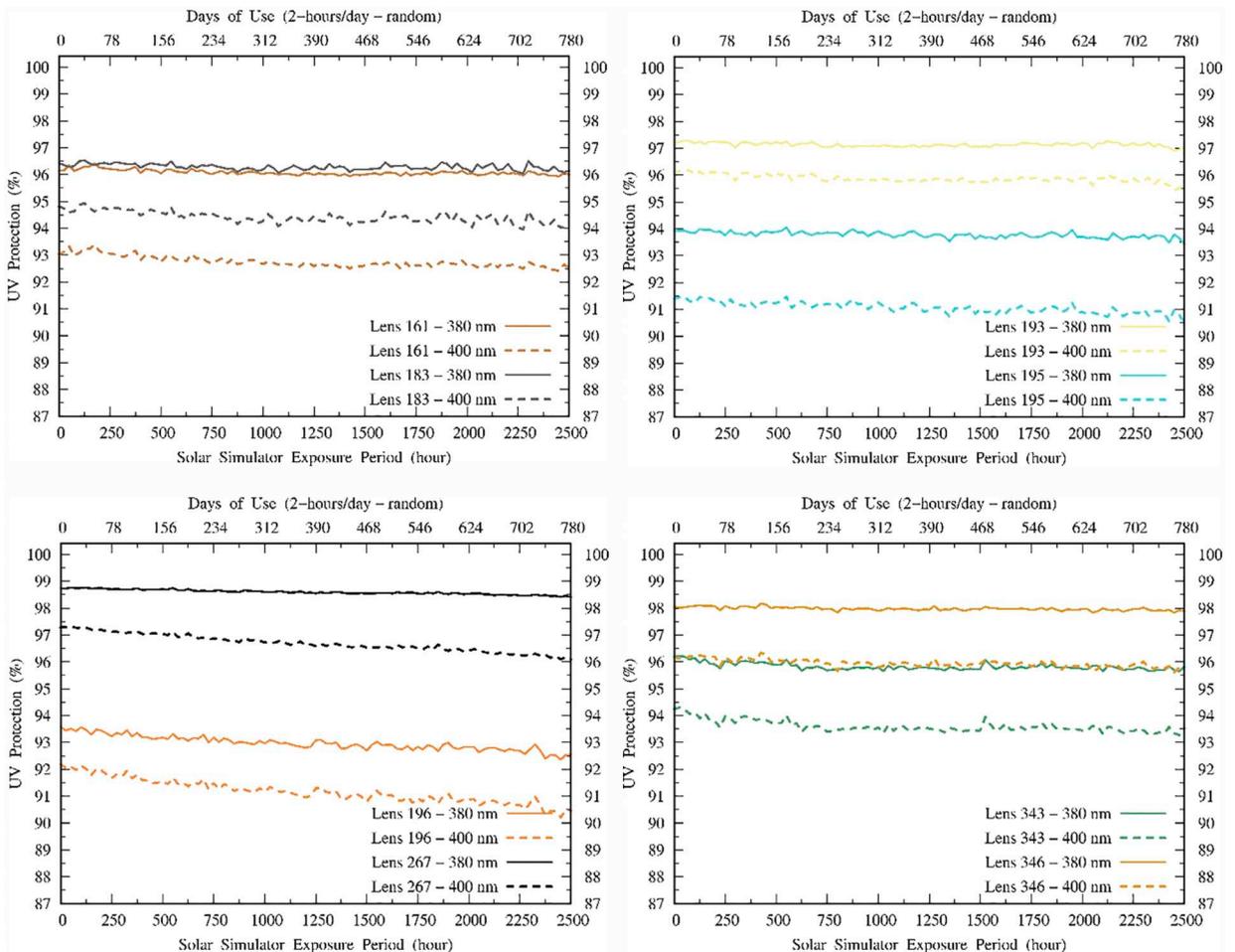**Fig. 5.** Time evolution of mean UV protection of 12 sample lenses.

Fig. 6. UV protection for some selected samples taking the UV upper limit as 380 nm (solid lines) and 400 nm (dashed lines).

for which the lenses eventually failed at least one of the compliance requirements, such as altering the luminous transmittance excessively as specified in Table 3 and/or UV transmittance as in Table 2. Tables 4 and 5 show results using the UV upper limit as 380 nm, as adopted by the standard ISO 12312-1 and show the corresponding results for UV upper limit of 400 nm. In Table 4 we

Table 4

Luminous transmittances and their relative changes after 50 h exposure time in solar simulator and after long-term exposure for both 380 nm and 400 nm as UV upper limit. Results in boldface represent test failure, i.e., non-conformity.

	Initial (0 h)		After 50 h in solar simulator		Exposure time at which test failure occurs (h)	
	Luminous transmittance		Relative change		Relative change	
	τ_V (%)		$\Delta\tau_V / \tau_V$ (%)		$\Delta\tau_V / \tau_V$ (%) (and failure time)	
Lens label	380 nm UV upper limit	400 nm UV upper limit	380 nm UV upper limit	400 nm UV upper limit	380 nm UV upper limit	400 nm UV upper limit
033	7.882	7.879	−3.870	−3.870	**−10.988** (150)	**−10.990** (150)
040	5.429	5.430	−7.832	−7.832	**−10.069** (300)	**−10.069** (300)
061	6.042	6.040	**−12.917**	**−12.919**	**−10.045** (25)	**−10.048** (25)
120	4.667	4.664	−5.797	−5.799	**11.291** (75)	**11.294** (75)
161	26.775	26.772	−6.501	−6.502	**8.393** (1175)	**8.392** (1175)
183	31.614	31.615	3.289	3.289	**9.170** (575)	**9.170** (575)
193	19.668	19.668	−2.816	−2.816	**9.806** (2050)	**9.804** (2050)
195	17.940	17.937	−1.810	−1.810	**8.369** (1225)	**8.368** (1225)
196	27.049	27.049	0.199	0.199	**10.050** (250)	**10.050** (250)
267	30.166	30.167	−0.492	−0.492	**8.999** (425)	**8.998** (425)
343	16.489	16.487	−1.015	−1.016	**13.308** (225)	**13.308** (225)
346	20.262	20.261	2.972	2.972	**−9.249** (100)	**−9.251** (100)

analyze the behavior of lenses' luminous transmittances and Table 5 is dedicated to UV transmittances requirements.

Table 4 lists the initial (0 h) average luminous transmittances of each lens. Following the standard's requirement, the respective transmittances measured after 50 h of exposure is listed, alongside their relative changes in transmittances. One observes that only one lens (label 061) failed to comply with the respective requirement listed in Table 3, i.e., the relative change in luminous transmittance shall be within ± 10% for a category 4 lens. In addition, Table 4 shows the exposure time (in parentheses) for which the luminous transmittances have changed for the limits imposed by the standard, as listed in Table 3. Note that, for most lenses, the exposure period that the lenses fail the transmittance requirements is very long with some reaching over 1000 h. This corroborates our claim that the standard's parameters of the resistance to radiation test are ineffective and should be revisited to ensure a minimum quality of the filters. The behavior is essentially the same overall for the UV upper limit as 400 nm, i.e., for transmittances in the visible range, it is not relevant the choice of either 380 nm or 400 nm as UV upper limit, in contrast with the UV protection, as pointed out in Masili et al (2015) [1] and further discussed in Table 5.

In Table 5, the UV-A and UV-B transmittances, as well as UV protection, are shown for 0 h exposure (initial) and after 50 h of exposure in the solar simulator. In 380 nm upper limit, 6 lenses (results in boldface) have already failed protection requirements from start, with one lens (label 195) failing both UV-A and UV-B requirements (cf. Table 2). After 50 h in solar simulator (standard's requirement), the radiant exposure delivered to lenses is only 7.8 MJ/m² [13], which is virtually harmless to the lenses, as can be seen in Table 5, by the respective 50 h UV transmittances and protection compared to their initial (0 h) values. Aside those lenses that did not meet the UV protection requirements at the start, 2 out of 5 lenses failed UV protection requirements after 25 h of exposure, with the remaining 3 lenses meeting the requirements after 2500 h of exposure. However, care must be taken because even in compliance after the stress test, the UV protection decreases, as depicted in Fig. 5. Owing to the cumulative effects of UV radiation upon biological tissues, the lenses UV protection loss might be an important concern. Table 5 shows a similar analysis for UV-A with 400 nm as an upper limit, where two more lenses fail UV-A protection requirement. Moreover, the UV protection for all, but one, lenses are smaller when compared with the corresponding ones with 380 nm upper limit.

3.2. NIST solar simulator

Regarding NIST's experiment, an additional set of 32 lenses, made of synthetic materials, was chosen to be irradiated in the SPHERE solar simulator in a total of 962 h of exposure time. Like Fig. 3, Fig. 7 shows the UV–Vis spectral transmittances of two selected lenses before and after 962 h of exposure in the NIST solar simulator.

In Fig. 7(a), the lens' spectral transmittance in the visible region increased while the UV region showed negligible changes. In contrast, Fig. 7(b) shows a lens with a significant change in the UV–Vis spectral transmittance. In this case, an increase in the average luminous transmittance is very prominent. In addition, a potentially dangerous decrease in protection against UV radiation is evident.

Tables 6 and 7 show the behavior of lenses' luminous and UV transmittances requirements, respectively. After the 962 h of exposure, 21 out of 32 lenses failed the standard luminous transmittances requirements, as listed in boldface in Table 6. Moreover, 16 samples dropped their category by 1 or even 2 places. One sample showed a relative change in luminous transmittance as high as 458% (label 150) and many others > 100% or 200%, both in 380 nm and 400 nm as UV upper limit.

In Table 7, results in boldface show the lenses that failed de UV transmittances requirements, summing up to 7 lenses that failed at the start, i.e., at 0 h. In both 380 nm and 400 nm as UV upper limit, one lens failed after 962 h of exposure. In all cases, UV protection decreased after the 962 h of exposure in the solar simulator. One lens (label 010) decreased 28 percentage points in regarding the UV

Table 5

UV transmittances and protection before and after 50 h exposure time in solar simulator and after long-term exposure for both 380 nm and 400 nm as UV upper limit. Results in boldface represent test failure, i.e., non-conformity.

Lens label	Initial (0 h)					After 50 h in solar simulator (and failure time)				
	380 nm UV upper limit			400 nm UV upper limit		380 nm UV upper limit			400 nm UV upper limit	
	UV-A transmittance (%) 315–380 nm	UV-B transmittance (%) 280–315 nm	UV protection (%) 280–380 nm	UV-A transmittance (%) 315–400 nm	UV protection (%) 280–400 nm	UV-A transmittance (%) 315–380 nm	UV-B transmittance (%) 280–315 nm	UV Protection (%) 280–380 nm	UV-A transmittance (%) 315–400 nm	UV protection (%) 280–400 nm
033	1.531	0.038	99.08	**4.845**	96.99	1.450	0.029	99.13	**4.660**	97.11
040	0.003	0.000	100.00	0.005	100.00	0.002	0.002	100.00	0.003	100.00
061	**1.843**	0.084	98.88	**4.857**	96.96	**1.676**	0.059	98.99	4.468	97.21
120	**2.019**	0.090	98.77	**4.752**	97.03	**1.958**	0.079	98.81	**4.619**	97.11
161	5.609	1.321	96.15	10.444	93.04	5.360	**1.213** (25)[a]	96.34	**10.040**	93.33
183	4.937	**1.604**	96.43	7.384	94.82	5.130	**1.690**	96.28	7.695	94.59
193	3.760	**1.387**	97.21	5.421	96.12	3.662	**1.349**	97.29	5.298	96.21
195	**9.002**	1.869	93.93	**12.749**	91.40	**8.951**	**1.942**	93.93	**12.624**	91.45
196	9.462	**2.062**	93.58	11.360	92.19	9.560	**2.075**	93.51	**11.491** (2050)[c]	92.10
267	2.050	0.146	98.73	4.301	97.28	2.005	0.132	98.76	4.267	97.31
343	5.765	0.993	96.20	**8.702**	94.24	5.768	**0.981** (25)[b]	96.20	**8.718**	94.23
346	3.012	0.399	98.06	5.932	96.18	3.054	0.422	98.03	6.027	96.11

Test failed at [a]1.379 (25), [b]1.022 (25), and [c]13.620 (2050) respectively.
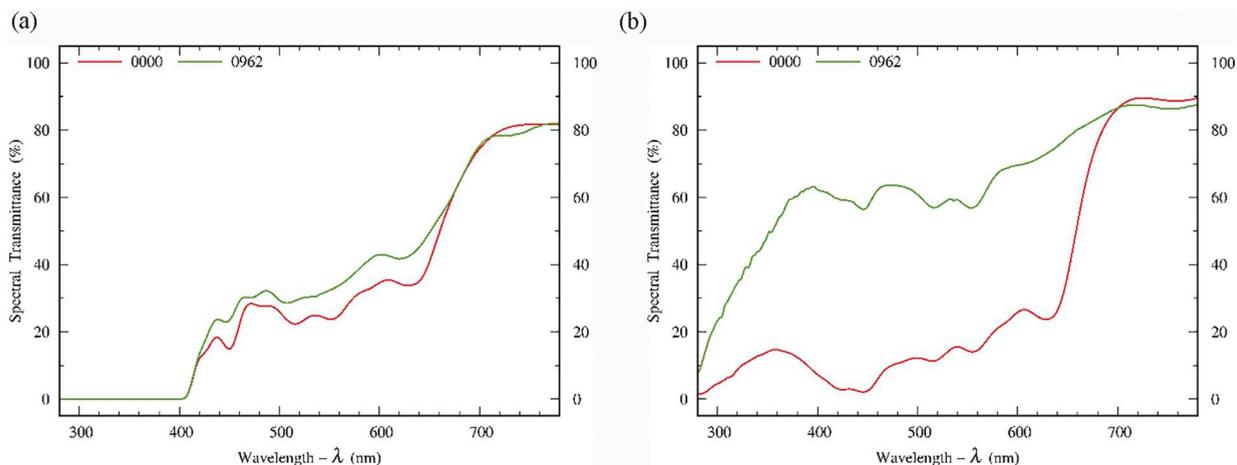
(a)

(b)

Fig. 7. Ultraviolet and visible spectral transmittances for two selected sunglasses lenses before (bottom red line) and after (top green line) 962 h of exposure in the NIST solar simulator. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 6
Luminous transmittances and their relative changes after 962 h exposure time in NIST solar simulator for both 380 nm and 400 nm as UV upper limit. Results in boldface represent test failure, i.e., non-conformity.

	Initial (0 h)		After 962 h in NIST solar simulator	
	Luminous transmittance		Relative change	
	τ_V (%)		$\Delta\tau_V / \tau_V$ (%)	
Lens label	380 nm UV upper limit	400 nm UV upper limit	380 nm UV upper limit	400 nm UV upper limit
010	17.510	17.512	**258.207**	**258.184**
034	7.000	7.001	**200.713**	**200.713**
052	11.436	11.436	**216.477**	**216.478**
072	15.668	15.667	**138.896**	**138.912**
075	9.635	9.632	**188.303**	**188.353**
085	4.880	4.878	**287.109**	**287.235**
087	22.355	22.353	**70.205**	**70.214**
105	9.362	9.363	**188.113**	**188.113**
135	21.081	21.084	**12.777**	**12.777**
136	9.530	9.527	**306.766**	**306.867**
150	4.947	4.944	**458.429**	**458.646**
151	5.850	5.851	**168.391**	**168.391**
174	31.041	31.043	**97.167**	**97.160**
178	29.893	29.894	**103.862**	**103.862**
189	11.437	11.439	3.165	3.156
190	10.735	10.736	−2.357	−2.347
221	20.010	20.009	**121.375**	**121.391**
238	2.318	2.318	4.875	4.875
245	2.604	2.604	−1.767	−1.767
303	7.213	7.214	**11.065**	**11.065**
304	2.442	2.442	**2.539**	2.539
307	4.106	4.107	0.390	0.390
309	5.154	5.155	−3.046	−3.065
310	4.317	4.318	7.320	7.318
311	3.290	3.291	**10.149**	**10.149**
364	8.062	8.063	−0.409	−0.409
372	27.858	27.862	**25.533**	**25.533**
373	28.169	28.173	**21.646**	**21.646**
374	12.206	12.208	−3.171	−3.170
377	9.296	9.298	**246.403**	**246.403**
379	10.882	10.883	**153.934**	**153.934**
380	11.915	11.917	−4.339	−4.347

Table 7

UV transmittances and protection before and after 962 h exposure time in NIST solar simulator for both 380 nm and 400 nm as UV upper limit. Results in boldface represent test failure, i.e., non-conformity.

	Initial (0 h)		After 962 h in NIST solar simulator	
	Luminous transmittance		Relative change	
	τ_V (%)		$\Delta\tau_V / \tau_V$ (%)	
Lens label	380 nm UV upper limit	400 nm UV upper limit	380 nm UV upper limit	400 nm UV upper limit
010	17.510	17.512	**258.207**	**258.184**
034	7.000	7.001	**200.713**	**200.713**
052	11.436	11.436	**216.477**	**216.478**
072	15.668	15.667	**138.896**	**138.912**
075	9.635	9.632	**188.303**	**188.353**
085	4.880	4.878	**287.109**	**287.235**
087	22.355	22.353	**70.205**	**70.214**
105	9.362	9.363	**188.113**	**188.113**
135	21.081	21.084	**12.777**	**12.777**
136	9.530	9.527	**306.766**	**306.867**
150	4.947	4.944	**458.429**	**458.646**
151	5.850	5.851	**168.391**	**168.391**
174	31.041	31.043	**97.167**	**97.160**
178	29.893	29.894	**103.862**	**103.862**
189	11.437	11.439	3.165	3.156
190	10.735	10.736	−2.357	−2.347
221	20.010	20.009	**121.375**	**121.391**
238	2.318	2.318	4.875	4.875
245	2.604	2.604	−1.767	−1.767
303	7.213	7.214	**11.065**	**11.065**
304	2.442	2.442	**2.539**	2.539
307	4.106	4.107	0.390	0.390
309	5.154	5.155	−3.046	−3.065
310	4.317	4.318	7.320	7.318
311	3.290	3.291	**10.149**	**10.149**
364	8.062	8.063	−0.409	−0.409
372	27.858	27.862	**25.533**	**25.533**
373	28.169	28.173	**21.646**	**21.646**
374	12.206	12.208	−3.171	−3.170
377	9.296	9.298	**246.403**	**246.403**
379	10.882	10.883	**153.934**	**153.934**
380	11.915	11.917	−4.339	−4.347

protection for the 380 nm UV upper limit and 30 percentage points for the 400 nm limit. Aside from this particular case, the maximum UV protection loss was about 3.6 percentage points in the 380 nm UV limit and 4.8 percentage points in the 400 nm limit.

4. Conclusion

We have conducted experiments designed to investigate the behavior of some optical properties of sunglasses lenses, such as UV–Vis spectral and mean transmittances as well as UV protection. In this study, we examined the UV range wavelength upper limit as 380 nm (as determined by the ISO 12312-1 standard) and the 400 nm upper limit.

Based on our results, some of the unbranded sunglasses were non-compliant with the ISO standard at the start, i.e., even before the resistance to radiation test, regardless of their prices.

Only one of the lens failed the luminous transmittances requirements, i.e., the relative change in luminous transmittance after 50 h exposure, as required by the standard. However, our long-term irradiation experiment in solar simulator shows that most lenses will eventually fail this requirement.

As for the mean UV transmittance requirements and UV protection, very few were not in compliance with the standard, although all samples became less safer regarding the ocular protection. We stress that care must be taken because even in compliance after the long-term resistance to radiation test, the UV protection loss of the filters might be an important issue due to the cumulative effects of UV radiation upon biological tissues.

In summary, our results support the hypothesis that the current parameters for the resistance to radiation test for sunglasses, required by ISO 12312-1 standard, is ineffective, and does not assure ocular safety for protection against harmful electromagnetic radiation within sunglasses lifetime of usage.

Acknowledgments

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