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The eye protection factor (EPF®): An improved solar UV rating system for sunglasses

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Abstract

Background/aims: Serious eye diseases caused from exposure to solar radiation continue to be a global public health hazard. Within the electromagnetic spectrum, the ultraviolet (UV) band and some of visible light band (high energy visible (HEV) light) pose the greatest health hazard to the human eye from solar radiation exposure. Wearing appropriate sunglasses is the most practical and cost-effective way of protecting the human eye from harmful solar radiation. The purpose of EPF® is to bring more public awareness of the ocular UV hazard and encourage use of appropriate protective sunglasses outdoors.

Methods: A new protection rating system for sunglasses, called the Eye Protection Factor (EPF®), is proposed that measures a sunglass product's capability of protecting the human eye from UVA and UVB, based on the sunglass lenses and frame coverage. Five well-known brands of sunglasses are tested for EPF® values and compared. Two sunglass products are tested for the contribution of total diffuse UV reaching the eye from the back surfaces of the sunglass lenses.

Results: EPF® ratings of the five-sunglass products were variable, ranging from 15 to 50+, depending on frame coverage. Wrap around frames and lenses did not necessarily provide high EPF® ratings. A very small percentage of the diffuse UV reaching the eye comes from lens backscatter.

Conclusion: EPF® rating provides a reasonable way to know the full UV protection of the sunglass product.

Synopsis: Frame coverage provided by sunglasses is a highly variable and important component of solar UV eye protection and should be included in the product information. EPF® ratings will provide that information. In this manuscript, five different sunglass products are EPF® rated for comparison.

Introduction

Ultraviolet radiation that reaches the earth's surface (UVA and UVB) is known to cause damage to virtually every part of the human eye and its adnexa [1-6]. The eyes, the skin and the immune system are all harmed by excessive exposure to UV radiation. The human eye is more sensitive and vulnerable to UV damage than the skin [7]. With ozone depletion and global warming, the risks from excessive UV eye exposure outdoors are increasing [8-9].

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Figure 1: Top row left to right: Solar Keratitis, Pterygium, Squamous Cell Cancer of the Conjunctiva,
Bottom row left to right: Cataract, macular degeneration (dry form)

There are at least five serious eye diseases that are known to be caused in part by exposure to UV or High Energy Visible (HEV) radiation; cataract, pterygium, keratitis, eyelid and ocular cancers and macular degeneration (Figure 1). Cataracts are the leading cause of blindness in the world and macular degeneration has resulted in millions of people globally becoming legally blind [10]. Although there is increasing exposure time occurring in the population to radiation emitted from computer screens and other electronic devices, solar radiation remains by far the most significant source of UV risk to human eyes [11,12].

Both direct and diffuse (scattered) solar radiation has the potential to harm the human eyes [13,14]. The shorter the wavelength of the solar radiation, the more scatter will take place. Because of its shorter wavelength, a substantial contribution of the total UV radiation reaching the eye comes from the diffuse solar UV component. The anatomical structures of the forehead, brow, eyelids and nose do a reasonably good job of protecting the eyes within their orbits from direct UV exposure originating from the sun above [14]. Most of the diffuse UV radiation reaching the eye comes from below and the temporal sides of the eyes. In most cases, the diffuse UV component will cause more harm to the human eyes than the direct UV component, particularly when humans are standing on or near highly reflective surfaces, such as water or snow. Even under the brim of a hat or a shaded tree, or while in cloudy weather conditions, diffuse UV radiation will reach the unprotected eye in abundance.

Sunglasses are the most practical and cost-effective way of protecting the eyes from both solar UV and HEV radiation [15,16]. The amount of solar protection from wearing sunglasses depends on the ability of the lenses to block the specific spectral wavebands for UVA, UVB and HEV and on the frame coverage of the sunglass product.

Sunglass frame coverage (FC) is defined by the capability of the sunglass product to prevent UV from reaching the eyes by going around the lenses and frame. Frame coverage is determined by the following; size, shape and base curve of the sunglass lenses, the size of the temples and frame, the pantoscopic tilt of the sunglass lenses, and the anatomical configuration of the face and orbit. There is tremendous variability in frame coverage among sunglass products.

From the measurement of the frame coverage of hundreds of sunglass products, we found that even when the lenses block 100% of the UV radiation, significant and highly variable quantities of UV can still reach the eye. With small frames and lenses, for example, as much as 20% of the total potential UV that could reach the unprotected human eye can still get there by going around the sunglass lenses and frame; from below, the sides or above the sunglasses.

The American National Standard Institute's Z80.3-2018 details compliance information for flammability, durability, cosmetic, refractive, and transmittance properties of sunglasses [17]. With respect to solar protection, the Z80.3-2018 standard provides no information on sunglass frame coverage. Attempts have been made by different groups to create a standard of solar rating sunglasses that is more comprehensive than the testing required by the ANSI Z80.3-2018 standard [18-21]. None of those proposed standards have gained global acceptance or widespread usage. Two of the proposed standards include a component of blocking diffuse UV radiation that is not transmitted through the sunglass lens [19,20]. Only one proposed standard includes the measurement of the sunglass lenses' capability of blocking HEV [19].

What is being proposed is a new standard, called the Eye Protection Factor (EPF®), which is based on the weighted transmittance of UVB and UVA radiation through the sunglass lenses and the frame coverage. EPF® measurements do not include evaluation of the lenses for their ability to block HEV or Infrared (IR) radiation. EPF® does not rate the optical quality of the lenses. Nor does EPF® provide any information about the flammability, durability, cosmetic or refractive properties of the sunglass lenses. Those values can and should be measured independently. EPF® measures the total UV eye protection of the sunglass product, including the lenses and frame.

Each different wavelength of the UVB and UVA bands within the spectrum presents a different level of hazard to the human eye. Since the eye behaves as a filter of the electromagnetic spectrum, differing wavelengths are absorbed by different tissues within the eye (Figure 2). In general, the shorter the wavelength of UV radiation, the higher the photon energy and the greater the hazard to the eye and adnexa. This relationship is not linear, however. The potential hazard from UV and HEV radiation to the human eye also depends on the quantity of each wavelength that reaches the specific tissue of the eye being evaluated and on the sensitivity of that tissue to that wavelength. The retina is the most delicate and sensitive of all the parts of the human eye, yet very little radiation within the UVB band of the spectrum reaches the retina. Since most UVB entering the eye is absorbed by the cornea, in developing the EPF® standard, that specific animal tissue was selected for the UVB hazard evaluation. Since some of the UVA waveband reaches the retina, and particularly with children when the lens is immature, that specific tissue was selected to evaluate the UVA hazard. All hazard determinations for EPF® are based on the action spectra from animal studies performed several decades ago [22-24]. More recent evaluations of the UV and HEV hazard function utilizing various spectral bandwidths and utilizing laboratory grown retinal cell cultures have confirmed that the previous action spectra determined from animal studies are valid [25-27].

Figure 2: Filtration of sunlight through human eye with associated diseases

Using an independent, certified testing Laboratory (Colt's Laboratories Oldsmar, Florida), five sunglass products were tested for EPF® ratings and are presented for comparison. Two sunglass products from one company (Essilor) were tested to determine the percentage of the diffuse component of UV radiation that reaches the eye by reflecting off the back surface of the sunglass lenses, with and without antireflective (AR) coatings.

Materials and methods

Determining the weighted UV lens transmittance

According to the current CIE and ISO standard, the defined waveband for UVB is 290-315nm and for UVA is 315-400 nm [28,29]. UVC does not reach the part of the earth's environment that is inhabited or visited by humans and is, therefore, not considered a risk factor.

For every 5nm waveband within the UVB and UVA parts of the spectrum, a relative toxicity level (RTL) and a relative toxicity factor (RTF) were determined. For UVB, the RTL was derived by multiplying the solar irradiance levels at sea level in North America in midsummer at noon (Eλ) by the relative sensitivity (S(λ)) of the cornea to the specific wavelength within the 5nm waveband [30,31]. For UVA, the RTL was derived by determining the solar irradiance levels at sea level in North America in midsummer at noon for a specific wavelength within each 5 nm waveband [32,33]. Those values were then multiplied by the percentage of transmittance of that wavelength to the retina (T) and by the relative sensitivity of the retina to that wavelength. Once an RTL was determined for a wavelength within each 5 nm waveband of the UVB and UVA range, the average RTL (RTL) was determined for both UVB and for UVA (Tables 1 and 2).

RTL (UVB) = Eλ x Sλ (cornea)

RTL (UVA) = Eλ x T x Sλ (retina)

Eλ is Solar Irradiance at Sea Level expressed in W/cm2

T is the percentage transmittance of the wavelength that reaches the adult retina

Sλ is the relative sensitivity of the cornea or retina to the wavelength

The RTF for each 5nm waveband was then determined by dividing the RTL of that wavelength by the average RTL over the entire UVA or UVB waveband. Since some wavelengths are more hazardous than the average and others less hazardous than the average, the actual UV transmittance through the sunglass lens, as measured by the spectrophotometer, was weighted by multiplying that percentage transmittance at each 5 nm waveband by the RTF for that wavelength. With respect to human eye toxicity, the weighted total percentage transmittance of UV (and HEV) provides a fairer measurement of the sunglass lens protection than by using the total percentage transmittance.

RTF(λ) = RTL (λ)/ Average RTL

Table 1: Threshold UV Exposure to the rabbit cornea in producing damage from UVB source

Wavelength λ (nm)	Solar irradiance sea level (Eλ) * (w/cm²)	Relative sensitivity (Sλ) (rabbit cornea)† (J/cm²)	Relative Toxicity Level (RTL)	Relative Toxicity Factor (RTF)
290	0.01	0.42	0.005	0.02
295	0.06	0.25	0.016	0.06
300	0.66	0.10	0.066	0.26
305	5.20	0.07	0.364	1.42
310	11.79	0.09	1.062	4.15
315	22.23	0.002	0.044	0.17

*Data from Yannuzi LA, Fisher YL, Krueger A, et al [30], †Data from Pitts DG, Kay KR [29]

Table 2: Threshold UV exposure to the rhesus retina in producing damage from 100 seconds of a UVA source.

Wavelength λ (nm)	Solar irradiance sea level (Eλ)* (w/cm²)	Transmittance of retina (T)† (%)	Relative sensitivity (Sλ) (rhesus retina) (w/m²) x 10 4	Relative toxicity level (RTL)	Relative toxicity Factor (RTF)
320	32.4	2.90	21.0	19.7	1.80
325	39.5	2.75	20.0‡	21.3	1.94
330	41.5	2.25	19.6	18.3	1.67
335	43.5	1.80	19.6	15.3	1.40
340	45.5	1.50	19.2	13.1	1.20
345	47.5	1.15	18.9	10.3	.94
350	51.0	0.95	18.5‡	9.0	.82
355	55.0	0.60	17.2	5.7	.52
360	59.0	0.55	16.1	4.9	.45
365	63.0	0.50	15.2	4.5	.41
370	65.0	0.50	14.3	4.6	.42
375	67.0	0.60	13.3	5.3	.48
380	69.0	0.70	12.3‡	5.9	.54
385	71.0	1.00	10.0	7.1	.65
390	73.0	1.60	8.7	10.2	.93
395	75.0	3.50	7.7	20.2	1.84

*Data from Pettit E [31].
†Data from Boettner EA and Wolter JR [32].
‡Data from Zuclich JA [33].

To determine the frame coverage for each pair of sunglasses, we utilized a standardized adult head form that represents the average adult head size of combined males and females (EN-168). It is the head form recommended for use in all official protection testing of headgear, goggles and sunglasses. Our customized EN-168 head form (Cadex Labs) included the placement of a moveable research-grade photometer (LiCor 1400, LiCor Biosciences, Lincoln NE) in the left orbit. This photometer has a flat circular light receiving aperture of 12 mm in diameter, approximately the same dimension as the human cornea. It can be moved forward or aft to coincide precisely with the same position as the eye in the right orbit of the head form using a gauge plate tool. The LiCor 1400 photometer has the capability of measuring all entering visible light accurately with an incident angle of approximately 10 degrees or more from its perpendicular plane (Figure 3).

Determining the Frame Coverage (FC)

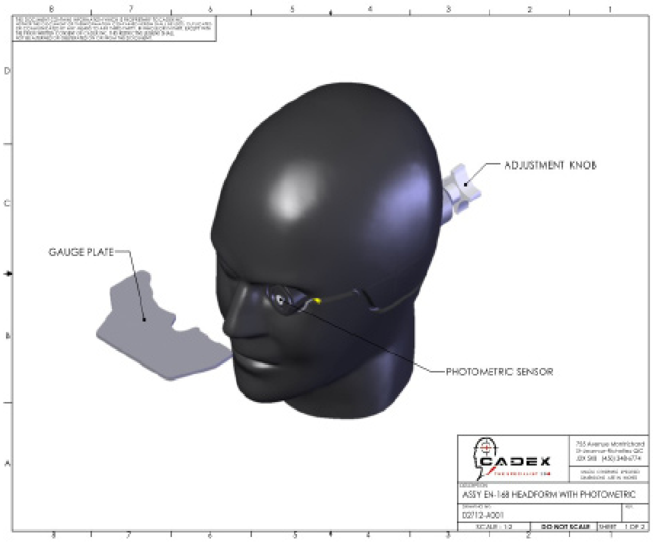

Figure 3: EN-168 Head form with photometer in left orbit.

The customized head form was secured on a table with five equal light sources geometrically placed around it (Figure 4). Each light source (100 Watt incandescent bulb placed in a 12 inch diameter silver reflecting bowl) was positioned precisely at 1 meter distance from the photometer in front, above, below and to the sides of the head form. The geometric placements of the light sources around the head form is designed to simulate the diffuse solar radiation that potentially reaches the eye.

In a darkroom, and with all five light sources on, a baseline reading of visible light from the photometer was derived from the average of two measurements taken without sunglasses placed on the head form. The lenses of each pair of sunglasses to be tested were then opacified with black tape, cut precisely to the lens shape. The opacified sunglasses were then placed securely on the head form, with the temples resting on the two protruding metal stems located on each side where the tops of the ears would typically be. Three photometric measurements were taken with the opacified sunglasses in place and averaged. The average photometric measurement with the opacified sunglasses in place was then divided by the average baseline photometric measurement (with no sunglasses on). This determines the percentage of visible light that reaches the photometer by going around the sunglass lenses and frames.

Figure 4: Frame coverage measurement from geometrically placed light sources

Because of its shorter wavelength and its higher rate of scatter, the diffuse component of UV reaching the eye will be a higher percentage of the total UV exposure when compared to the same for visible light. In order to estimate the amount of UV that will reach the eye with the sunglass product on, the average percentage of visible light reaching the photometer around the lens/frame combination was increased by a factor of 14%. This percentage increase in UV exposure is based on research done by Parisi et al, where the measured percentage of diffuse visible light was compared to the diffuse UVA and UVB during full sun throughout the day and year [34].

Determining the EPF® value

The weighted UV transmittance through the sunglass lenses and the estimated percentage of UV reaching the eye by going around the lens and frame combination were then summed to derive the total percentage of UV reaching the eye with the sunglasses on. That total, subtracted from 100, results in the approximate percentage of UV blocked by the sunglass lenses and frame together.

After testing hundreds of sunglasses, we found that the percentages of UV blocked by wearing the sunglasses ranged from about 80% with the smallest frames to over 99% with the tightest wraparound frames. In order to develop accurate EPF® values that are also similar to SPF values, we modeled the EPF® system after the UPF system for solar-rating textiles, where a logarithmic scale is used [35].

SPF values used for sunscreen are based solely on the effect of UVB radiation, while UPF values consider both the UVA and UVB hazard to skin. The most porous clothing will block just over 90% of the UV from reaching the skin, while the most protective clothing will block 100% of the UV. A UPF rating of 10 simply means that the textile blocks 9/10 of the UV, or 90%. A UPF rating of 50 means that the textile blocks 49/50 of the UV, or 98%. By converting to a logarithmic scale, UPF has altered the range from 90 to 100 to a range of 10 to 50+, similar to the SPF values.

Since the total UV blockage from sunglasses ranges from around 80% to nearly 100%, to derive the EPF® value, a logarithmic scale is used where a value of 10 represents that the sunglasses block 8/10 of the UV, or 80%, and a value of 50 represents that the sunglasses block 48/50 of the UV, or 96%. Derived EPF® values are rounded to the nearest 5 for simplicity. In this manner, the range of EPF® values for sunglasses is similar to both UPF and SPF values, which are both familiar and recognizable to consumers (Table 3).

Results

Five pairs of sunglasses from well-known manufacturers were measured for their weighted UV lens transmittance and frame coverage to determine the EPF® values (Table 4). According to its EPF® value, each pair of sunglasses was categorized as moderate, good, very good or excellent UV protection.

Two sunglass products (Costa del Mar) were measured for EPF values and frame coverage with the backs of the lenses unaltered and with the backs of the sunglass lenses opacified (no reflection). One of the sunglasses (Cut UT 73) had AR coating applied to the back surface of the lens at the factory. The other (Blackfin BL10) did not. The frame coverage values were then compared to determine the percentage of UV reaching the eyes as a result of scatter from the back surfaces of the sunglass lenses (Table 5).

Table 3: Proposed EPF values based on total UV blockage with protection category

EPF Value	% UV Blocked	Protection Category
10	80	Moderate
15	86.6	Good
20	90	Good
25	92	Very Good
30	93.3	Very Good
35	94	Very Good
40	95	Excellent
45	95.5	Excellent
50	96	Excellent
50+	>96	Excellent

Table 4: EPF® comparison of five brands of sunglass products.

Product	% UVA lens block	% UVB lens block	% FC block	EPF® rating	UV Protection Category
Roka CP-1X	100	100	94.1	35	Very good
Ray Ban ORB2140	100	99.99	88.1	15	Good
Costa del Mar Blackfin BL10	100	100	98.6	50+	Excellent
Oakley Gas can	100	100	91.7	20	Good
Spy Optic Wraparound	99.99	99.99	90.6	20	Good

Table 5: Determination of contribution to diffuse UV component from lens backscatter.

Product	EPF® rating	% FC blockage	% FC blockage (back lenses opacified)	Difference
Costa del Mar Blackfin BL10	50+	98.6	99.1	.5%
Costa del Mar Cut UT 73	20	90.7	91.0	.3%

Discussion

Every effort possible should be taken to encourage the use of sunglasses outdoors, particularly with children who spend more time outdoors and whose eyes are more susceptible to UV damage. In the purchase of sunglasses, information is typically included by manufacturers about the UV eye protection provided by the lenses, but not for the entire product; frame and lenses combined. The essential information on frame coverage is missing.

In some environments, such as around water, sand or snow, the amount of UV exposure to the eyes increases dramatically. In some of these higher risk places, the UV eye exposure may nearly double, when compared to standing on grass at sea level. Consumers need to know the total amount of UV protection the entire sunglass product provides, not just the lenses, and particularly for higher risk environments where higher EPF® ratings are desirable.

From our testing of five well-known brands of sunglasses, we found that it is not easy to predict the full UV protection of sunglasses by simply looking at the products. The results of the EPF® testing of the five sunglasses were quite varied, purely on the basis of differing frame coverage. All five of the sunglass lenses blocked virtually 100% of the UV radiation. Even so, at least one wraparound style of sunglasses tested did not have a very high EPF® rating, perhaps not enough for certain riskier environments. EPF® testing performed by reliable, certified laboratories with proper product labeling is the best way to know the true UV protective value of the sunglass product.

With the two Costa del Mar sunglass products, we found that the percentage of UV reaching the eyes reflected off the back surface of the lenses was very small (less than 1%). The AR coating applied to the back surfaces of the lenses reduced the amount of UV reaching the eye compared to the non-AR coated lenses, but also by a small amount (.2%). Eliminating the reflection of UV from the back surface of the sunglass lenses did not change the EPF value of either sunglass product.

Conclusion

It is essential to know the full UV protection provided by the complete sunglass product. That requires knowledge of the sunglass frame coverage, as well as the weighted UV protection from the lenses. EPF® is the first sunglass standard available that provides complete information for UV eye protection from both the lenses and frame together.

The amount of UV eye protection a person requires from sunglasses will differ, depending on the environmental conditions. Providing EPF® labels on sunglasses will help consumers find the right amount of UV eye protection for their specific outdoor purposes. Placing AR coatings on the back surface of the sunglass products' lenses will not appreciably improve the eye protection from diffuse UV exposure. Selecting the right sunglass product can. EPF® labels will hopefully bring more attention to the vital need of wearing sunglasses outdoors and to wearing the appropriate sunglass product to help prevent serious and harmful eye diseases.

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