



INTERNATIONAL  
REVIEW OF  
OPHTHALMIC OPTICS

# UV and Blue-Violet Light Definitions, risks and prevention

Collection of articles from 2011 to 2015  
[e-Book]

Special Edition

Online publication [www.pointsdevue.com](http://www.pointsdevue.com)

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## Special Edition

Collection of articles from 2011 to 2015  
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# **I. UV AND BLUE-VIOLET LIGHT: DEFINITION AND RISKS**

# 1. ULTRAVIOLET

# THE EYE AND SOLAR ULTRAVIOLET RADIATION

New understandings of the hazards,  
costs, and prevention of morbidity

## REPORT OF A ROUNDTABLE

June 18, 2011, Salt Lake City, UT, USA

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# UV Exposure and Ocular Health:

## A Serious Risk that is Widely Ignored

The idea that sunlight can be damaging to the eyes is not new—evidence of ultraviolet's negative effects has been accumulating for over a century. Sunlight exposure has been implicated to varying degrees in a variety of ocular pathologies involving the eyelids, conjunctiva, cornea, lens, iris, vitreous, and possibly the retina. These ophthalmic conditions have been collectively described as "ophthalmohelioses," the ophthalmic equivalent of dermatohelioses.<sup>1,2</sup>

The evidence for a causative connection between ultraviolet (UV) light and ocular pathology ranges from strong to highly suggestive, depending on the disease state. In the case of pterygium, a common ocular disease with highest incidence in tropical, high-altitude, and highly reflective environments, sun exposure is the only scientifically proven risk factor, and the critical role of UV damage in pterygium pathogenesis is well established. On the other hand, while there is some evidence that UV exposure may play a role in the development of age-related macular degeneration (AMD), that role has not been definitively proven.

There is no question, however, that UV exposure—particularly the cumulative effect of long-term exposure to sunlight—is damaging to the eyes. While dermatologists have done a superb job alerting the public to the hazards of exposing skin to UV, the general population—and even many eyecare professionals—remain somewhat uninformed about the ocular hazards of UV. The result has been a low level of interest in and knowledge about sun protection for the eyes.

This may stem in part from a lack of effective communication of what we already know about the ocular hazards of UV exposure. More important in the longer term, perhaps, are gaps in our understanding of eye protection and the absence of consensus on standards for eye protection—we have, for example, nothing like the sun protection factor (SPF) that could tell sunglass consumers how effectively their new eyewear will protect them. Yes, we know that some

clear and most sunwear lenses will block transmitted UV below 350 nanometers (nm) from reaching the retina, but what that does not tell us is how much UV still reaches the eyes without passing through the lenses. So while sunblock lotion buyers know the relative protection one preparation offers versus another, there is no similar scale for buyers of sunglasses.

Similarly, while the UV Index can tell consumers how much solar UV to expect on a given day; as this report documents, even that is flawed as a measure of ocular UV exposure. While excess exposure to UV is clearly hazardous, the situation is complex—moderate exposure to sunlight is important, perhaps even necessary, for good health. In dealing with UV risk, we must be thoughtful and sophisticated, balancing beneficial exposure with the need to protect both skin and eyes from overexposure.<sup>3</sup>

In an effort to raise awareness about the serious risks of ocular sun exposure and what can be done about them, Essilor brought together an expert panel in June 2011, comprising 11 optometrists, ophthalmologists, dermatologists, chemists, and physicists, for a comprehensive discussion of the dangers UV poses to the eye and ways to protect the eye from UV. Our goals were to:

- Delineate what is known and not known about the damaging effects of UV on the eye,
- Review the costs in terms of both dollars and morbidity of UV-induced eye disease, and
- Identify the stumbling blocks to greater adoption of effective eye protection.

The high points of that wide-ranging discussion are reported here. One point came across with great clarity: we know that UV presents a serious hazard to the eye, but we have not found means to communicate that effectively enough to get the public or even the majority of eyecare practitioners to act on that knowledge. The goal of this work, then, is to inform and by that means to incite action to protect eyes from the very real dangers of long- and short-term solar injury.

# UV AND HUMAN HEALTH

- Although a small amount of UV comes from artificial sources, the overwhelming bulk of the UV to which people are exposed comes from the sun
- UV can cause health effects both through direct damage to DNA and through photosensitizing reactions that cause the production of free radicals and oxidative damage
- The retina and other posterior ocular structures are protected from UV by the cornea and the crystalline lens, which together absorb almost all of the UV that enters the eye. This, however, puts the protective structures at risk
- Although UV can be harmful, some UV exposure is necessary for good health

## UV Radiation: The Nature of the Hazard

UV radiation is electromagnetic radiation with wavelengths ranging from 100 nm to the edge of the visible light spectrum (Figure 1). The UV spectrum has itself been divided into bands based upon the biologic effects of the wavelengths: UVA comprises wavelengths from 380 to 315 nm, UVB from 315 to 280 nm, and UVC from 280 to 100 nm.\* (The visible light spectrum runs from 380 to 760 nm.)

UVA, which can penetrate further into skin than UVB, is known to be responsible for sun tanning and skin aging and wrinkling. More biologically active than UVA, UVB causes tissue damage such as erythema and blistering, and is known to play a critical role in the development of skin cancer. UVC may also cause skin cancer; in addition, UVC can kill bacteria, hence the use of UVC as a germicidal agent.

## Sources of UV

Natural sunlight is the primary source of terrestrial UV radiation. In normal circumstances, wavelengths below 290 nm are almost completely absorbed by the ozone layer of the stratosphere, so solar UVC is not a problem on the surface of the earth (although man-made UVC from industrial processes is sometimes a hazard). Because the ozone layer can more efficiently absorb short UV wavelengths than longer ones, the UV that reaches the earth's surface is constituted by about 95% UVA and 5% UVB.<sup>4</sup>

UV can also come from artificial sources such as electric arc welding devices and some new, specialized, or unusual light sources. Lamps often used in tanning

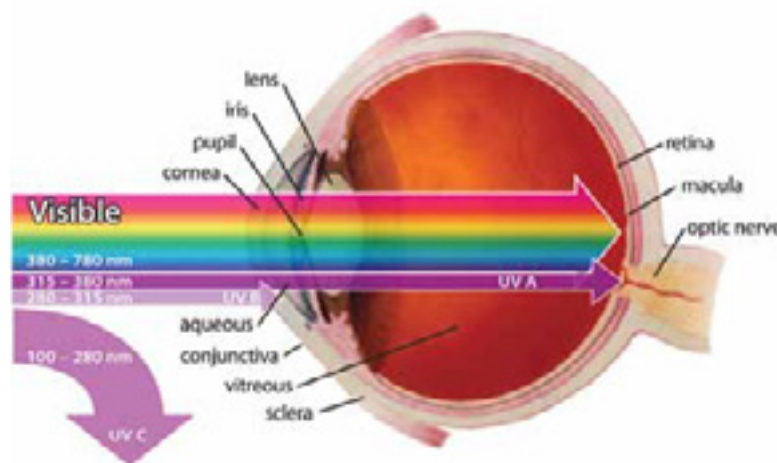


Figure 1 The visible and invisible light spectrum.

\* The precise cutoff points for various UV bands are somewhat arbitrary and differ slightly in work by different groups.

salons are a common and potentially dangerous source of UV radiation. The current trend in indoor lighting is to replace conventional incandescent lamps with more energy-efficient ones, such as compact fluorescent lamps; but light production by fluorescent lamps relies on the release of UV radiation. To help address this, one solution is a double glass envelope which can effectively filter out the emitted UV. However, compact fluorescent lamps with a single-envelope design may lead to an increased risk of UV exposure, particularly when they are used closer to the body (eg, table lamps) for long periods of time.

### UV Damage Mechanisms

UV can cause both direct and indirect cellular damage (Figure 2). Direct damage from UV penetrating a cell occurs when molecules absorb the radiation. DNA, which readily absorbs UVB, can be damaged this way. When UVB photons are absorbed by a DNA molecule, they add energy and raise the DNA molecule to an excited state; this, in turn, can initiate photodynamic reactions that result in structural changes to the DNA. One typical structural change is the formation of thymine dimers, the most abundant DNA lesions following direct UV exposure.<sup>5</sup> Thymine dimerization has been shown to occur virtually instantly when UV is absorbed.<sup>6</sup>

UV-induced DNA damage can be repaired through multiple repair pathways inherent to organisms. These protective mechanisms, however, can be overwhelmed by sudden high levels of radiation or chronic lower-level UV exposure. Unrepaired lesions cause distortion of the DNA helix and transcription errors that can be passed on through replication, leading ultimately to mutagenesis or cell apoptosis.

UVA radiation causes no direct DNA damage because it is not absorbed by the DNA molecule. Its absorption by other cellular structures, however, can trigger photochemical reactions that generate free radicals known to be damaging to essentially all important cellular components including cell membranes, DNA, proteins, and important enzymes. Free radicals can also induce depolymerization of hyaluronic acid and degradation of collagen, changes found in photoaging of the skin and vitreous liquefaction of an aging eye.

### Beneficial vs Harmful Effects of UV

It has long been known that the optimum wavelengths for vitamin D synthesis in human skin fall within a narrow band from 295 to 315 nm.<sup>7</sup> Studies have found increasing rates of vitamin D deficiency worldwide, and some have suggested that this is attributable to reduced vitamin D production due to sun avoidance, as people take measures to prevent diseases such as skin cancer.<sup>8,9</sup>

The balance between beneficial and harmful effects of UV on human health appears to be the single area of disagreement among specialists in the physiologic effects of UV. For example, many dermatologists remain

## REPTILE LIGHTS: THE GOOD, THE BAD, AND THE SURPRISING

[The following story was related by  
Dr. Jan Bergmanson at the Roundtable\*]

Reptiles, particularly lizards, gain part of the energy that they need for metabolism and reproduction from UV. In the desert, these creatures' natural habitat, they can get adequate UV from bathing in the sun for half an hour. For captive (pet) lizards, however, a half hour of desert sunlight is hard to come by, so these reptiles require an artificial source of UV, typically a "reptile light," that can be purchased at pet stores.

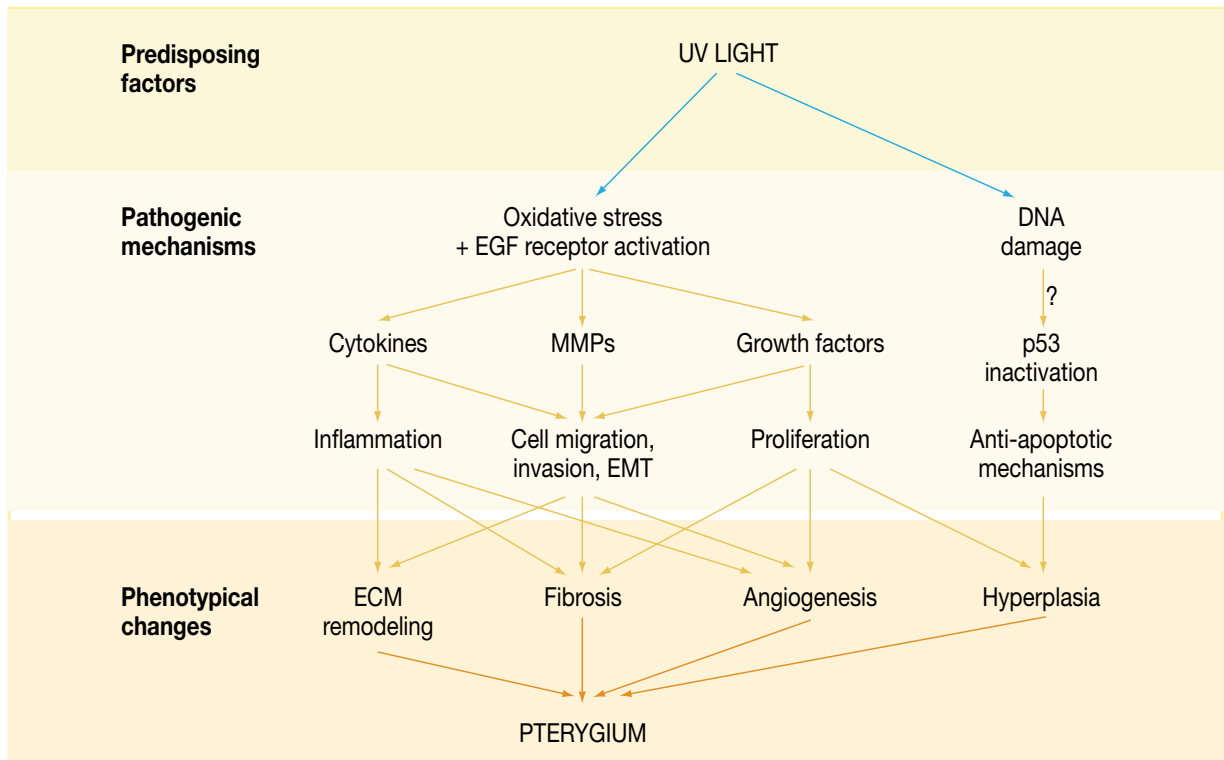
One day in the summer of 2010, Dr. Bergmanson was asked to buy one for his daughter's pet lizard. Curious about them, he bought not just one but six different reptile lamps and brought them into his lab, where he tested them with his research partner.

What they found came as a surprise; many of the lights emit high levels of UVB—more UVB than one would get in the middle of a sunny summer day in Texas. Even at 30 cm from the bulbs, the recommended safe distance, UVB levels were very high. Some of the lamps also emit toxic shorter wavelengths (UVC) not found in ambient solar radiation.

Dr. Bergmanson and his colleagues also noticed that none of the lamps came with any warning about the potential danger of UV. They did find emission spectra on the packages, but the curves on the labels bore little relation to what they found in the lab. Interestingly, some of the lights did not emit any UV at all. So some UV lamps can harm people, while others, though safe for people, are no good for lizards!

The bottom line is that artificial sources of UV can be dangerous, and labeling is not necessarily an accurate guide to exposure. By asking patients their hobbies, practitioners may be able to identify potential UV exposure risks.

\* This work on reptile lights by Dr. Bergmanson and his colleagues was presented at the 2011 meeting of the Association for Research in Vision and Ophthalmology in a poster titled "Commercially Available Reptile Lights—Good For Animal Bad For Handler?"



**Figure 2 Multiple processes activated by UV contribute to pathogenesis of pterygium.**

focused on skin cancer, and suggest that to raise vitamin D levels, sun exposure be replaced by vitamin D supplements; other groups question whether oral vitamin D is equivalent to vitamin D produced by the action of sunlight on skin.

### Absorption and Transmission of UV in the Eye

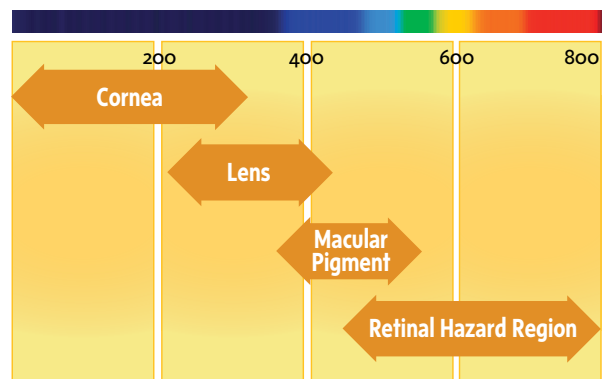
The eye is rich in light-absorbing pigmented molecules (chromophores), making it particularly susceptible to photochemical reactions. The human retina should be at high risk for UV damage, but fortunately only 1% or less of the UV incident upon the eye reaches the retina.<sup>10</sup> The overwhelming bulk of the UV is filtered out by anterior ocular structures, in particular the cornea and crystalline lens.

The absorption of UV by ocular tissues is wavelength-dependent (Figure 3). The cornea absorbs light at wavelengths below 295 nm, including all UVC and some UVB.<sup>11</sup> Initially the majority of this absorption was thought to occur in the corneal epithelium, but the corneal stroma actually absorbs a significant amount of UV, and Bowman's membrane is also an effective absorber.<sup>12,13</sup>

Unlike the cornea, whose UV absorbance characteristics are stable over time, the crystalline lens undergoes significant changes in UV absorbance as it ages. Specifically, the lens turns more yellow with age, resulting in greater absorption of UV wavelengths. So, while younger lenses can transmit wavelengths as short as 300 nm, the adult lens absorbs almost all wavelengths up to 400 nm.<sup>14,15</sup> In

children under age 10, the crystalline lens transmits 75% of UV; in adults over 25, UV transmission through the lens decreases to 10%.<sup>16,17</sup> This makes it especially important for children to have UV protection for their eyes.

Thus, the cornea and lens function together as an efficient UV filtration system, removing essentially all UVC wavelengths and the overwhelming majority of UVA and UVB. The "flaw" in this natural design is that it puts the protective structures, the cornea and the lens, at great risk from cumulative UV exposure. Not surprisingly, the most common ocular pathologies associated with sun exposure (including climatic droplet keratopathy, pinguecula, pterygium, and cortical cataract) involve the anterior eye.



**Figure 3 Absorption of UV by different ocular structures.**

# CLINICAL AND SOCIAL SIGNIFICANCE OF UV EXPOSURE

## DAMAGE FROM UV IS CUMULATIVE

- Cumulative UV damage is linked to corneal and anterior segment diseases
- Pterygium, climatic droplet keratopathy, and cortical cataract are chronic diseases definitively linked to cumulative UV exposure
- Age-related macular degeneration has been linked to UV exposure, but a causal connection has not been proved
- The majority of skin cancer cases are linked to sun exposure

## Chronic Diseases

Because of the difficulty involved in collecting quantitative data on UV exposure in large populations over periods long enough to allow estimation of lifetime dose, establishment of the relationship between specific eye diseases and sunlight exposure has had to rely heavily on epidemiological studies.<sup>18</sup> These studies have implicated UV damage from chronic sun exposure in a number of ocular diseases, including climatic droplet keratopathy, pinguecula, pterygium, cataract, and possibly AMD (Table 1).

UV-associated ocular diseases have a tremendous impact on both individuals and society. Impaired vision often causes lost productivity and social limitations; treatment of the diseases increases healthcare costs, adding to the economic burden of lost productivity.

**Pterygium** Pterygium is most prevalent in areas close to the equator and at higher altitudes, both of which are places with higher levels of UV exposure. An elevated incidence of pterygium is also found in places with high ground reflectivity.<sup>19,20</sup>

In the southern US, for example, the incidence of pterygium is estimated to be more than 10%, and it affects about 15% of the elderly population in Australia and more than 20% in Pacific islanders and in high-altitude populations in central Mexico.<sup>21-24</sup>

Without intervention, a pterygium may eventually invade the central cornea, causing blindness in severe cases. Although the abnormal tissue can be surgically removed and the affected bulbar conjunctiva/limbus reconstructed, surgery is time-consuming, costly, and may be associated with a relatively high recurrence rate.

**Climatic droplet keratopathy** Climatic droplet keratopathy is a condition in which translucent material accumulates in the corneal stroma in the band between the lids. People who spend considerable time outdoors are at particular risk for this condition, which can cause significant visual disability. It is believed that the translucent material consists of plasma proteins denatured by exposure to UV.<sup>25</sup>

**Cataract** Cataract continues to be the leading cause of blindness worldwide. Although surgery can prevent vision loss in almost every case, many nonindustrialized countries lack the resources to make cataract surgery

TABLE 1

### Ophthalmic Conditions in which UV has been Implicated in Pathogenesis

#### EYELID

- Wrinkles; sunburn, photosensitivity reactions, malignancy—basal cell carcinoma, squamous cell carcinoma

#### OCULAR SURFACE

- Pinguecula, pterygium, climatic keratopathy (Labrador keratopathy), keratitis (flash, snow blindness), dysplasia and malignancy of the cornea or conjunctiva

#### CRYSTALLINE LENS

- Cortical cataract

#### UVEA

- Melanoma, miosis, pigment dispersion, uveitis, blood–ocular barrier incompetence

#### VITREOUS

- Liquification

#### RETINA

- Age-related macular degeneration

available to large segments of their population; and it is estimated that worldwide as many as 5 million people go blind from cataract each year.<sup>26</sup>

In industrialized nations, where crystalline lens removal and replacement with an intraocular lens is a simple, effective, and near-universal procedure, the cost of the surgery overall has a significant economic impact. In the US alone, more than 3 million cataract surgeries are performed each year, costing at least \$6.8 billion annually for Americans over age 40.<sup>27,28</sup>

While further studies are needed to fully determine the role of UV in the formation of nuclear and posterior subcapsular cataract, UV has been established as an important risk factor for cortical cataract.<sup>29–33</sup> Because the cornea focuses and concentrates light on the nasal limbus and nasal lens cortex, one would expect those sites to be more prone to UV damage than other loci within the eye.<sup>1,34</sup> Epidemiologic studies of cortical cataract localization have consistently observed that early cortical cataract most often occurs in the lower nasal quadrant of the lens—exactly what one would predict if UV plays a role in the development of cortical cataract.<sup>35–37</sup>

**AMD** Though extensively studied, the role of UV in the development of AMD remains unclear. Epidemiologic studies have some suggestive evidence but no clear association between sunlight exposure and AMD.<sup>38–44</sup> This is not altogether surprising; unlike the cornea, and to a lesser degree, the crystalline lens, which are relatively heavily irradiated with UV (in part due to Peripheral

Light Focusing [PLF]), the amount of solar UV that reaches the retina is small, only 1% or less of the UV that strikes the cornea.

Also, AMD is a multifactorial disease; genetic predisposition, age, smoking, diet, and light toxicity are all likely risk factors. Future study of the link between UV and AMD is warranted to determine its place among the many other factors that have been implicated in AMD. One challenge in this process will be to get an accurate measure of retinal UV dose, which can vary with pupil size and increasing age as the absorption spectrum of the crystalline lens changes.

### UV Exposure and Skin Cancer

One major effect of excessive sun exposure is the development of skin cancer. Although UVA penetrates more deeply into the dermis and subcutaneous layers, it is not absorbed by DNA and thus previously deemed to be less harmful than UVB as a skin hazard. But we now know that, while UVA is less efficient in causing direct DNA damage, it can contribute to development of skin cancer through photosensitizing reactions that produce free radicals, which, in turn, cause DNA damage.<sup>45</sup>

Over the past 31 years, there have been more cases of skin cancer than all other cancers combined.<sup>46</sup> Melanoma, while less common than other skin cancers, is life-threatening and accounts for the majority of skin cancer deaths. It is estimated that about 64% of melanoma and 90% of nonmelanoma skin cancers (basal and squamous cell carcinomas) stem from excessive UV exposure.<sup>47,48</sup> The vast majority of the more than 33,000 gene mutations identified in the melanoma genome are caused by UV exposure, providing a strong link between UV exposure and the development of this skin malignancy.<sup>48</sup>

In the US, nonmelanoma skin cancers increased at a rate of 4.2% per year between 1992 and 2006.<sup>49</sup> Equally alarming is that melanoma incidence also increased by 45%, or about 3% per year, between 1992 and 2004, a rate faster than any other common cancer.<sup>50</sup> Skin cancer places a significant economic burden on society—the direct costs for the treatment of nonmelanoma skin cancers in 2004 came to \$1.5 billion.<sup>51</sup> Treatment of melanoma in adults 65 or older costs about \$249 million annually.<sup>52</sup> These numbers are expected to rise in parallel with the rising incidence of skin cancer.

Both melanoma and nonmelanoma skin cancers occur in the eyelids, which is the site of approximately 5–10% of nonmelanoma skin cancers.<sup>53</sup> It has been noted clinically that eyelid cancers are four times more likely to occur in the lower than the upper lids, perhaps because the upper orbital rim shades the upper lid more than the lower.<sup>54</sup> In addition to eyelid malignancy, UV exposure has also been associated with an increased risk of uveal melanoma.<sup>55,56</sup>

# EXPOSURE FACTORS

## PARTICULAR EXPOSURE FACTORS AND NEWLY UNDERSTOOD HAZARDS

- The intensity of ambient UV exposure is a function of solar angle, which varies with time of day, time of year, and latitude. Physical surroundings can increase ambient UV through reflection; and heavy cloud cover can decrease UV
- UV is greater at higher altitudes, where there is less atmosphere to absorb or reflect incoming UV
- UV exposure and associated eye diseases are expected to increase over the next few decades due to depletion of the ozone layer
- Nearly half of the UV that reaches the eye comes from exposure to scattered or reflected light
- Over 40% of the annual UV dose is received under conditions when people are less likely to wear sunglasses (Table 2)
- Peripheral light focusing increases the deleterious effect of reflected UV
- At most times of the year (and in most locations) the greatest ocular sun exposure occurs in the early morning and late afternoon rather than at solar noon
- Conventional sunglasses do not provide protection against side exposure
- UV reflection from the back surface of anti-reflective ophthalmic lenses is a newly recognized hazard

## Sources of Exposure

Multiple factors determine the intensity of ambient UV, which can vary dramatically with location and time of day or year. Direct sunlight contributes to only a portion of the ambient UV, more than 50% of which actually comes from localized light scattering and cloud reflection and scattering.<sup>57</sup>

In general, adults and children get exposed to about 2 to 4% of the total available annual UV while adults working outdoor get about 10%.<sup>58</sup> The average annual UV dose is estimated to be about 20000 to 30000 J/m<sup>2</sup> for Americans, 10000 to 20000 J/m<sup>2</sup> for Europeans, and 20000 to 50000 J/m<sup>2</sup> for Australians, excluding vacation, which can add 30% or more to the UV dose.<sup>58</sup>

UV that reaches the ocular surface can be measured by contact lens dosimetry as the ratio of ocular-to-ambient UV exposure, which was reported to range from 4 to 23% at solar noon.<sup>59</sup> Unlike the skin or ambient exposure, UV exposure of the eye is further determined by natural protective mechanisms, including squinting, pupil constriction, and geometric factors related to the orbital anatomy. These unique factors mean that peak ocular UV exposure may not coincide with peak skin exposure.

There are many popular misconceptions with respect to ocular UV exposure.<sup>60</sup> Understanding the factors that determine ocular exposure is challenging but critical for accurate assessment of ocular UV risks and determination of specific defense strategies against them.

TABLE 2

Condition	Sunlight exposure (Lx)	Percent of UV exposure per year
Indoor	500	8%
Clouded sky	5000	5%
Clear sky	25000	30%
Summer sky	100000	58%
Total		100%

\*Calculation based on urban workers in Northern hemisphere.

## UV INDEX

The UV Index, which ranges from 0 to the mid-teens, is a linear scale developed to describe the UV intensity at the earth's surface. The Index is calculated by an international standard method that takes into account the date, a location's latitude and altitude, and forecast conditions for ozone, clouds, aerosols, and ground reflection. The higher the value, the more intense the ambient UV and the greater the likelihood of UV damage to exposed skin.

Intended to guide people who need to make ordinary decisions such as how long they can stay outside on a given day and whether or not they need to wear sun protection, the Index has been widely incorporated into weather forecasts to predict the peak UV level at solar noon.

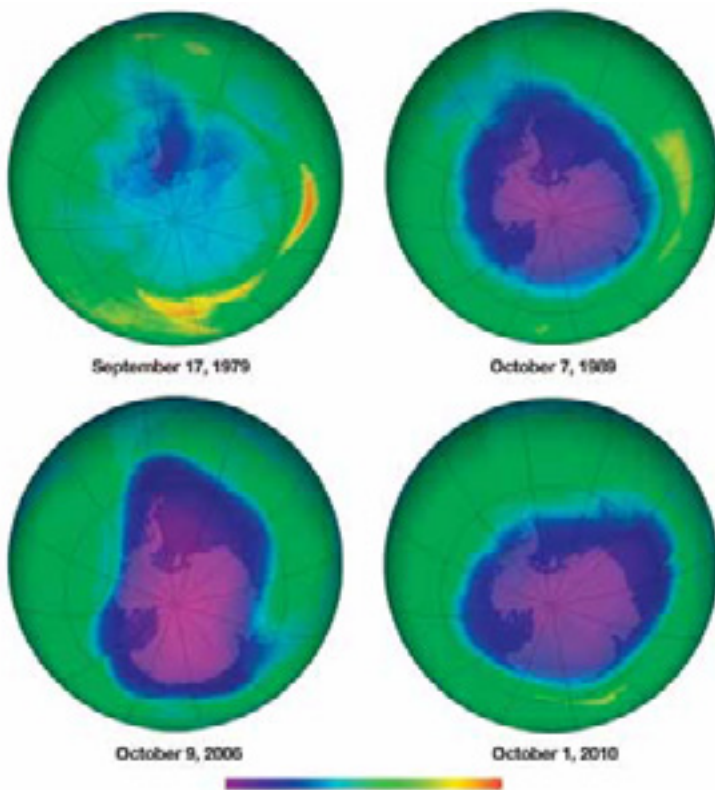
A vital shortcoming of the UV Index is that what it projects is only the predicted degree of UV danger to the skin. The Index does not correlate well with the risk of ocular UV damage, due in large part to the exposure geometry of the eye.

## Critical Factors in Determining Atmospheric UV Intensity

**The ozone layer** The ozone layer absorbs virtually all solar UVC and up to 90% of UVB, providing a natural shield from UV light.<sup>4</sup> In the past three decades, however, human activity has reduced the concentration of atmospheric ozone. Between 2002 and 2005, the ozone at mid-latitudes was depleted by about 3% from 1980 levels in the northern hemisphere and by about 6% in the southern hemisphere.<sup>61</sup>

This ozone reduction can be expected to increase human exposure to UV. It has been estimated that for every 1% reduction in the ozone layer there will be penetration of between 0.2% and 2% more UV.<sup>62</sup> A greater proportion of the increased radiation will be shorter wavelengths, which are absorbed by the ozone layer.

**Solar angle** Solar angle is the most significant determinant of ambient UV intensity.<sup>63</sup> Sunlight intensity peaks when the sun reaches its zenith, because perpendicular light projects to a smaller surface area than oblique light projection, so the light energy per unit area is more concentrated when the spot size is smaller. Also, when the sun is high in the sky, sunlight travels less distance through the atmosphere to reach the surface, so it is less diffused and attenuated.



**FIGURE 4** The Antarctic ozone hole on the day of its maximum depletion (the thinnest ozone layer, as measured in Dobson Units [DU]) in four different years.\*

*Top left:* on September 17, 1979, the first year in which ozone was measured by satellite, the ozone level was at 194 DU.

*Top right:* ozone dropped to 108 DU on October 7, 1989. This was the year that the Montreal Protocol went into force.

*Bottom left:* ozone measured 82 DU on October 9, 2006.

*Bottom right:* the measurement was back up to 118 DU by October 1, 2010.

\*The ozone measurements were made by National Aeronautics and Space Administration (NASA)'s Total Ozone Mapping Spectrometer (TOMS) instruments from 1979 to 2003 and by the Royal Netherlands Meteorological Institute (KNMI) Ozone Monitoring Instrument (OMI) from 2004 to present. Purple and dark blue areas are part of the ozone hole.



For this reason, surface level of UV varies with time of day and time of year, as well as with latitude: all factors that affect the solar angle. All other things being equal, UV intensity is greatest when the solar angle is closest to perpendicular. (This is thought to explain the observation that pterygium is most common in equatorial regions and highly reflective environments.<sup>64</sup>)

**Cloud cover** Clouds are complex and ever changing, facts that have a significant bearing on the variability of ambient UV. While a thick cloud cover substantially reduces the amount of UVA and UVB that reaches the earth's surface, thin and broken clouds have much less effect. Also, cumulus clouds can actually increase UVB radiation by 25% to 30% due to reflection from their edges.<sup>65</sup>

**Surface reflection (albedo)** Reflection from the ground and surrounding surfaces, known as albedo, can add significantly to ambient UV levels—especially the level measured at the eye, which, as noted, is protected from overhead UV. Due to reflection, one can be exposed to UV in completely shaded areas.<sup>66</sup> Highly reflective substances, such as fresh snow, reflect as much as about 90% of incoming UV back into the atmosphere (Table 3A&B).<sup>67,68</sup> Sand can reflect between 8% and 18% of incident UV, water from 3% to 13%, and lawn grass from 2% to 5%.<sup>67</sup>

**Altitude** Since UV passes through less atmosphere to reach higher grounds, it has less chance to be absorbed by atmospheric aerosols, which, like the ozone, can absorb and attenuate UV.<sup>69</sup> As a result, populations at higher altitudes are generally exposed to higher levels of UV. In the United States, there is 3.5% to 4% percent decrease in UV for each 300 m of descent in elevation.<sup>70-72</sup>

## Ocular UV Exposure

**Exposure geometry** Since our eyes are set deep in the orbital bone structure, sunlight entering the eye parallel to the visual axis has the clearest path. When the sun is directly overhead near its zenith, little direct UV strikes the corneal surface due to the natural shield of the brow and upper eyelids.<sup>60</sup> Thus, despite the fact that the ambient UV usually reaches its maximum strength at solar noon (at which point skin exposure is at its peak), the level of UV that enters the eye may be lower than it is at earlier and later times of the day.

**Contribution of scattered and reflected light** Short-wavelength radiation (UVB) is effectively scattered by air particles and highly reflected by certain surfaces (Table 3A). This indirect radiation from light scattering and reflection actually contributes to nearly half of the UV we receive, warranting its significance in any consideration of UV protection.<sup>73</sup>

When the solar altitude reaches about 40 degrees, direct UV exposure in the eye decreases rapidly, presumably because the upper eyelids and possibly the eyebrow ridge shield the eye from the incident overhead light.<sup>74</sup>

TABLE 3A

Representative terrain reflectance factors for horizontal surfaces measured with a UVB UV radiometer and midday sunlight (290-315 nm)

Material	Percent Reflectance
Lawn grass, summer, MD, CA, and UT	2.0-3.7
Lawn grass, winter, MD	3.0-5.0
Wild grasslands, Vail Mountain, CO	0.8-1.6
Lawn grass, Vail, CO	1.0-1.6
Flower garden, pansies	1.6
Soil, clay/humus	4.0-6.0
Sidewalk, light concrete	10-12
Sidewalk, aged concrete	7.0-8.2
Asphalt roadway, freshly laid (black)	4.1-5.0
Asphalt roadway, two years old (grey)	5.0-8.9
Housepaint, white, metal oxide	22
Boat dock, weathered wood	6.4
Aluminum, dull, weathered	13
Boat deck, wood, urethane coating	6.6
Boat deck, white fiberglass	9.1
Boat canvas, weathered, plasticised	6.1
Chesapeake Bay, open water	3.3
Chesapeake Bay, specular component of reflection at Z = 45°	13
Atlantic Ocean, NJ coastline	8.0
Sea surf, white foam	25-30
Atlantic beach sand, wet, barely submerged	7.1
Atlantic beach sand, dry, light	15-18
Snow, fresh (2 days old)	88

All measurements performed with cosine-corrected hemispherical UVB detector head of IL 730 radiometer. Reflectance is ratio of "down"/zenith measurement.

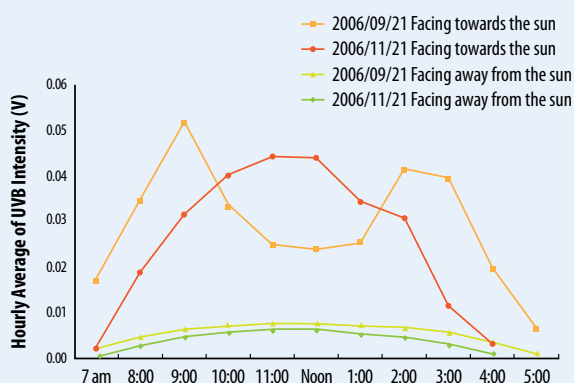
TABLE 3B

Surface	UVA albedo,%	UVB albedo,%	Percent of UVA albedo,%	Percent of UVB albedo,%
Sand	13	9	59	41
Grass	2	2	50	50
Water	7	5	58	42
Snow	94	88	52	48

## NEW RESEARCH IDENTIFIES DISTINCT TIMES FOR PEAK UV EXPOSURE TO THE EYE

In their recent work, Sasaki and colleagues provide a clear demonstration of the relationship between solar angle and ocular UV exposure.<sup>74</sup> Using a specially designed mannequin equipped with UV sensors, the group measured ocular UV exposure as a function of time of day in September and November in Kanazawa, Japan.

Surprisingly, they found that the level of UV entering the eye in the early morning (8:00 AM to 10:00 AM) and late afternoon (2:00 PM to 4:00 PM) is nearly double that of midday hours (10:00 AM to 2:00 PM) at most times of the year (Figure 5). When measured by a sensor on top of the skull, UV exposure rises and falls in parallel with the solar altitude. A sensor positioned at the eye, however, typically finds peak exposure times before and after solar noon. This suggests that, although it is widely believed to be the case, maximum ocular UV exposure may not occur at solar noon, and we very likely need to rethink our strategies about when is most important to protect the eyes from sunlight.



**Figure 5** Change of UV intensity in the eye over time during the day.

With the higher sunlight angles, the eye is primarily exposed to scattered and reflected radiation—contrary to the popular belief that direct sunlight around noon puts us at risk for maximal UV exposure.

**Peripheral light focusing (Coroneo effect)** The configuration of the human eye and face permits a large temporal field of vision and thus allows a significant amount of the incident light that reaches the cornea to come from the side. The groundbreaking work of Coroneo and colleagues established that this radiation from the side represents a particularly significant hazard due to the way it is focused on the nasal limbus by the PLF mechanism.

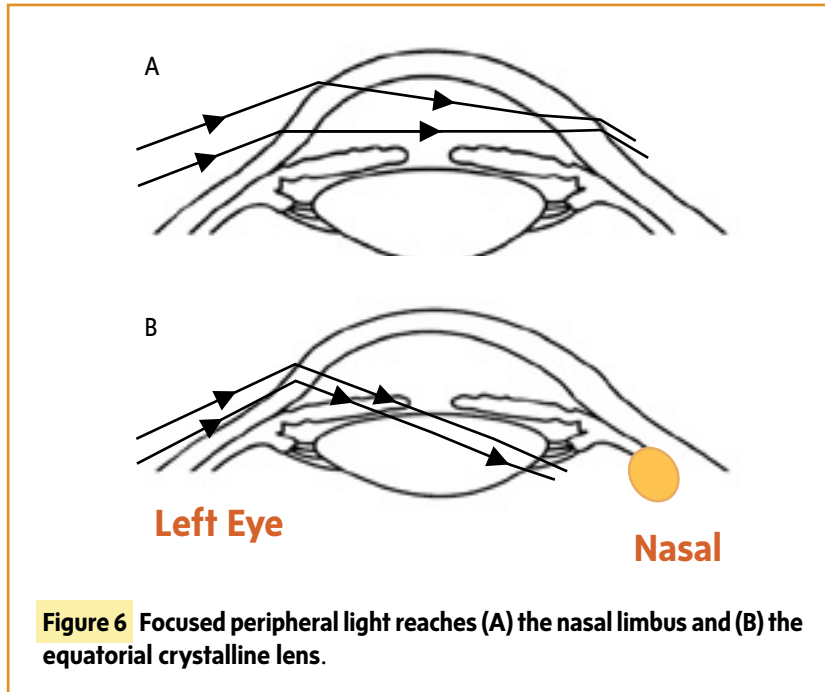
In PLF, oblique light (including UV) is refracted by the peripheral cornea, causing it to travel across the anterior chamber and focus at the nasal limbus, where the corneal stem cells reside (Figure 6A).<sup>1,34,75</sup> The maximum PLF effect at the limbus has been shown to occur when the angle of incidence is 104 degrees from the visual axis.<sup>76</sup> While limbal stem cells are normally protected from direct UV exposure, PLF concentrates sunlight at the nasal limbus by a factor of 20 times.<sup>1</sup>

Compelling epidemiologic evidence and laboratory results have demonstrated that this peripherally focused light plays a critical role in the development of pterygium.<sup>77</sup> The prevalence of pterygium is thought to rise by 2.5% to 14% with every 1% increase in UV exposure.<sup>22</sup> Almost 20 years ago, Coroneo suggested that pterygium could be an indicator of UV exposure.<sup>34</sup>

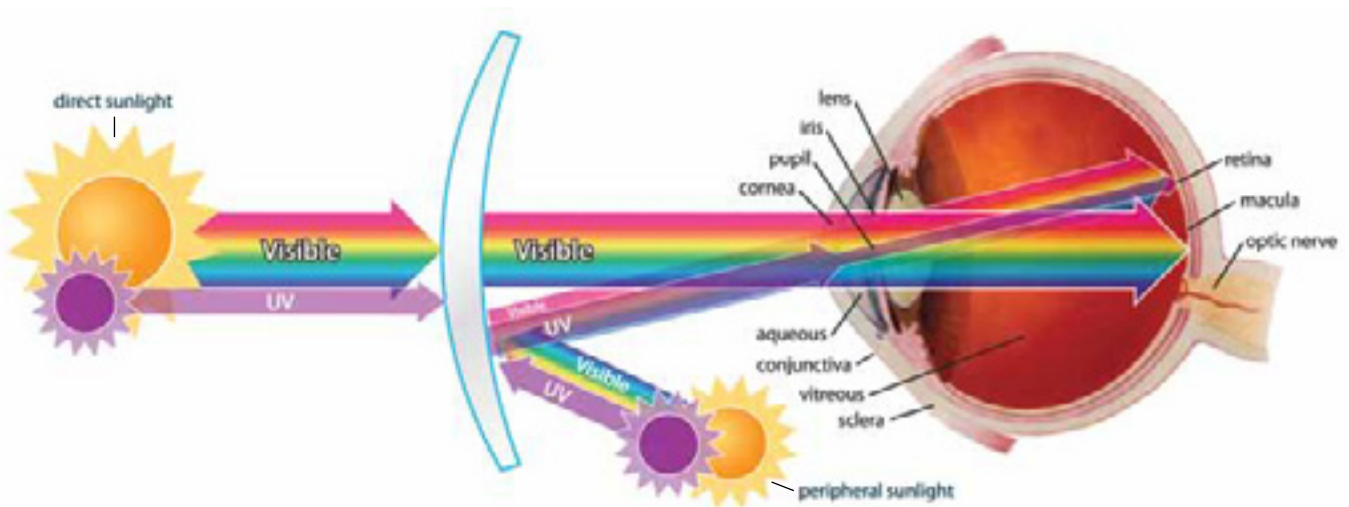
We know today that, in addition to the nasal limbus, PLF also affects the nasal crystalline lens equator and the eyelid margin (Figure 6B), which, like the limbus, are sites of stem cell populations. Stem cell damage resulting from focused peripheral light at these loci is believed to be accountable for onset of early cortical cataract and skin malignancy in the eyelid margin.<sup>78,79</sup>

**Spectacle lenses and back surface reflection** The back surface of clear spectacle lenses has been found to reflect light coming from behind onto the eye, increasing ocular UV exposure.<sup>80-82</sup> Anti-reflective coatings, intended to enhance the optical performance of spectacle lenses by increasing light transmission and eliminating reflection and glare, turns out (surprisingly) to significantly increase UV reflectance of the back lens surface (Figure 7).<sup>82</sup>

Reflectance measurements have demonstrated that, while clear lenses without anti-reflective treatment reflect about 4% to 6% of UVA and UVB (and less than 8% of UVC), anti-reflective lenses reflect an unexpectedly high level of UV light—an average of 25% for most UV wavelengths and close to 90% for certain wavelengths.<sup>82</sup> This reflected UV can potentially reach the temporal limbus or the central cornea; however, it can be prevented with a high-wrap frame design that protects against back surface exposure, or with an optimized anti-reflective coating with low UV reflection.<sup>82</sup>



**Figure 6** Focused peripheral light reaches (A) the nasal limbus and (B) the equatorial crystalline lens.



**Figure 7** UV reflection from the back surface of spectacle lenses.

### Sunglasses

Most sunglasses can efficiently block UV coming from directly in front of the lens. The American National Standards Institute (ANSI) Z80.3 standard is based on measurement of UV transmission and classifies sunglasses into one of two categories: Class 1 lenses absorb at least 90% of UVA and 99% of UVB; and Class 2 lenses block at least 70% of UVA and 95% of UVB. As voluntary consensus standards, however, these criteria may or may not be followed by all sunglass manufacturers.<sup>83,84</sup>

Even when the Z80.3 standard is closely adhered to, the transmittance value of sunglasses can be misleading, since it is at best a partial measure of eyewear's ability to protect the eye from UV exposure. In particular, the transmission value does not address the radiation coming from around the lenses, the quantity of which is determined by the shape of the frame and its fit to the face. Unless the glasses have a goggle frame, a significant amount of UV can reach the eye via routes around the lenses (Figure 8).<sup>85,86</sup> Measurements in mannequins have found that just

## WHAT MOUNTAINEERS' EYES TELL US

A study of 96 alpine mountain guides was conducted in Chamonix, France.\* In the study, the high-mountain guides' eyes were compared to those of people who, although living in the Alps, spent much less time at high altitudes. The goal was to compare ocular damage from sunlight exposure in the two groups, the assumption being that more time at significantly higher altitudes would equate with elevated UV exposure.

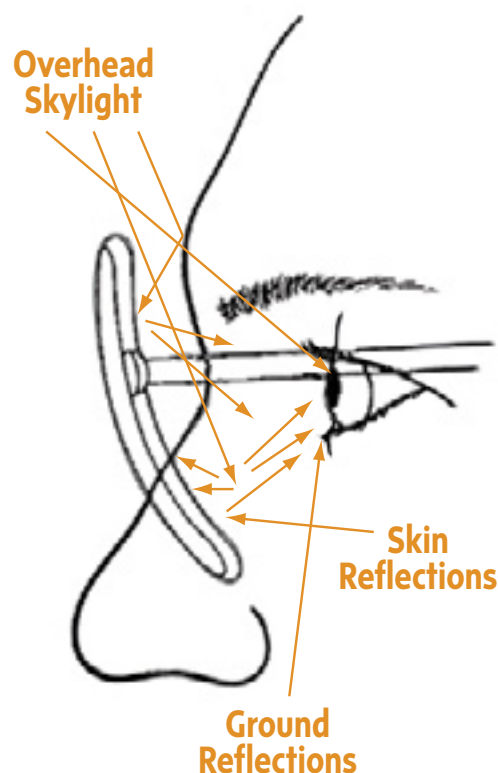
The study showed a significantly higher incidence of pterygium, pinguecula, and cortical cataract among the guides than in the age-matched group of locals who kept to lower altitudes, providing additional evidence for the critical role of UV exposure in these diseases. The study also found that the proportion of guides with retinal drusen deposits was nearly double that of the control group.

\* El Chehab H, Blein JP, Herry JP, et al. Ocular phototoxicity and altitude among mountaineer guides. Poster presented at the European Association for Eye and Vision Research; October 2011; Crete, Greece.

14% of ambient UV reaches the eye when the sunglasses are worn close to the forehead, but up to 45% reaches the eye when the distance between the glasses and forehead is as little as 6 mm.<sup>85</sup>

A goggle frame that wraps around the eye can effectively reduce the side exposure, but the majority of sunglasses do not offer protection from radiation incident from the side.<sup>57,80,82,85</sup> Under certain conditions, sunglasses without side protection can expose wearers to dangerous doses of UV. Skiers, for example, are at high risk for UV exposure due to the high level of UV reflectance from snow. Unaware of the side exposure issue, however, skiers in standard sunglasses may spend an extended period of time on the slopes, assuming their eyes are adequately protected with ordinary sunglasses. If the sunlight is sufficiently intense, these skiers may suffer painful photokeratitis—literally the ocular equivalent of sunburn. (Welders who fail to wear proper protection and tanning bed users who are not careful in using the right eyewear can also cause themselves to suffer from photokeratitis.)

Sunglasses that allow light to enter from the sides may actually increase a wearer's level of UV exposure. The darkness of the lenses may reduce the eye's natural squinting reflex and increase pupil size, increasing the UV entering the eye.<sup>87-89</sup>



**Figure 8** Pathways for UV to reach the eye with UV-blocking spectacle lenses.

### UV-blocking Contact Lenses

For patients who already wear contact lenses, UV-blocking contact lenses can offer significant UV protection.<sup>90,91</sup> Typically, contact lenses are inserted in the morning and worn all day, providing full-time protection. Soft contact lenses that extend to or past the limbus can block UV from all angles, protecting the stem cells in the limbal region by blocking peripheral radiation and negating the PLF effect. The geometrical factors of the eye are complex, and only a goggle frame or a full coverage contact lens can provide complete protection for the eye.

The ANSI Z80.20 standard recognizes two levels of contact lens protection: Class I lenses must absorb more than 90% of UVA (316 to 380 nm) and 99% of UVB (280 to 315 nm), and are recommended for high exposure environments such as mountains or beaches.<sup>92</sup> These criteria were adopted by American Optometric Association (AOA), which has offered a seal of acceptance for qualified lenses. Class II lenses, recommended for general purposes by the FDA, block more than 70% of UVA and 95% of UVB. However, contact lenses do not offer protection for the eyelids.

# PREVENTION AND RISK REDUCTION

## CURRENT STATE OF EYE PROTECTION

- The level of public awareness of the ocular hazards of UV is dangerously low; eye protection is rarely included in the general consideration of UV protection
- High-risk populations such as children and aphakic patients are not properly protected
- Few practitioners incorporate UV protection into their daily patient routines
- There is no agreed-upon system for grading the comprehensive effectiveness of eyewear and specifically UV reflection, a newly recognized hazard

## APPROACHES TO IMPROVING EYE PROTECTION

- Educate the public
- Educate healthcare professionals
- Develop a simplified eye protection factor similar to the SPF
- Fill knowledge gaps

## Importance of Protection from Cumulative UV Exposure

Although new ozone layer data is encouraging, indicating that atmospheric ozone levels may be beginning to stabilize, ozone layer thickness will not rebound to pre-1980s levels for several decades, at least.<sup>93,94</sup> Ongoing reduced ozone levels mean that accumulated sunlight exposure will have a growing impact on eye health, and prevention of eye diseases associated with UV exposure will become correspondingly more important.<sup>95</sup>

Also, the population is growing older worldwide, and with longer life comes greater risk for cumulative UV damage. As shown in Figure 9, the accumulative UV dose received by an individual increases linearly with age. Based on an 80-year lifespan, people will, on average, receive about a quarter of their lifetime dose every 20 years.<sup>58</sup>

Higher incidence of ocular diseases associated with chronic UV exposure implies both higher morbidity and increased healthcare costs. In contrast to the high cost of treating UV-related disease, reducing exposure to UV is relatively simple and inexpensive. UV exposure can be readily reduced by sun avoidance and wearing proper prescription or sunwear lenses. If the majority of the population were to become aware of the ocular hazards of UV and were to wear eye protection, significant morbidity and costs could be prevented.

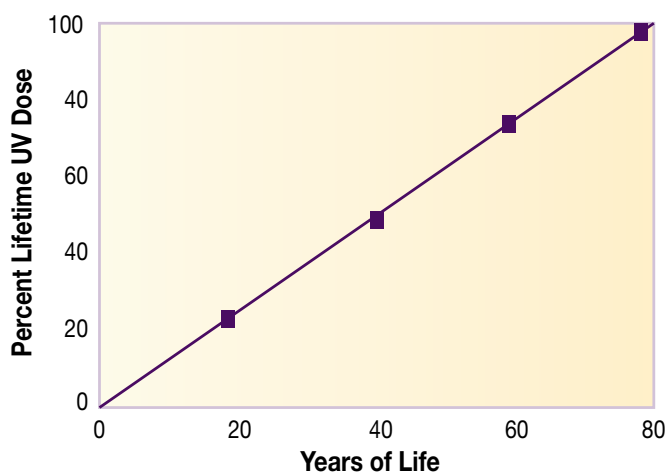


Figure 9 Percent lifetime UV dose.

## Current State of Eye Protection

Despite what professionals know about the ocular hazards of UV, what the public knows about eye protection is low, compared to the message about skin protection. A 2002 survey found that 79% of the population knew about the skin hazards of UV exposure, but only 6% was aware of the association between UV and eye disease.<sup>73</sup> A survey done by Glavas et al has shown that 23% of people are not wearing any sunwear protection among a population of 1,000 participants in the US.<sup>96</sup> Another more recent survey by the AOA found that although two-thirds of Americans were aware of the need for eye protection when spending extended time in the sun, only 29% of parents made sure their children wore sunglasses while outdoors.<sup>97</sup>

More concerning, perhaps, than public ignorance of ocular UV hazards, is the lack of discussion on UV hazards between eyecare professionals and their patients. As we have seen, there is very little discussion of UV hazards between practitioners in different specialties. Dermatologists educate their patients every day about UV hazards to the skin without ever making reference to the need for eye protection.<sup>98</sup>

In the US, standards for protective eyewear are voluntary, whereas in Europe and Australia, mandatory standards are used as ways of implementing public policy. This puts the US at a disadvantage when it comes to eyewear regulation and UV protection.

## Improving Eye Protection

Preventing UV damage to the eye requires that we translate existing knowledge of UV hazards and eye protection into effective multi-component interventions. These must be implemented among all parties involved: the public, healthcare providers, and industry. The most fundamental and important strategy involves education of the public and eyecare providers.

**Public education** Public education is the keystone of any serious effort to reduce the effects of UV on ocular health, because implementation of eye protection is ultimately a matter of what individuals do each day—the habit of UV-protective eyewear in real-life situations.

There have been large public education programs on UV protection, but, unfortunately, almost all have focused on the skin rather than the eyes. The upside, though, is that at least the public is aware that UV in sunlight is a potential danger. More campaigns aimed at increasing eye protection or both eye and skin protection are clearly needed. One example of a campaign running for over two years is The Vision Council's extensive UV awareness campaign toward the profession.

As part of educating the public about ocular UV hazards, it will be important to eliminate misconceptions about the solar conditions that create maximum risk. That the peak ocular UV hazard occurs in the early morning and late afternoon rather than the hours just before and after solar noon

is little known within the eyecare community and virtually unknown outside it. Also, few members of either the public or the eyecare professions are aware of the dangers of albedo and other limitations of sunglasses. The message that must get out is not only the need for eye protection, but also what constitutes effective protection and when to use it (see Table 2).

The task is daunting—human behavior is not easily changed. In Australia, despite decades of strong messages about the need for sun protection, public compliance is still relatively low. There is much to be learned about *how* to educate the public. Going forward, cooperation between dermatologists and eyecare professionals will be an important part of successful education with respect to UV hazards and protection.

**Education of eyecare professionals** The challenge in educating eyecare professionals is not in disseminating information but in making sure that that information is used to counsel patients appropriately. The importance of sun protection is a message frequently taught in schools and at professional meetings, but often that message gets lost between the classroom and the clinic. It should, therefore, be a goal of every practitioner education effort to ensure that practitioners use the knowledge they gain to educate patients about UV protection of the eye and prescribe proper UV-protective solutions.

**High-risk populations** Everyone who is at risk for UV exposure (which is to say anybody who spends time in the sun) should consider adopting protective measures for their eyes. People with darker skin may not have to worry about sunburn and skin cancer to the degree that fair skinned people do, but this may actually increase their risk of ocular exposure because they may feel it less important to wear a hat to protect facial skin.

Certain populations are particularly vulnerable to UV damage. Adults spending extended time or working outdoors is one such group. Children are at elevated risk for two reasons: they typically spend more time outdoors than adults, and their crystalline lenses transmit much more short-wavelength radiation than do the crystalline lenses of older eyes. Young children should start wearing sunglasses with a proper frame design as soon as practicable when they go outdoors.

Aphakic patients, who lack a crystalline lens to absorb UV, may also be at elevated risk.<sup>99-101</sup> Similarly, patients whose corneas are thin—including those whose corneas have been thinned by laser vision correction and those with naturally occurring corneal ectasias, such as keratoconus and pellucid marginal degeneration—may be at elevated risk, because the corneal stroma absorbs a very significant amount of UV.<sup>13,102</sup> Also, patients who are taking photosensitizing medications may be more susceptible to potential adverse effects of UV. For all patients with elevated risk, sun protection is extremely important.

# GOALS FOR THE FUTURE

A number of short- and long-term needs were identified at the meeting. In addition to education, we need tests that will allow us to assess risk and standards that will allow clinicians to prescribe and wearers to buy appropriate protective solutions. A list of identified needs follows.

- UV damage is cumulative, and some people will be well ahead of their contemporaries in the amount of UV they have absorbed due to heavy exposure in their early years. These people are at higher risk for UV-associated diseases later in life. Today, we have no practical means of discovering who these people are so they may be counseled to protect themselves from additional exposure. Thus, a biomarker for UV exposure would be extremely useful for preventing future disease.  
Coroneo has developed an ocular UV fluorescence photographic technique that appears able to demonstrate preclinical ocular surface evidence of solar damage.<sup>77</sup> Conceivably this technology could be developed as an “early warning system” to detect excess UV exposure.
- An index for eyewear similar to the SPF system for sunblocking lotions would enable rational purchase decisions by people seeking UV protection.<sup>91,103</sup> Such a system would take into account frame design as well as the transmission spectrum of the lenses.
- The current UV Index is far more relevant to skin exposure than ocular exposure. A system that adjusts the current UV Index for the effects of solar angle is needed.
- Cooperation with dermatology is necessary to harmonize messages.<sup>96</sup> A method must be found to recognize the importance of skin protection without slighting the special needs related to eye protection.
- Research is needed in many areas, including:
  - a) The importance, in quantitative terms of UV reflection, for the backside of ophthalmic lenses
  - b) Mechanisms by which UV causes ocular damage
  - c) Mechanisms of light damage to the retina, including photochemical, photothermal, and photomechanical mechanisms<sup>104</sup>
  - d) Effective treatment for pterygium
  - e) Pathogenic role of other environmental factors, such as the ambient temperature in ocular diseases like as nuclear cataract<sup>92,105</sup>

There is much work to be done. It is vital for eyecare professionals to do more to understand UV hazards and protect our patients. Simply talking to patients on a routine basis about the importance of owning and wearing a pair of glasses that provides good UV protection is a valuable and simple first step.

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## Damage of the ultraviolet on the lens

### *Los daños que ocasionan los rayos ultravioleta en el cristalino*



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#### The human lens

The lens is a key refractive element of the eye which, with the cornea, focuses images of the visual world onto the retina. This is achieved by its biconvex shape, high refractive index, almost perfect transparency<sup>[1]</sup>. Lens transparency is due to the three dimensional arrangement of the lens proteins and these proteins are prone to aggregation by heating, which increases the optical density<sup>[2]</sup>.

The lens is clear for the first 3 years of life and then gradually develops yellow pigments (3-hydroxy kynurenine and its glucoside). This is a protective pigment, which absorbs UV radiation and safely dissipates its energy<sup>[3]</sup>. The crystalline lens filters UV and its total transmission of visible light decreases with age as the color becomes yellower<sup>[1]</sup>. An aged lens absorbs a great part of the short wavelength region of the visible light as it contains chromophores that help absorbing the radiation<sup>[3]</sup>. The crystalline lens readily absorbs UV -A and the remaining 2% of the UV-B not absorbed by the cornea and aqueous humour<sup>[4]</sup>. It is important to protect the crystalline lens against the potential hazards of UV exposure.

As the crystalline lens ages, a process known as brunescence occurs. The lens becomes denser and more opaque, allowing less light, especially at shorter wavelengths, to reach the retina<sup>[5]</sup>.

#### Lens transparency

The transparency of the crystalline lens depends on its avascularity, paucity of organelles, narrow inter-fibre spaces and the regular organization of its cells and proteins. At the cellular level, there is limited light-scattering by cellular organelles, which are relatively sparse in the central epithelium and displaced to the equator in the fibres, away from the light path<sup>[1]</sup>.

In the lens cortex, transparency is enhanced by the high spatial order of the fibre architecture and the narrow intercellular spaces. This compensates for light-scattering caused by fluctuations of the refractive index between membranes and cytoplasm<sup>[1]</sup>.

#### El cristalino

*El cristalino es un elemento clave para la refracción del ojo y, junto con la córnea, focaliza las imágenes del mundo visual en la retina. Esto es posible gracias a su forma biconvexa, su elevado índice refractivo y su transparencia casi perfecta<sup>[1]</sup>. La transparencia del cristalino se debe a la disposición en tres dimensiones de las proteínas del cristalino, dichas proteínas son proclives a la agregación mediante el calentamiento, lo cual aumenta la densidad óptica<sup>[2]</sup>.*

*El cristalino es transparente durante los 3 primeros años de vida y paulatinamente va desarrollando pigmentos amarillos (3-hidroxi quinurenina y su glucósido). Este es un pigmento protector que absorbe la radiación UV y disipa su energía de manera segura<sup>[3]</sup>. El cristalino filtra los UV y su transmisión total de la luz visible disminuye con la edad conforme el color se vuelve cada vez más amarillo<sup>[1]</sup>. El cristalino de una persona mayor absorbe una gran parte de la zona del espectro de longitudes de onda cortas de la luz visible ya que contiene cromóforos que contribuyen a la absorción de la radiación<sup>[3]</sup>. El cristalino absorbe fácilmente los UV - A y el 2% restante de los UV - B que no absorbe la córnea y el humor acuoso<sup>[4]</sup>. Es importante proteger al cristalino contra los riesgos potenciales de la exposición a los UV.*

*Conforme envejece el cristalino, ocurre un proceso conocido como brunescencia. El cristalino se vuelve cada vez más denso y opaco, permitiendo cada vez menos el paso de la luz que llega a la retina, especialmente en las longitudes de onda más cortas<sup>[5]</sup>.*

#### Transparencia del cristalino

*La transparencia del cristalino depende de su avascularidad, poca presencia de organelos, sus estrechos espacios interfibrilares así como la organización regular de sus células y proteínas. A nivel celular, los organelos celulares realizan una difusión de luz limitada, éstos son relativamente raros en el epitelio central y se desplazan hacia el ecuador en las fibras, lejos del camino de la luz<sup>[1]</sup>.*

### Lens growth

Lens growth is achieved by the addition of new fibres to the surface of the fibre mass over the lifespan. At a certain depth, the superficial, active, nucleated fibres lose their organelles and become transcriptionally incompetent, relatively inactive metabolically and lacking in synthetic capability<sup>[1]</sup>.

Aside from the skin, the eye is the organ most susceptible to sunlight and artificial lighting-induced damage. Solar radiation exposes the eye to ultraviolet-B (UV-B; 280–315 nm), UV-A (315–380 nm), and visible light (380–780 nm)<sup>[3]</sup>.

### Description of ultraviolet radiation

The eye dependent on the visible light energy and can be damaged by the contiguous ultraviolet and infrared wavelengths. The conditions in which sunlight is implicated in the pathogenesis is termed the "ophthalmohelioses", for example, pterygium and cataract formation<sup>[6]</sup>. Exposure to UV radiation from the sun is one of the widespread risk factors for the development of cataract and various skin diseases.

The spectrum of nonionizing radiation ranges from short wavelength UV RADIATION (wavelength 100 nm) through to far infrared radiation (1 mm or 1 000 000 nm). The visible spectrum lies between 380 nm to 780 nm. Above the visible spectrum is infrared radiation, and below the visible spectrum are the shorter wavelengths of nonionizing radiation called UV radiation. Wavelengths below 290 nm are totally absorbed by the ozone layer in the stratosphere, and longer wavelengths are absorbed to a lesser extent. Thus, in nature, one does not encounter UV radiation below 290 nm, although the physical spectrum of UV radiation ranges from 100 nm to 380 nm<sup>[7]</sup>.

Although UV radiation is only 5% of the sun's energy, it is the most hazardous portion encountered by man. UV radiation has been subdivided into three bands:

UV-A or near UV (315-380 nm): Produces sun tanning (the browning of the skin due to an increase in the skin content of melanin), as well as photosensitivity reactions.

UV-B (280-315 nm): It is the sunburn spectrum and causes sunburn and tissue damage (blistering) and also associated with skin cancer.

UV-C (100-280 nm): It is germicidal and may also cause skin cancer.

UV-C, or far UV, is not commonly encountered on the earth's surface and comes entirely from artificial sources such as germicidal UV lamps or arc welding. Furthermore, UV-B is much more biologically active than UV-A<sup>[7, 8]</sup>.

The temporal side of the eye is most vulnerable to solar UV radiation, focusing the light on the nasal part of the cornea and lens<sup>[9]</sup>. The intensity of the light, the age of the recipient, the wavelength emitted and received by ocular tissues determines the damage to the eye due to UV radiation. However, the human lens is continuously exposed to small quantities of UV exposure every day, but, if this exposure exceeds a certain level, the lens may become irreversibly damaged<sup>[10]</sup>.

Exposure to UVB and UVA radiation is associated with photochemical damage to cellular systems. UV radiation can generate free radicals including oxygen-derived species, which are known to cause lipid peroxidation of cellular membranes. It has also been shown that UV can damage DNA directly, decrease mitochondrial function, and induce apoptosis. Oblique rays entering the eye from the temporal side, can reach the equatorial (germinative) area of the lens.

*En el córtex del cristalino, la transparencia es acentuada por el alto orden espacial de la arquitectura de las fibras, así como por los estrechos espacios intercelulares. Esto compensa la dispersión de la luz ocasionada por fluctuaciones del índice refractivo entre las membranas y el citoplasma<sup>[1]</sup>.*

### Crecimiento del cristalino

*El crecimiento del cristalino se lleva a cabo mediante la adición de nuevas fibras a la superficie de la masa fibrosa a lo largo de toda la vida. En una cierta profundidad, las fibras nucleadas superficiales, activas, pierden sus organelos y se convierten incompetentes en el ámbito transcripcional, desde el punto de vista metabólico se vuelven relativamente inactivas y carecen de capacidad sintética<sup>[1]</sup>.*

*Además de la piel, el ojo es el órgano más susceptible a los daños ocasionados por la luz solar y artificial. La radiación solar expone al ojo a los rayos ultravioleta B (UV-B; 280–315 nm), UV-A (315–380 nm), y la luz visible (380–780 nm)<sup>[3]</sup>.*

### Descripción de la radiación ultravioleta

*El ojo depende de la energía de la luz visible y puede ser dañado por las longitudes de onda infrarroja y ultravioleta contiguas a la misma. Las condiciones en las que la luz solar participa en la patogénesis se denomina "oftalmoheliosis", por ejemplo, la formación de pterigión y cataratas<sup>[6]</sup>. La exposición a la radiación ultravioleta del sol es uno de los factores de riesgo mayormente difundidos del desarrollo de catarata y de varias enfermedades de la piel.*

*El espectro de la radiación no ionizante va de la radiación UV de longitud de onda corta (longitud de onda 100 nm) hasta la radiación infrarroja lejana (1 mm ó 1 000 000 nm). El espectro visible se encuentra entre 380 nm hasta los 780 nm. Por arriba del espectro visible se encuentra la radiación infrarroja y por debajo del espectro visible están las longitudes de onda más cortas de la radiación no ionizante denominadas radiación UV.*

*Las longitudes de onda inferiores a los 290nm quedan totalmente absorbidas por la capa de ozono en la estratósfera y las longitudes de onda más largas quedan absorbidas en menor medida. Por lo tanto, en la naturaleza, uno no encuentra radiación inferior a los 290 nm, aunque el espectro físico de la radiación UV va de los 100 nm a los 380 nm<sup>[7]</sup>.*

*Aunque la radiación UV representa solamente el 5% de la energía solar, se trata de la porción más peligrosa para el ser humano. Se ha subdividido la radiación UV en 3 bandas:*

*Los UV-A o ultravioleta cercanos (315-380 nm). Producen el bronceado de la piel (el bronceado de la piel debido a un aumento del contenido de melanina en la piel), así como reacciones fotosensibles.*

*Los UV-B (280-315 nm). Es el espectro de quemaduras de sol causando así quemaduras de sol y daños tisulares (ampollas) también está asociado con cáncer de la piel.*

*Los UV-C (100-280 nm). Es germicida y también puede causar cáncer de la piel.*

*Los UV-C o UV distantes no se encuentran habitualmente en la superficie de la tierra y provienen completamente de fuentes artificiales como las lámparas germicidas con UV o soldadura de arco. Además, los UV-B son mucho más activos biológicamente que los UV-A<sup>[7, 8]</sup>.*

*El lado temporal del ojo es el más vulnerable a la radiación UV, al focalizar la luz en la parte nasal de la córnea y el cristalino<sup>[9]</sup>.*

The intraocular filters effectively filter different parts of the UV spectrum and only allow 1% or less to reach the retina<sup>[11]</sup>.

The eye is largely shielded from this by the eyelids and brow ridges. Thus, for the eye, reflection (for example, off grass, sand, or snow) and scattering (for example, from patchy cloud cover) are important sources of UV exposure, with the dose and location of the incident UV radiation (Fig. 1).

### Penetration of UV radiation to various structures of the eye

UV radiation incident on the eye is largely absorbed by the tear film, the cornea and the lens. The cornea is transparent to visible light but absorbs a significant portion of the UV-B radiation and a very small amount of UV-A radiation. The anterior layers of the cornea (epithelium and Bowman layer) are believed to be up to twice as effective at absorbing UV-B radiation as the more posterior layers.

Ultraviolet wavelengths from 295 to 317 nm are absorbed in the aqueous humor, due to the presence of ascorbic acid. It also provides antioxidant protection from UV-induced damage to the lens surface.

The UV radiation transmission also varies from the tear film to the retina. The figure below shows the percentage of light transmitted through each ocular tissue<sup>[8]</sup> (Fig. 2).

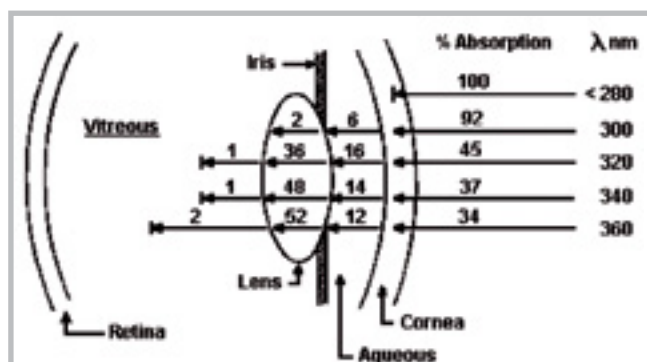


Fig. 2 Showing the percentage of light transmittance through ocular media<sup>[8, 13]</sup>. Authorised reproduction

Fig. 2 Muestra el porcentaje de la transmittancia de la luz a través de los medios oculares<sup>[8, 13]</sup>.

The incidence of cataract is high in countries with excessive sunlight. Yellow to brown coloration of cataracts were noted in countries with higher solar intensities due to photooxidation of proteins such as tryptophan moieties, when compared to people living in higher latitudes.

High incidence of cataracts in countries with excessive light could be because of the photochemical generation of reactive oxygen species (ROS), including superoxide and its derivatization to other potent entities such as hydrogen peroxide, hydroxyl radicals, and singlet oxygen, in the aqueous and the lens resulting oxidative damage<sup>[14]</sup>.

La intensidad de la luz, la edad de la persona, la longitud de onda emitida y recibida por los tejidos oculares determinan el daño ocular ocasionado por la radiación UV. No obstante, el cristalino humano está continuamente expuesto a pequeñas cantidades de UV diariamente, pero, si esta exposición excede un cierto nivel, el cristalino puede tener daños irreversibles<sup>[10]</sup>.

La exposición a la radiación UVB y UVA está asociada con daño fotoquímico a los sistemas celulares. La radiación UV puede generar radicales libres incluyendo especies derivadas de oxígeno, conocidas por ocasionar la peroxidación lipídica de las membranas celulares. También se ha demostrado que los UV pueden causar daños directos al ADN, disminuir la función mitocondrial e inducir apoptosis. Los rayos oblicuos que penetran el ojo desde el lado temporal, pueden alcanzar el área ecuatorial (germinativa) del cristalino. Los filtros intraoculares filtran efectivamente

las diferentes partes del espectro UV y sólo permiten el paso al 1% o menos hacia la retina<sup>[11]</sup>.

Los párpados y los arcos superciliares protegen al ojo. Por lo tanto, el reflejo proveniente del césped, arena o nieve; así como la dispersión de luz a través de una cubierta nubosa entrecortada, constituyen fuentes significativas de exposición a los UV, con la dosis y ubicación de la radiación UV incidente (Fig. 1).

### Penetración de la radiación UV en varias estructuras del ojo

La radiación UV incidente en el ojo queda ampliamente absorbida por la película de lágrimas, la córnea y el cristalino. La córnea es transparente a la luz visible pero absorbe una gran parte de la radiación UV-B y una parte muy pequeña de la radiación UV-A. Se cree que las capas anteriores de la córnea (epitelio y capa de Bowman) son dos veces más efectivas en la absorción de la radiación de UV-B con respecto a las capas más posteriores.

El humor acuoso absorbe las longitudes de onda ultravioleta de 295 a 317 nm gracias a la presencia de ácido ascórbico. También brinda protección antioxidante de los daños ocasionados por los UV a la superficie del cristalino.

La transmisión de la radiación UV también varía de la película de lágrimas a la retina. La figura a continuación muestra el porcentaje de la luz transmitida a través de cada tejido ocular<sup>[8]</sup> (Fig. 2).

La incidencia de cataratas es elevada en países con luz solar excesiva. Se ha observado una coloración de las cataratas que va del amarillo al marrón en países con intensidades solares más elevadas debido a la foto-oxidación de las proteínas como los triptófanos cuando se hace una comparación con poblaciones que viven en latitudes más elevadas.

La alta incidencia de cataratas en países con exceso de luz podría explicarse mediante la generación fotoquímica de las especies reactivas al oxígeno (ROS en inglés "reactive oxygen species"), incluyendo el superóxido y su derivación a otras entidades potentes como el peróxido de hidrógeno, radicales hidroxilos y el oxígeno singlete, en el humor acuoso y en el cristalino resultando en daño oxidativo<sup>[14]</sup>.

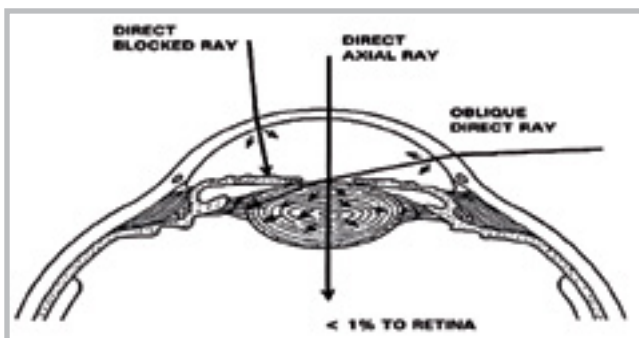


Fig. 1 Showing the oblique rays reaching the equatorial (germinative) area of the lens<sup>[12]</sup>. Authorised reproduction.

Fig. 1 Muestra los rayos oblicuos llegando al área ecuatorial (germinativa) del cristalino<sup>[12]</sup>.

The inferonasal localization of early cortical cataract has been confirmed in various epidemiological and animal model studies. The germinative zone of the crystalline lens is located equatorially, this region is more sensitive to UV radiation than other parts of the crystalline lens. It is for this reason, the resultant cataract is predominantly spoke shaped<sup>[6]</sup>.

Damage to the ocular tissue by UV irradiation occurs by many mechanisms such as protein cross-linking, dysfunction of enzymes, ion pump inhibition, genetic mutations, and membrane damage. Short term complaints of UV exposure include excessive blinking, swelling, or difficulty looking at strong light. UV exposure can also cause acute photokeratopathy, such as snow blindness or welders' flash burns.

It is estimated that in Australia, where UV levels are consistently high, almost half cases of pterygium treated annually are caused by sun exposure and 10% of cataracts are potentially caused by UV radiation exposure. By the year 2050, assuming 5% to 20% ozone depletion, there will be 167,000 to 830,000 more cases of cataracts<sup>[4]</sup>.

UV exposure is based on environmental conditions (altitude, geography, cloud cover, ground reflection) and factors like extent of outdoor activities<sup>[4]</sup>.

Ground reflectance ( $p$ ) will determine if photokeratitis will result from spending time in outdoor daylight. The "global" (whole sky) reflection, and the typical, effective actinic UV reflectance is approximately 20%. Thus walking on a concrete pavement produces nearly 10-fold more UV-effective dose to the cornea than walking over green grass. Sunlight reflection from water gives the highest natural UV exposure. It has been found in various animal models that oral administration of vitamin E had a protective action against UV radiation-induced cataract<sup>[15]</sup>.

Previous epidemiological studies have shown a significant frequency of cataracts in populations that have a high annual exposure to sunlight and UV radiation<sup>[16]</sup>. Higher odds ratios for cortical cataract were found in people who spend more than 4 hours outside in the daytime during their 20s to 30s and their 40s to 50s in comparison with people who spend hardly any time outside during the day. No similar relationship was found for nuclear cataract, although smoking was found to increase the risk of nuclear opacification<sup>[17-20]</sup>.

The mechanism of light damage to the eye due to UV radiation is either due to inflammatory response or due to photooxidation.

In inflammatory response, acute exposure to intense radiation causes a burn in the eye similar to sunburn that can damage the cornea, lens, and retina. The eye is immune privileged, which means that under ordinary stress its immune response is suppressed. In the presence of very intense UV and visible light (for instance, emitted from lasers), this suppression is overwhelmed. There is a release of interleukin-1, a T-cell and macrophage invasion at the site of irritation and a subsequent release of superoxide and peroxides and other reactive oxygen species, which eventually damage the ocular tissues<sup>[3]</sup>.

In photooxidation, chronic exposure to less intense radiation damages the eye through a phototoxidation reaction. In this, a pigment in the eye absorbs light, produces reactive oxygen species such as singlet oxygen and superoxide, and these damage ocular tissues<sup>[3]</sup>.

*La ubicación inferonasal de la catarata cortical precoz se ha confirmado en varios estudios epidemiológicos y con modelos animales. La zona germinativa del cristalino se ubica en el ecuador, esta región es más sensible a la radiación UV que otras partes del cristalino. Por este motivo, la catarata resultante tiene generalmente forma radiada<sup>[6]</sup>.*

*Los daños al tejido ocular por irradiación UV ocurren mediante toda una serie de mecanismos como por ejemplo el entrecruzamiento de proteínas, la disfunción de enzimas, la inhibición del bombeo de iones, las mutaciones genéticas y los daños a la membrana. Algunas dolencias expresadas poco tiempo después de la exposición UV incluyen parpadeo excesivo, hinchazón o dificultades de mirar hacia la luz intensa. La exposición UV también puede ocasionar fotoqueratopatía aguda, como ceguera del esquiador o quemaduras del soldador.*

*Se ha estimado que en Australia, donde los niveles de UV son regularmente elevados, casi la mitad de los casos de pterigión tratados anualmente con ocasionados por la exposición solar y el 10% de las cataratas son potencialmente ocasionadas por exposición a la radiación UV. En el año 2050, si se parte del supuesto que del 5% al 20% de la capa de ozono habrá desaparecido, se contarán de 167,000 a 830,000 casos adicionales de cataratas<sup>[4]</sup>.*

*La exposición a los UV se determina basándose en condiciones medioambientales (altitud, geografía, cobertura nubosa, reflejo del suelo) y factores como el grado de actividades realizadas en exteriores<sup>[4]</sup>.*

*La reflectancia del suelo ( $p$ ) determinará si la fotoqueratitis será el resultado de las actividades exteriores durante la luz del día. El reflejo "global" (todo el cielo) y la reflectancia UV actínica efectiva es de aproximadamente el 20%. Por lo tanto, caminar en la acera de hormigón produce casi diez veces más dosis efectivas de UV a la córnea que caminar sobre césped verde. El reflejo de la luz solar en el agua es la exposición natural más elevada a los UV. Se ha observado en varios modelos animales que la administración oral de vitamina E tenía una acción protectora contra la catarata inducida por radiación UV<sup>[15]</sup>.*

*Estudios epidemiológicos previos han mostrado una frecuencia significativa de cataratas en poblaciones con una alta exposición anual a la luz solar y a la radiación solar elevada<sup>[16]</sup>. También se ha determinado un coeficiente de probabilidad superior de cataratas corticales en personas que pasaban más de 4 horas en el exterior durante el día de los 20 a los 30 años y de los 40 a los 50, en comparación con personas que casi no pasaban tiempo en el exterior durante el día. No se encontró ninguna relación similar para las cataratas nucleares, aunque se determinó que el tabaquismo aumenta el riesgo de opacificación nuclear<sup>[17-20]</sup>.*

*El mecanismo de daño solar al ojo debido a la radiación UV se debe o bien a la respuesta inflamatoria o bien a la foto-oxidación.*

*En la respuesta inflamatoria, la exposición aguda a la radiación intensa causa una quemadura en el ojo similar a la quemadura de sol que puede dañar la córnea, el cristalino y la retina. El ojo es inmunológicamente privilegiado, lo cual significa que bajo estrés ordinario su respuesta inmunitaria queda suprimida. En presencia de UV y luz visible muy intensos (por ejemplo, emitidos con láser), esta supresión queda desbordada. Se libera la interleuquina-1, se inicia la invasión de células T y macrófagos en el lugar de la irritación con la subsecuente liberación de superóxido y peróxidos así como otras especies de oxígeno reactivo, lo cual puede ocasionar daños a los tejidos oculares<sup>[3]</sup>.*

## Antioxidants

As the normal production of antioxidants in the eye decreases with increasing age, increasing the intake of fruits and vegetables has been suggested to replace the missing protection and have been found to retard age-related cataracts and macular degeneration. In addition, supplementation with vitamins and antioxidants, including Vitamin E and lutein, quenches photooxidative damage, whereas N-acetyl cysteine has been shown to be particularly effective in quenching UV phototoxic damage and inflammation. Other natural products such as green tea, which contains polyphenols (epigallocatechin gallate) and Ashwagandha (root of *Withania somnifera*) used in traditional Ayurvedic medicine has also been shown to retard light-induced damage to the lens<sup>[3]</sup>.

Lens epithelial cells are a likely target for UVB damage because they are the first cells in the lens to be exposed to UV radiation. Epithelial cells, which serve key transport functions for the entire lens, are key sites of enzyme systems that protect the lens from oxidative stress. Exposure of cells to UVB radiation induces DNA damage and triggers alterations in the synthesis of specific proteins. Thus, the lens is particularly susceptible to the long-term effects of stressors such as environmental near-UV radiation. UV absorption by human lenses increases substantially with age<sup>[21, 22]</sup>.

A concentration of cortical cataract in the lower nasal quadrant of the lens was found by many reviewers<sup>[19, 23]</sup>. The bony configuration of the orbit and the most probable gaze position during peak sunlight hours suggest that the lower nasal lens region receives the greatest dose of UVB. UVB is proved to be an established risk factor for cortical cataract, due to the fact that the differential exposure by region could account for spatial variation in cataract severity<sup>[19]</sup>.

Age-related cataractous changes originating in the deep equatorial cortex of the lens are most likely exacerbated by UVB exposure through mechanisms such as increased oxidative radical burden and lipid peroxidation. UVB exposure had a variable effect on cataract severity, with little to no effect in the upper nasal regions of the lens and a maximum effect in the lower regions<sup>[24]</sup>.

## Prevention

Guidance from the World Health Organisation at its Intersun webpage advises people to wear “wrap – around” sunglasses under many conditions<sup>[6, 12]</sup>.

The use of UV- blocking contact lenses provides safe, effective, and inexpensive protection of the cornea, limbus, and crystalline lens, especially where sunglasses or hats are undesirable or impractical. Contact lenses can offer UV protection against all angles of incidences.

UV blocking contact lenses are labeled as class 1 and class 2, with each of the different classes indicating the level of UV protection.

*Class 1* contact lenses must block 90% of UVA (315 to 380 nm wavelengths) and 99% of UVB (280 to 315 nm wavelengths).

*Class 2* contact lenses must block at least 70% of UVA and 95% of UVB radiation. Non – UV – blocking contact lenses have been documented to absorb on average, only 10% UV-A and 30% of UVB<sup>[4]</sup>.

*En la foto-oxidación, la exposición crónica a radiación menos intensa ocasiona daños oculares mediante una reacción de foto oxidación. En este proceso, un pigmento del ojo absorbe la luz, produce especies reactivas al oxígeno como oxígeno singlete y superóxido, los cuales dañan al tejido ocular<sup>[3]</sup>.*

## Antioxidantes

*Puesto que la producción normal de antioxidantes en el ojo disminuye con la edad, se ha sugerido que el aumento de la ingesta de frutas y verduras puede sustituir la protección que va escaseando y se ha demostrado que retrasan la aparición de la catarata asociada a la edad y la degeneración macular. Además, la ingesta de suplementos de vitaminas y antioxidantes, incluyendo la vitamina E y la luteína, contienen el daño foto-oxidativo y se ha demostrado que, por su parte, la N-acetil cisteína es particularmente efectiva para contener el daño y la inflamación foto-tóxicos de los UV.*

*Se ha demostrado que otros productos naturales como el té verde, que contiene polifenoles (epigallocatequin galato) y la Ashwagandha (raíz de Withania somnifera) utilizada en la medicina tradicional ayurveda, retrasan los daños que la luz ocasiona al cristalino<sup>[3]</sup>.*

*Las células epiteliales del cristalino son una diana probable para los UVB porque son las primeras células del cristalino que se exponen a la radiación UV, con los daños consecuentes. Las células epiteliales, que realizan funciones de transporte clave para todo el cristalino son centros primordiales de los sistemas enzimáticos que protegen al cristalino del estrés oxidativo. La exposición de las células a la radiación UVB induce daños al ADN y desencadena alteraciones en la síntesis de proteínas específicas. Por lo tanto, el cristalino es particularmente susceptible a los efectos a largo plazo de factores estresantes como la radiación cercana a los UV que se encuentra en el entorno. La absorción de los UV del cristalino humano aumenta significativamente con la edad<sup>[21, 22]</sup>.*

*Se ha encontrado, en un gran número de estudios, una concentración de cataratas corticales en el cuadrante nasal inferior del cristalino.<sup>[19, 23]</sup> La configuración ósea de la órbita y la posición más probable de la mirada durante las horas de luz solar más intensa sugieren que la región nasal inferior del cristalino recibe la mayor dosis de UVB. Se ha comprobado que los UVB son un factor de riesgo de la catarata cortical, debido al hecho de que la exposición diferencial por área puede explicar la variación espacial en la gravedad de la catarata<sup>[19]</sup>.*

*Muy probablemente, los cambios en las cataratas asociadas con la edad y que se originan en el córtex ecuatorial profundo del cristalino se acentúan mediante la exposición a los UVB a través de mecanismos como la mayor carga de radicales oxidativos y la peroxidación lipídica. La exposición a los UVB ha tenido un efecto variable en la gravedad de las cataratas con poco o ningún efecto en las áreas nasales superiores del cristalino y con un efecto máximo en las áreas inferiores<sup>[24]</sup>.*

## Prevención

*Las directrices de la Organización Mundial de la Salud en su página web Intersun aconseja la utilización de gafas de sol “envolventes” en toda una serie de situaciones<sup>[6, 12]</sup>.*

*La utilización de lentes de contacto con bloqueo de UV brindan una protección segura, efectiva y poco onerosa de la córnea, el limbo y el cristalino, particularmente en situaciones en las que el uso de gafas de sol o un sombrero o gorro no es deseable o poco práctico. Los lentes de contacto pueden brindar protección UV contra todos los ángulos de incidencia.*

## Diet

Sunlight-induced processes such as oxidative stress in the skin or in the eye would trigger inflammation. A protective effect for weekly consumption of fish, shellfish, drinking tea daily, and a high consumption of vegetables, in particular carrots, cruciferous and leafy vegetables and fruits, and of these in particular citrus fruits was found<sup>[6]</sup>.

Above all, Public and practitioner awareness is of critical importance in advising a wrap-around sunglasses or contact lenses or a wide-brimmed hat in different situations. □

*Las lentes de contacto que bloquean los UV tienen etiquetado de categoría 1 y categoría 2 y cada categoría indica el nivel de protección contra los UV.*

*Las lentes de contacto de Categoría 1 deben bloquear el 90% de los UVA (de longitud de onda de 315 a 380 nm) y el 99% de los UVB (de longitud de onda de 280 a 315 nm).*

*Las lentes de contacto de Categoría 2 deben bloquear por lo menos el 70% de los UVA y el 95% de la radiación UVB. Se ha publicado que las lentes de contacto no bloqueantes absorben, en media, sólo el 10% de los UV-A y el 30% de los UV-B<sup>[4]</sup>.*

## Dieta

*Los procesos inducidos por la luz solar como el estrés oxidativo en la piel o en el ojo pueden provocar inflamación. Se ha comprobado la existencia de un efecto protector con el consumo semanal de pescados y mariscos; el tomar té diariamente así como un consumo elevado de verduras, particularmente zanahorias, frutas, verduras de hoja verde y hortalizas, especialmente los cítricos<sup>[6]</sup>.*

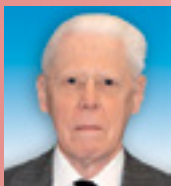
*Sobre todo, la concienciación del público y de los profesionales tiene una importancia crítica para aconsejar el uso de gafas de sol envolventes o lentes de contacto o sombrero de ala ancha en diferentes situaciones. □*

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## Transmission of solar radiation to and within the human eye

### *Transmisión de la radiación solar hacia el ojo humano y su interior*



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#### **Solar radiation - Introduction**

The spectrum of solar radiation at the surface of the earth extends from about 300 nm to about 2500 nm. Its maximum occurs at about 550 nm. Absorptions in the atmosphere remove all radiant energy outside of this band. The concentration of ozone affects the amount of absorption at the shorter wavelengths of the ultraviolet band (300 nm to 400 nm). Absorption by water vapor and carbon dioxide occur at several wavelengths of the near-infrared band (780 nm to 2500 nm). Because the actinic activity of this longer wavelength region is very small, the focus of this report is on ultraviolet and visible radiation (300 nm to 780 nm).

Many measurements of the spectral composition (radiant power as a function of wavelength) at ground level (various altitudes) and above the atmosphere have provided excellent information on solar spectra. Complex computer calculations that incorporate several of the physical parameters that affect the transmission of radiation through the atmosphere provide reliable tables of spectral irradiances that can be used to calculate ocular irradiances for defined exposure experiences. This report uses solar spectra from Publ. No CIE 85<sup>[1]</sup>.

Except for occasions of the sun low in the sky, direct viewing of the solar disc and its very bright aureole should be, and usually is, avoided, and even the low sun should be viewed only briefly. Therefore, we derive the solar spectrum of the horizon sky under an overhead (air mass 1) sun and a clear sky. Except for a brightly lit snowfield (diffuse reflectance about 80%), the horizon sky is the brightest source ordinarily seen in terrestrial experience. In the blue-light region of the spectrum (380 nm to 500 nm), it is about three times as bright as the surface of the ground having a typical diffuse reflectance of 20% (at every wavelength).

#### **Calculating ocular exposures to solar radiation**

The diffuse solar irradiance from the whole sky on a horizontal surface at ground level is equal to the global irradiance minus the direct irradiance<sup>[1,2]</sup>. From this, the average radiance of the sky is  $\pi^{-1}$  (= 0.3168) times that total diffuse irradiance. Kondratyev<sup>[2]</sup> says that the radiance of the clear sky increases from the zenith to the horizon. An increase by a factor of two has been found experimentally.

#### **Radiación solar - Introducción**

*El espectro de la radiación solar en la superficie de la tierra se extiende desde 300 nm hasta 2500 nm, aproximadamente. Su punto máximo se sitúa en torno a los 550 nm. Fuera de esta franja, las absorciones que se llevan a cabo en la atmósfera bloquean toda la energía radiante. La concentración de ozono afecta la cantidad de absorción en las longitudes de onda más cortas de la franja de los ultravioletas (300 nm a 400 nm). La absorción por vapor de agua y dióxido de carbono se lleva a cabo en varias longitudes de onda de la franja de los infrarrojos cercanos (780 nm, a 2500 nm). Debido al hecho de que el actinismo de esta longitud de onda más larga es muy pequeño, este artículo se focalizará en las radiaciones ultravioleta y visible (300 nm a 780 nm).*

*Toda una serie de mediciones de la composición espectral (poder radiante como función de longitud de onda) a nivel del suelo (varias altitudes) y por encima de la atmósfera han suministrado información excelente sobre los espectros solares. Toda una serie de cálculos computacionales complejos que incorporan varios de los parámetros físicos que afectan la transmisión de la radiación a través de la atmósfera suministran tablas fiables de irradiancia espectral que pueden utilizarse para calcular la irradiancia ocular correspondiente a una exposición determinada. Este artículo utiliza los espectros solares de la Publ. No CIE 85<sup>[1]</sup>.*

*Salvo por las ocasiones en las que el sol se encuentra muy bajo en el horizonte, la visión directa del disco solar y su aureola, extremadamente brillante, debería evitarse, y, de hecho, esto es así; e incluso, sólo debería observarse brevemente el sol bajo. Por lo tanto, se calcula el espectro solar sobre la base de una observación hacia el horizonte, en un día soleado, una masa de aire 1 y cielo despejado. Salvo en el caso de un campo nevado brillante (cuya reflectancia difusa es de aproximadamente el 80%), el cielo del horizonte es la fuente más brillante que habitualmente se ve en la experiencia terrestre. En la región de la luz azul del espectro (300 nm a 500 nm) ésta es aproximadamente tres veces más brillante que la superficie del suelo con una reflectancia difusa típica del 20% (en cada longitud de onda).*

#### **Calculando las exposiciones oculares a la radiación solar**

*La irradiancia difusa solar proveniente de todo tipo de cielo sobre una superficie horizontal a nivel del suelo es igual a la irradiancia global*



He also states that, although limited clouds in a particular configuration slightly increase the global irradiance, a long-term average of varied cloudiness shows that clouds should generally be assumed always to decrease global irradiance (hence, too, average sky radiance). Clear-sky conditions should be assumed when calculating retinal irradiance, thereby avoiding under-estimation.

The average radiance of the ground is  $\pi^{-1}$  (0.3168) times the diffuse reflectance of the ground times the global irradiance.

The spectral irradiance of the retina,  $E_{\text{retina}}(\lambda)$ , from a source with spectral radiance,  $N(\lambda)$  is<sup>[3]</sup>:

$$E_{\text{retina}}(\lambda) = N_{\text{source}}(\lambda) \times A_{\text{pupil}} \times \tau_{\text{eye}}(\lambda) / (f_{\text{eye}})^2$$

where:  $A_{\text{pupil}}$  is the area of the pupil

$f_{\text{eye}}$  is the focal length of the eye, nominally 17 mm, and

$\tau_{\text{eye}}(\lambda)$  is the transmittance of the elements of the eye anterior to the retina; it is mainly determined by absorption in the crystalline lens. Other absorptions are small enough to be ignored.

The area of the pupil is determined by calculating the luminance of the source using spectral radiances of the source from 380 nm to 780 nm.

To calculate the irradiance of the cornea, an average radiance for the scene viewed, part horizon sky, and part ground surface, is estimated. The solid angle subtense of the scene is estimated.

### Transmittances of the elements of the eye

#### 1. The cornea, aqueous, and vitreous

The cornea is about 78% water<sup>[4]</sup>; therefore it is a strong absorber of infrared radiation. Similar absorption in the aqueous ensures that almost no infrared radiation reaches the crystalline lens, but any that penetrates to the vitreous will be completely absorbed therein.

The reflectance of the tear film on the cornea is about 2%. It is too slowly varying with wavelength for the effect to be considered. Reflectances at interior interfaces are negligibly small.

The spectral transmittances of these three elements are high; this author does not have numerical values. The transmittance of the cornea (and probably the aqueous and vitreous, as well) rolls off below 380 nm to approach zero near 300 nm (Fig. 1).

- 1 - Lens of a newborn, one specimen.
- 2 - Average transmittances of 9 lenses, birth to 2 yrs.
- 3 - Average of 17 lenses, 2 to 9 yrs.
- 4 - Average of 27 lenses, 10 to 19 years.
- 5 - Average of 36 lenses, 20 to 29 years.

#### 2. The crystalline lens

The crystalline lens is the strongest absorber of ultraviolet and visible radiation. Barker and Brainard<sup>[5]</sup> measured direct (visual axis)

menos la irradiancia directa<sup>1,2</sup>. De ahí que, la radiancia media del cielo es  $\pi^{-1}$  (= 0.3168) multiplicada por la irradiancia difusa total. Kondratyev<sup>[2]</sup> afirma que la radiancia del cielo claro aumenta desde el zénit hacia el horizonte. Se ha encontrado experimentalmente un incremento por un factor de dos. También afirma que, aunque la presencia limitada de las nubes en una configuración particular aumenta ligeramente la irradiancia global, una media a largo plazo de nubosidad variada muestra que debería partirse del supuesto de que las nubes siempre disminuyen la irradiancia global (por lo tanto, la radiancia media del cielo también). A la hora de calcular la irradiancia retiniana debería partirse del supuesto de que existen condiciones de cielo claro con el fin de evitar una infravaloración.

La radiancia media del suelo es  $\pi^{-1}$  (0.3168) multiplicada por la reflectancia difusa del suelo multiplicada por la irradiancia global.

La irradiancia espectral de la retina,  $E_{\text{retina}}(\lambda)$ , de una fuente con radiancia espectral,  $N(\lambda)$  es<sup>[3]</sup>:

$$E_{\text{retina}}(\lambda) = N_{\text{fuente}}(\lambda) \times A_{\text{pupila}} \times \tau_{\text{ojo}}(\lambda) / (f_{\text{ojo}})^2$$

en el que:  $A_{\text{pupila}}$  es el área de la pupila

$f_{\text{ojo}}$  es la longitud focal del ojo, nominalmente 17 mm, y

$\tau_{\text{ojo}}(\lambda)$  es la transmitancia de los elementos del ojo anteriores a la retina; se determina principalmente por absorción en el cristalino. Otras absorciones son lo suficiente pequeñas pueden ser ignoradas.

El área de la pupila se determina calculando la luminancia de la fuente utilizando radiancias espectrales de la fuente de 380 nm a 780 nm.

Para calcular la irradiancia de la córnea, se hace la estimación de la radiancia media del panorama observado, una parte del cielo en el horizonte y una parte de la superficie del suelo. Se estima también la subtensa del ángulo sólido.

### Transmitancias de los elementos del ojo

#### 1. La córnea, el humor acuoso y el humor vítreo

La córnea está constituida de aproximadamente 78% de agua<sup>[4]</sup>; por lo tanto, es un gran absorbente de la radiación infrarroja. Una absorción similar en el humor acuoso asegura que prácticamente ninguna radiación de infrarrojos alcanza al cristalino, pero en el caso de que penetre alguna cantidad en el humor vítreo, ésta quedará absorbida por el mismo.

La reflectancia de la película lagrimal de la córnea es de aproximadamente del 2%. Esta varía con demasiada lentitud con la longitud de onda para que el efecto se tome en consideración. Las reflectancias en interfaces interiores son insignificantes.

Las transmitancias espectrales de estos tres elementos son elevadas y este autor no tiene valores numéricos. La transmitancia de la córnea (y probablemente el humor acuoso y vítreo también) se sitúa por debajo de los 380 nm para alcanzar cero cerca de los 300 nm (Fig. 1).

- 1 - Cristalino de un recién nacido, un espécimen.
- 2 - Media de transmitancias de 9 cristalinos, del nacimiento a los 2 años.

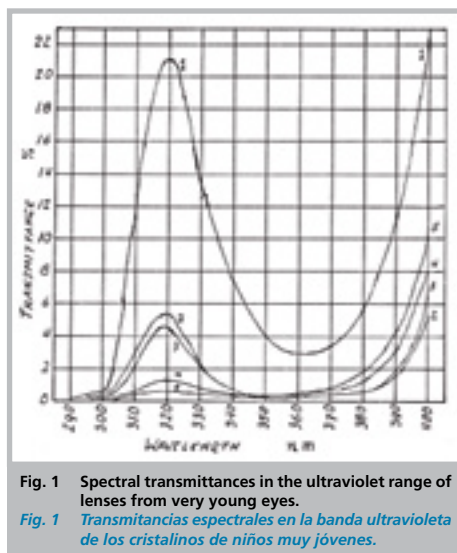


Fig. 1 Spectral transmittances in the ultraviolet range of lenses from very young eyes.  
Fig. 1 Transmitancias espectrales en la banda ultravioleta de los cristalinos de niños muy jóvenes.

transmittances of excised eyes. Their report details spectral transmittances from 200 nm to 2500 nm and reports averaged spectral values by age groups: birth to 2 yrs; 2-9 yrs; 10-19 yrs; 20-29 yrs; and by decades to 90-99 yrs. Above 20 years of age, ultraviolet transmittances below 380 nm are less than 1%. There is a "window" around 320 nm in younger eyes. Figure 1 shows five spectra of the average transmittances, 300 nm to 400 nm. A peak transmittance of 21% at 320 nm, for one of the eyes, at birth, is listed.

Figure 2 shows average transmittances, 380 nm to 700 nm, for four decades of age: 2 – 9 yrs; 20 – 29 yrs; 40 – 49 yrs; and 70-79 yrs (Fig. 2).

- 1 – 2 to 9 yrs.
- 2 – 20 to 29 yrs.
- 3 – 40 to 49 yrs.
- 4 – 70 to 79 yrs.

Infrared transmittances are about 70%, 700 nm to 1350 nm; there is a very strong absorption band (water), 1350 nm to 1500 nm, after which transmittances range over 5% to 20%, and are essentially zero beyond 1900 nm. Average infrared transmittances do not vary appreciably with age.

#### Solar spectral irradiances and radiances

Global and direct solar spectral irradiances on a horizontal surface at sea level for an Am-1 sun and clear sky were used to calculate, in accordance with the procedures described in Clause 2, the diffuse irradiance from the whole sky, the average radiance of the sky, and the radiance of the horizon sky. Using the stated diffuse reflectance of the ground surface (20 %), which affects the global irradiance, the spectral radiances of the ground were calculated. These results are displayed in Figure 3. From an analysis not shown in this report, a multiplier was determined for converting irradiances and radiances at sea level to their corresponding values at 3 km altitude. Curve 7 of figure 3 represents the radiance of the horizon sky at 3 km; it corresponds closely with curve 3 of figure 3.

- 1 – Direct irradiance on horizontal surface.
- 2 – Global irradiance.
- 3 – Irradiance from whole sky diffuse radiation.
- 4 – Average radiance of sky.
- 5 – Radiance of horizon sky.
- 6 – Radiance of ground
- 7 – Radiance of horizon sky at 3 km altitude.

#### Irradiance of the retina by radiation from the horizon sky at sea level

The spectral irradiances ( $\mu\text{W cm}^{-2}$ ) of the retina over the wavelength range 380 nm to 700 nm are shown in figure 4. The diameter of the

- 3 - Media de 17 cristalinos, de 2 a 9 años.
- 4 - Media de 27 cristalinos, de 10 a 19 años.
- 5 - Media de 36 cristalinos, de 20 a 29 años.

#### 2. El cristalino

El cristalino es el mayor absorbente de las radiaciones ultravioleta y visible. Barker y Brainard<sup>[5]</sup> han podido medir transmitancias directas (eje visual) en ojos extirpados. En su informe se pormenorizan las transmitancias espectrales de 200 nm hasta los 2500 nm e incluye datos de los valores espectrales con las medias por grupo de edad: del nacimiento a los 2 años de edad; de 2 a 9 años; de 10 a 19 años; de 20 a 20 años y por décadas hasta los 90 a 99 años. Más allá de los 20 años de edad, las transmitancias ultravioleta por debajo de los 380 nm son inferiores al 1%. Existe una "ventana" alrededor de los 320 nm en los ojos más jóvenes. La figura 1 muestra cinco espectros de las transmitancias medias, 300 nm a 400 nm. Figura en la lista una transmitancia pico del 21% a los 320 nm en uno de los ojos, al nacimiento.

En la figura 2 se muestran las transmitancias medias, 380 nm a 700 nm, de cuatro décadas de edad: 2 - 9 años; 20-29 años; 40-49 años y 70-79 años (Fig. 2).

- 1 – 2 a 9 años.
- 2 – 20 a 29 años.
- 3 – 40 a 49 años.
- 4 – 70 a 79 años.

Las transmitancias de los rayos infrarrojos son aproximadamente del 70%, 700 nm a 1350 nm; existe una franja de muy fuerte absorción (agua), 1350 nm a 1500 nm, después de que las transmitancias sean superiores al 5% y hasta el 20% y son esencialmente de cero más allá de los 1900 nm. Las transmitancias medias de los infrarrojos no varían de manera apreciable con la edad.

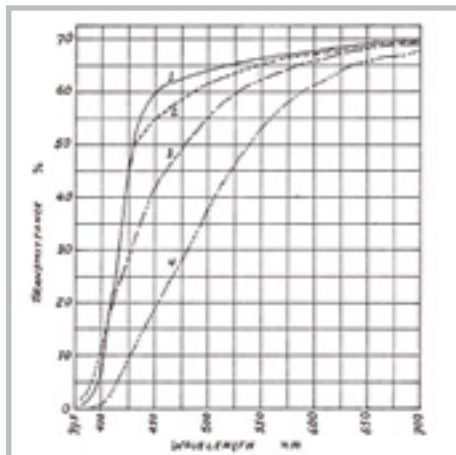


Fig. 2 Average spectral transmittances, 378 nm to 700 nm, of lenses from four decades of age.  
Fig. 2 Transmitancias espectrales medias, 378 nm a 700 nm, de los cristalinos de cuatro décadas de edad.

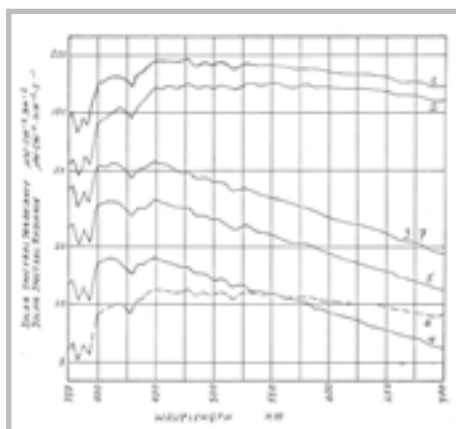


Fig. 3 Solar spectral irradiances ( $\mu\text{W cm}^{-2} \text{ nm}^{-1}$ ) and radiances ( $\mu\text{W cm}^{-2} \text{ nm}^{-1} \text{ sr}^{-1}$ ), 375 nm to 700 nm, for an AM<sup>1</sup> sun, clear sky, diffuse ground reflectance of 20%, at sea level.  
Fig. 3 Radiancias ( $\mu\text{W cm}^{-2} \text{ nm}^{-1} \text{ sr}^{-1}$ ) e Irradiancias ( $\mu\text{W cm}^{-2} \text{ nm}^{-1}$ ) espectrales solares de 375 nm a 700 nm en un sol AM<sup>1</sup>, con cielo claro, reflectancia del suelo difusa del 20% a nivel del mar.

#### Irradiancias y radiances espectrales solares

Para calcular, de conformidad con los procedimientos descritos en la Cláusula 2, la irradiancia difusa de todo el cielo, la radiancia media del cielo y la radiancia del cielo del horizonte, se han utilizado las irradiancias espectrales solares directas y globales sobre una superficie horizontal a nivel del mar a Am-1 con cielo claro y soleado. Se calcularon las radiancias espectrales del suelo utilizando la reflectancia difusa establecida de la superficie del suelo (20%), que afecta a la irradiancia global. Esos resultados se muestran en la figura 3. Del análisis n, que no figura en este informe, se determinó un multiplicador para convertir las radiancias e irradiancias a nivel del mar con sus valores correspondientes a 3 km de altitud. La curva 7 de la figura 3 representa la radiancia del cielo en el horizonte a 3 km; se corresponde muy de cerca con la curva 3 de la figura 3.

pupil, 1.74 mm, was determined by calculating the luminance of the horizon sky at sea level. The spectral transmittances of the lens were the averages for the age-group, 10 – 19 years, from<sup>[5]</sup>. Because of the very small spectral transmittances of teen-age and adult lenses, ultraviolet irradiances of the retina are usually negligibly small for solar radiation when direct viewing of the solar disc is excluded. □

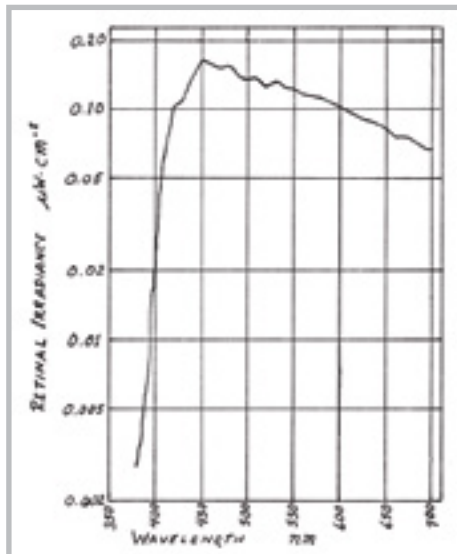


Fig. 4 Spectral irradiances ( $\mu\text{W cm}^{-2}$ ) 300 to 700 nm, of the retina by radiation from the horizon sky, 1.74 mm pupillary diameter, using the average spectral transmittances of lenses in the age group 10 to 19.

Fig. 4 Irradiancias espectrales ( $\mu\text{W cm}^{-2}$ ) 300 a 700 nm de la retina por radiación desde el horizonte, diámetro de la pupila 1.74mm, utilizando las medias de transmittancias espectrales de los cristalinios en el grupo de edad de 10 a 19 años.

1 – Irradiancia directa en superficie horizontal.

2 – Irradiancia global.

3 – Irradiancia de la radiación difusa de todo el cielo.

4 – Radiancia media del cielo.

5 – Radiancia del cielo del horizonte.

6 – Radiancia del suelo

7 – Radiancia del cielo mirado hacia el horizonte a 3 km de altitud.

**La irradiancia de la retina con la radiación del horizonte a nivel del mar**

Se muestran en la figura 4 las irradiancias espectrales de la retina ( $\mu\text{W cm}^{-2}$ ) por encima de la longitud de onda el rango de 380 nm a 700 nm. Se ha determinado el diámetro de la pupila, 1,74 mm, mediante el cálculo de la luminancia del cielo mirado hacia el horizonte a nivel del mar. Las transmittancias espectrales del cristalino eran las medias en el grupo de edad 10 - 19 años<sup>[5]</sup>. Debido al hecho de que las transmittancias espectrales de los cristalinios de adolescentes y adultos son muy pequeñas, las irradiancias ultravioleta de la retina son habitualmente insignificantes para la radiación solar cuando se excluye la visión directa de disco solar. □

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## **2. BLUE LIGHT**



# **BLUE LIGHT HAZARD: New Knowledge, New Approaches to Maintaining Ocular Health**

REPORT OF A ROUNDTABLE  
March 16, 2013, New York City, NY, USA

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Kirk Smick, OD, FAAO

**PRESENTER**

Thierry Villette, MSc, PhD  
*Research & Development  
Essilor International*

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William Jones, OD, FAAO  
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Ron Melton, OD, FAAO  
Randall Thomas, OD, MPH, FAAO

**COMMENTARY**

David H. Sliney, MS, PhD  
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## SUMMARY

Short wavelength visible light, the spectrum from 380 to 500 nm that includes violet, indigo, blue, and some blue-green light, plays a paradoxical role in health and vision. Not only is blue light essential for color vision, recent research has found that light in this band triggers critical physiological responses, including pupil constriction and circadian rhythm synchronization. However, blue light may also be damaging to the eye, and the term “blue light hazard” has been coined to describe the danger this light presents to critical structures within the eye.

Blue light can induce formation of toxic reactive oxygen species that cause photochemical damage, leading to the death by apoptosis first of critical retinal pigment epithelial (RPE) cells and then photoreceptors. This slow process, in which damage accumulates over a lifetime, has been implicated in the pathogenesis of retinal degenerative diseases such as age-related macular degeneration (AMD).

The fact that blue light is both beneficial and toxic raises a critical question: Can we protect the eye from harmful blue light without simultaneously denying it the physiologically necessary blue light? One way to accomplish this would be with a lens that selectively filters out the harmful wavelengths while transmitting the beneficial ones. Recent work has enabled this by more fully defining the range of harmful blue light.

To determine whether specific bands within the blue-violet spectrum are responsible for blue light’s phototoxic effects on the RPE, researchers from Essilor’s Paris research and development laboratories joined forces with scientists from the Paris Vision Institute to develop a unique illumination system that allowed cultured porcine retinal cells to be exposed to narrow (10-nm) bands of light at moderate irradiances normalized to typical retinal sunlight exposure. Using this test system, it was discovered that RPE phototoxicity was concentrated in a relatively narrow band, with little overlap of the wavelengths necessary for the beneficial physiological effects of blue light. This finding paved the way for selective photofiltration: the creation of lenses that reduce the level of exposure to the harmful portion of the blue-violet spectrum while permitting the rest of the visible spectrum to enter the eye at a normal level. Thus, the eye’s necessary visual and non-visual functions can be maintained while exposure to hazardous wavelengths is reduced.

With the creation of Crizal® Previncia™ No-Glare lenses, Essilor has turned this concept into a reality. These lenses reduce exposure to ultraviolet (UV) light — coming from in front or reflecting off the back surface of lenses — and they attenuate the harmful wavelengths of blue light. Because they reduce (but don’t fully block) transmission of just a narrow band of blue-violet light, excellent color transmission, as well as transparency, are maintained, providing superior clarity of vision. Because the damaging effects of blue-violet light are cumulative, wearing Crizal® Previncia™ No-Glare lenses may help protect the eye by reducing lifetime exposure to harmful UV and blue-violet light. With more and more clinicians prescribing spectacle lenses from the chair, Crizal® Previncia™ No-Glare lenses provide a helpful tool for patients to protect themselves from UV and the harmful wavelengths in the blue-violet spectrum.

## INTRODUCTION

The human eye is adapted to life in a world of light. Sunlight not only enables vision, it triggers essential physiologic functions, including circadian entrainment (synchronization of internal circadian rhythms) and the pupillary light reflex.<sup>1</sup> But along with its many beneficial effects, sunlight exposure can also bring harm to both skin and eyes—the spectrum of optical radiation spans a wide range of wavelengths, not all of which are benign.

The eye is subject to injury from both acute and long-term exposure to solar and man-made optical radiation. The serious dangers that UV radiation presents to both eyes and skin are well established. Now, mounting evidence has alerted scientists and clinicians to the damage that long-term exposure to blue light may cause to retinal photoreceptors.

With this in mind, Essilor formed an expert panel that met in March 2013 to evaluate what is known about blue light hazard and the means of ocular protection available. This report, which summarizes the roundtable discussion, will:

- ▶ Provide an overview of the interaction between light and the eye;
- ▶ Describe the current understanding of the role blue light plays in health and vision;
- ▶ Review the present state of knowledge about blue light hazard and the mechanisms by which blue light may damage retinal cells;
- ▶ Discuss a recent research study identifying a specific, narrow band of blue light that is phototoxic to the retinal pigment epithelium cells; and
- ▶ Introduce a new spectacle lens solution that for the first time offers a way to reduce exposure to both UV and damaging blue light without affecting either color vision or blue light's beneficial effects.

## LIGHT AND THE EYE

### Optical Radiation

The electromagnetic spectrum has three bands of what is termed optical radiation: UV encompasses wavelengths from 100 nm to 380 nm; visible light comprises radiation between 380 nm and 780 nm; and infrared (IR) consists of wavelengths from 780 nm to 10,000 nm (Figure 1). These can all be further divided into sub-bands. Within the UV spectrum there is UVA (315 nm to 380 nm), UVB (280 nm to 315 nm), and UVC (100 nm to 280 nm)\*; the IR spectrum contains IRA (780 nm to 1,400 nm), IRB (1,400 nm to 3,000 nm), and IRC (3,000 nm to 10,000 nm); and the visible light spectrum can be generally classified as short- (blue), medium- (green), and long-wavelength (red) light.<sup>2</sup>

Visible light, like all electromagnetic radiation, has energy; the amount of photon energy is a function of wavelength, with shorter wavelengths being most energetic. Thus, blue-violet light is the highest-energy band of the visible spectrum.

\*The exact wavelengths of various bands differ slightly in work by different groups.

### Light Absorption in the Eye

Visual perception occurs when light strikes the retina, an intricate structure of highly specialized cells that form the innermost layer of the globe. Before reaching the retina, incoming light must penetrate the ocular media, the transparent tissues and fluids that lie between the front of the eye and the retina. The ocular media—consisting of the cornea, aqueous humor, lens, and vitreous humor—either absorb or transmit light, depending on its wavelength.

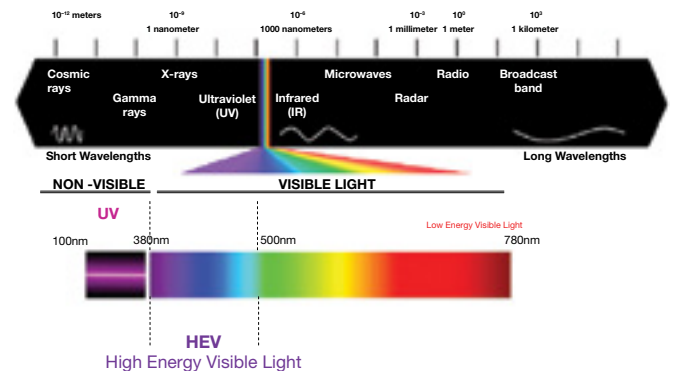


FIGURE 1. The electromagnetic spectrum and optical radiation.

Almost all of the UV that reaches the eye is absorbed by the cornea or the crystalline lens, so that in adult eyes only 1% to 2% of incoming UV is transmitted to the retina.<sup>3</sup> The cornea and crystalline lens also block IR above 980 nm; and the vitreous absorbs the IR above 1400 nm that is not absorbed by the lens. The net result of light filtering by the ocular media is that the retina is exposed almost exclusively to the visible portion of the solar spectrum (Figure 2).

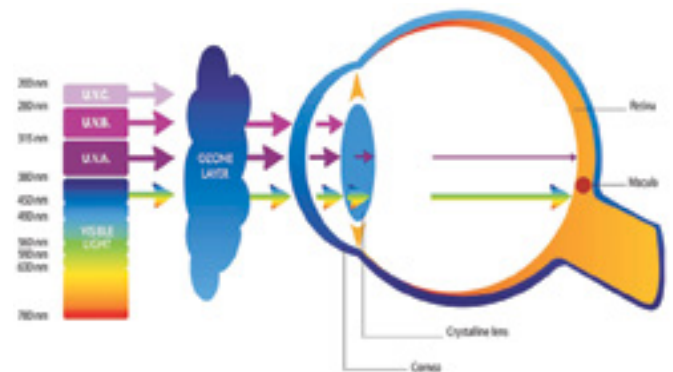


FIGURE 2. Absorption and transmission of solar radiation in the eye. The cornea and crystalline lens filter out UVB and most UVA, so that the most energetic light reaching the retina is short wavelength blue-violet light.

### Light Transduction: the Visual Cycle

Visual function depends on two types of photoreceptors within the retina: rods and cones. Required for scotopic vision, rod vision lacks color information and is characterized by high sensitivity but low resolution. Highly concentrated in the center of the macula, cones enable both sharp image resolution and color detection.

Rods and cones in the retina initiate the visual process when

## BLUE LIGHT HAZARD

visual pigments absorb photon energy and convert it into neural signals. This biological conversion of light to electrical signals is supported by an enzyme-mediated process called the “visual cycle” that allows efficient reuse of key chemicals in the reaction.

The visual pigments that initiate the process are made up of an opsin combined with the chromophore 11-*cis*-retinal. The important photochemical reaction is the conversion of the 11-*cis*-retinal to all-*trans*-retinal, caused by photon energy striking the pigment. This changes the shape of the retinal molecule, breaking its connection with opsin and leaving the opsin free to initiate a series of reactions that leads to a neural signal and ultimately to vision.

In the meantime, the all-*trans*-retinal is converted to all-*trans*-retinol and transported to the retinal pigment epithelium (RPE) where it is either stored or reconverted to the 11-*cis*-retinal form for transport back to the photoreceptors. There it can recombine with opsin to complete the visual cycle (Figure 3).

The visual cycle takes place within the outer segment of the rods and cones and in the RPE cells. The RPE cells are not photoreceptive, but they are essential to the regeneration of visual pigments and also play a critical role in the survival

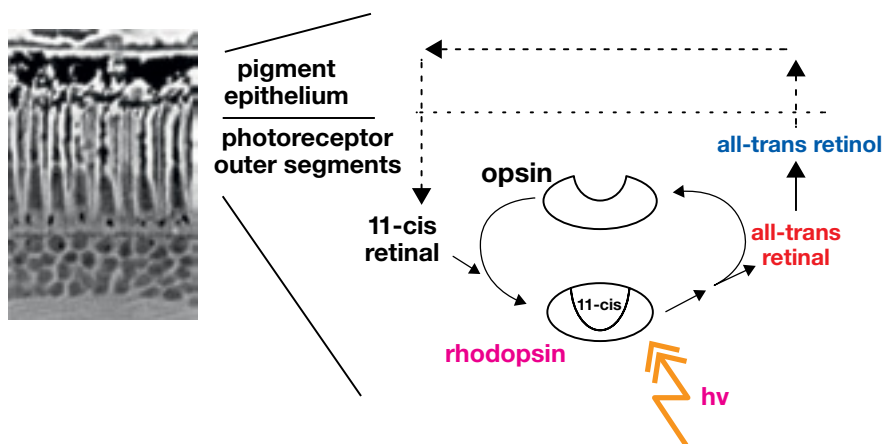


FIGURE 3. The visual cycle.

and normal function of photoreceptors. With microvilli on their apical surfaces interdigitating with the outer segments of photoreceptors, the RPE cells supply the photoreceptors with nutrients and oxygen. They also help maintain the homeostasis of photoreceptors by phagocytosis and digestion of oxidized photoreceptor outer segments.

### Light Damage in the Eye

Although light is essential to vision, light exposure can also cause pathological changes to ocular tissues through absorption of photon energy. When absorbed, photon energy can be dissipated

## COMMENTARY: An Insurance Policy for the Eyes

Short wavelength visible light, particularly violet and indigo, reaches the retina in substantially greater doses than does ultraviolet (UV) radiation. Indeed, the conditions associated with UV exposure are generally confined to the anterior segment of the eye, due to nearly complete absorption of UV by the crystalline lens.<sup>1</sup>

When we think about how light interacts with the molecules that compose living cells and tissues, what concerns us is photon energy, which is inversely correlated with wavelength. At a 400-nm wavelength, for example, photons are much more energetic and have a greater potential to alter the molecules they strike than photons at 500 nm. Light at wavelengths in the neighborhood of 400 nm consists of the highest-energy photons to reach the retina, and there is reason for concern about this high-energy light's effects there.

### The “Blue-light Hazard”

The most certain impact on retinal

health and vision from exposure to higher-energy visible (indigo and blue) light is acute phototoxicity, as seen in humans who stare directly at an arc lamp or the sun. It is established that this damage is photochemical, not thermal, and studies in primates have made it possible to define the action spectrum for this type of damage, which peaks around 440 nm.<sup>2</sup>

It is certainly reasonable to suppose that over the long term, and especially as aging changes erode cellular defense mechanisms, retinal exposure to high-energy light could have a damaging effect. Many *in vitro* studies, including those detailed in this report, have helped us to understand the photochemical and cellular mechanisms by which this damage occurs.

Visual pigment, retinoids, and bisretinoids (in particular A2E, a major photosensitive component of lipofuscin) have been implicated in photochemical damage to the outer retinal layers, and additional not-yet-identified chromophores may also act in this way. High energy vis-

ible light exposure also induces oxidative damage, to which retinal cells are especially vulnerable.<sup>3</sup>

### Challenges to Research

Corresponding epidemiological studies examining the link between light exposure and AMD have been less conclusive, in part because of the difficulties of conducting such studies. For example, the dosimetry necessary to conduct a conclusive epidemiological study of light exposure and AMD is extremely challenging. Two otherwise similar people, standing side by side at a beach and facing the same direction may easily have significantly different pupil sizes and lid-openings, and therefore different levels of retinal light exposure. But epidemiological studies tend to assume that two such people's retinas would receive the same light dose.

In addition, much of the data on which these epidemiologic studies rely is retrospective, and thus subject to the vagaries of memory. I can't say for certain



as heat and/or trapped via a photochemical reaction. Acute exposure to intense light can cause thermal injury (eg, skiers' photokeratitis), while lower levels of exposure may, over a lifetime, cause the slow accumulation of harmful photochemical waste products that lead ultimately to cell death.

It is well established that solar UV is hazardous to ocular health. Chronic exposure to solar UV has been shown to increase the risk of developing pterygium, cataract, and a variety of other ophthalmic conditions. But because UV is almost fully absorbed by the ocular media before reaching the retina, the harmful effects of UV radiation are concentrated in the cornea and the crystalline lens. However, scientific findings on blue light suggest that fully protecting the eyes from light damage requires more than just blocking UV.

### Blue Light: Concept and Sources

In the visible spectrum, wavelengths between 380 and 500 nm include violet-, blue-, and green-appearing wavelengths. This portion of the spectrum is also known as high-energy visible (HEV) light because of the high photon energy associated with these short wavelengths.

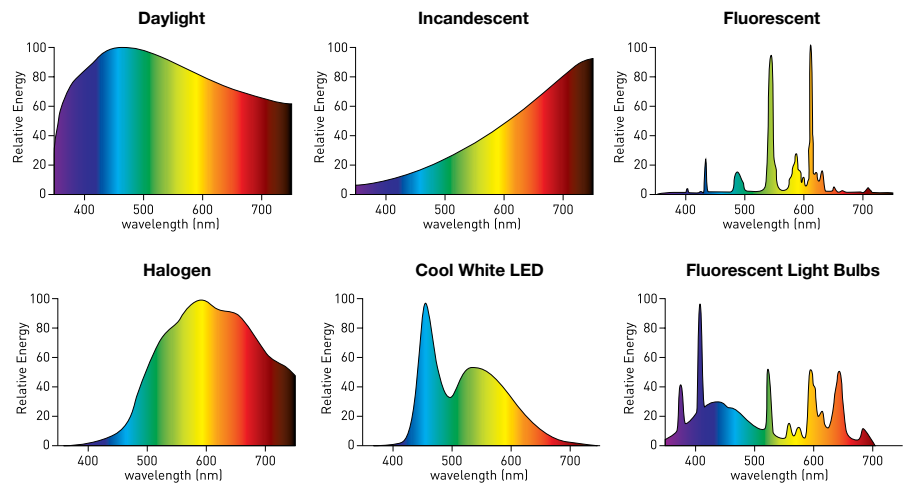


FIGURE 4. Spectral distribution of different light sources.

The sun is the primary natural source of blue light, but human beings are also increasingly exposed to blue light from artificial sources, which vary widely in spectral distribution. Solar radiation is 25% to 30% blue light, depending on the reference solar spectrum; and while conventional incandescent lamps emit very little blue light (about 3%), newer artificial light sources produce a considerably higher amount of blue light (Figure 4). Approximately 26% of the light from the energy-efficient and increasingly popular compact fluorescent lamps is in the blue portion of the

### DAVID H. SLINEY, MS, PHD

how much I played outdoors as a child; and although I might venture to guess I spent more time outside than the average child of today, the modern child's indoor environment likely contains multiple blue-rich displays and light sources.

### Blue Light in Health and Vision

There is no evidence that short wavelength light (below 440 nm) has significant ocular benefit. On the contrary, sharpshooters and others who demand very sharp outdoor vision often rely on blue-light-filtering lenses, both because light of shorter wavelengths is scattered by the atmosphere more greatly than longer-wavelength light and because UV and high-energy visible light cause the crystalline lens to fluoresce very slightly, resulting in a thin haze which may increase with age.<sup>4</sup>

Of course, lenses that block the entire blue spectrum are impractical for everyday use, not only because of their effects on color perception and facial appearance but also because of the physi-

ologically important circadian function, which requires irradiance in the range of 470 nm. So while blocking the entire blue spectrum, as with the yellow-hued blue blockers available in convenience stores, is undesirable, some attenuation of the shortest visible wavelengths would be expected to have minimal impact on vision or health—and may even improve vision very slightly in some environments.

### Increased Exposure?

While there is a global trend toward more energy-efficient lighting with LED and compact fluorescent lamps, consumer preference in the US has not favored those blue-rich light sources. Here, the bigger concern may be with modern, higher-luminance displays (computer monitors, smartphones, and tablets) which are blue-rich and virtually ubiquitous.

It is unclear what long term effect this increased exposure to short-wavelength light will have on us; but it is certainly cause for further study and for taking

some steps to reduce needlessly high exposures to short wavelength light. Therefore, lenses designed to reduce violet light exposure and accomplish this without interfering with vision and circadian function, seem like a very reasonable insurance policy.



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spectrum; and the 35% of the optical radiation from cool white light-emitting diodes (LEDs) is blue.<sup>4</sup>

## BLUE LIGHT IN HEALTH AND VISION

UV and visible light have long been observed to cause photochemical damage to retinal photoreceptors and RPE cells.<sup>5-7</sup> Since the anterior structures of a healthy eye naturally protect the retina from UV, retinal phototoxicity is primarily due to photochemical damage induced by the cumulative effects of long-term exposure to visible light, in particular blue light.

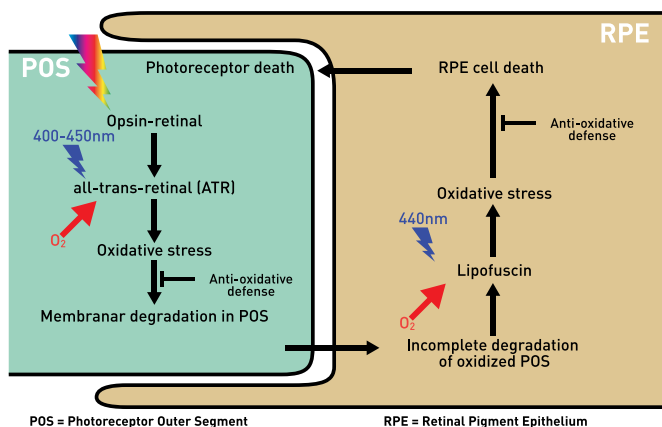


FIGURE 5. Phototoxicity mechanisms in outer retina.

Being in the most energetic portion of the visible spectrum, blue light has the greatest potential to induce the photochemical damage that may ultimately be a factor in retinal disorders such as age-related macular degeneration (AMD).<sup>8-11</sup> On the other hand, blue light is important to visual processes including color perception. More recent research has also demonstrated that blue light plays an essential role in non-visual functions, such as circadian entrainment and the pupillary light reflex.<sup>1,12,13</sup>

### Blue Light is Vital for Life

These non-visual functions depend on a newly discovered third photoreceptor type that exists along with the rods and cones. Called intrinsically photosensitive retinal ganglion cells (ipRGCs), these cells contain melanopsin, a photopigment, and, unlike cone cells, they are not concentrated in the fovea. Instead ipRGCs form a photoreceptive network broadly across the inner retina.<sup>12</sup> Because melanopsin is so important to the daily resetting of our biological clocks, the absorption spectrum of melanopsin is sometimes called the chronobiological spectral band. This band peaks at about 480 nm, within the blue range.<sup>13</sup>

The ipRGC response to light in the chronobiological band regulates many

non-visual physiologic functions in the human body, including circadian entrainment, melatonin regulation, pupillary light reflex, cognitive performance, mood, locomotor activity, memory, and body temperature.<sup>1,13-16</sup> Studies have shown that pupil constriction, the eye’s natural defense against exposure to strong light, is wavelength-dependent and peaks at 480 nm.<sup>14-16</sup> The exact physiology by which ipRGCs control these functions have not been fully elucidated.

What is clear, however, is the essential role that blue light plays in daily life. Thus, simply filtering out the entire blue spectrum in order to reduce the “blue light hazard” may interfere with the physiological functions driven by the reaction between ipRGCs and light in the chronobiological band. Indeed, one recent study has shown that blocking light at 470 nm could disrupt the sustained phase of the pupil constriction reflex.<sup>17</sup>

### Blue Light Phototoxicity

Blue light damage occurs when a photosensitizer absorbs photon energy of a specific wavelength, setting in motion a series of intracellular chemical reactions. Rods, cones, and RPE cells of the outer retina—the cells responsible for photon absorption and visual transduction—are rich in photopigments and therefore susceptible to photochemical damage.

Blue light can cause damage to both photoreceptor and RPE cells in primates.<sup>9,18</sup> Cumulative exposure to light in the 380 nm to 500 nm range can activate all-trans-retinal accumulated in the photoreceptor outer segments (Figure 5).<sup>19</sup> This blue light photoactivation of all-trans-retinal can induce production of reactive oxygen species (ROS), such as singlet oxygen, hydrogen peroxide, and other free radicals, in the photoreceptor outer segments.

The ROS attack many molecules, including polyunsaturated fatty acids, a major component of cell membranes. The large concentration of cell membranes in the retina makes it highly sensitive to oxidative stress. In particular, this stress may disrupt the membranous structures of the photoreceptor outer segments, causing incomplete phagocytosis and digestion of oxidized outer segments in the RPE. The consequence is an accumulation of the waste product lipofuscin in RPE cell granules.

In the eye, lipofuscin, also known as “the age pigment,”

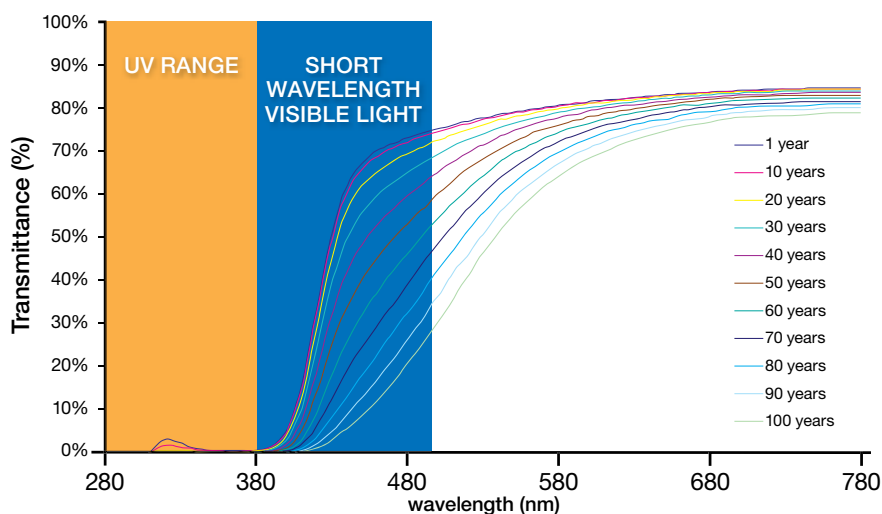
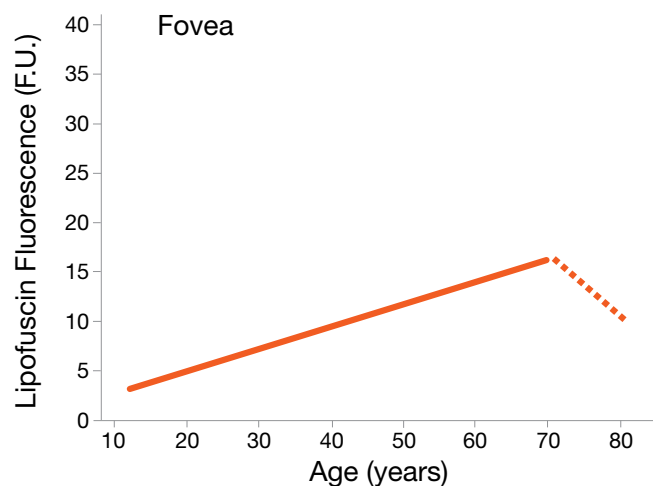


FIGURE 6. Light transmittance of clear ocular media in aging human phakic eye.



**FIGURE 7.** Lipofuscin levels in the human fovea increase with age. (Figure adapted from Delori FC, Goger DG, Dorey CK. Age-related accumulation and spatial distribution of lipofuscin in RPE of normal subjects. *Invest Ophthalmol Vis Sci.* 2001;42[8]:1855-66.)

accumulates over the years and builds up at a faster rate in some retinal diseases.<sup>20</sup> Composed of lipids, proteins, and a number of chromophores, lipofuscin is highly susceptible to photochemical changes that can produce permanent cellular damage.<sup>21</sup> Lipofuscin accumulation has been implicated in the pathogenesis of AMD, and intense lipofuscin autofluorescence is frequently observed in regions surrounding the leading edges of geographic atrophy lesions in the retina.<sup>22</sup>

A2E (N-retinylidene-N-retinylethanolamine) is a key photosensitive fluorophore that mediates lipofuscin phototoxicity.<sup>23,24</sup> (A fluorophore is a chromophore that can re-emit light after excitation.) With maximum absorption at around 440 nm, A2E is excited by blue light.<sup>19</sup> The photosensitization of A2E leads to the formation of ROS and to an inhibition of lysozyme's ability to break down cellular structures for recycling.<sup>25,26</sup>

Excessive oxidative stress can cause dysfunction in the RPE cells and, eventually, cell death by apoptosis. Without the supportive functions of the RPE, photoreceptors cannot function properly and will degenerate as well. Lipofuscin accumulation and A2E photosensitization are involved in this cascade of phototoxic effects, which has been implicated in the pathogenesis of AMD.<sup>20</sup>

### Aging and Susceptibility to Phototoxicity

Retinal changes associated with age have significant influence over the potential for photodamage. As the eye ages, light transmission and absorption change, primarily owing to the gradual yellowing of the crystalline lens. As a result, the aging lens transmits less visible light overall, with a disproportionate drop in transmission of blue light due to yellow discoloration of the lens (Figure 6).<sup>27-28</sup> But even though it decreases with age, the level of blue light transmitted to the retina remains significant throughout life. Early in life, blue represents about 20% of the visible light received by the retina, dropping to about 14% at 50 years of age and to 10% at 70 years.<sup>29</sup>

Lipofuscin starts to build up in the early years of life, becoming apparent in the RPE cells of healthy human retinas by the age of 10 (Figure 7).<sup>30,31</sup> Accumulating in the lysosomes of RPE cells, lipofuscin increases the potential for photochemical damage in

the retina. In the visual cycle, RPE cells actively engulf and digest oxidized photoreceptor outer segments and help to regenerate visual pigments; but debris and waste products accumulated in the lysosomes negatively affect this process.

### Weakened Defense Mechanisms

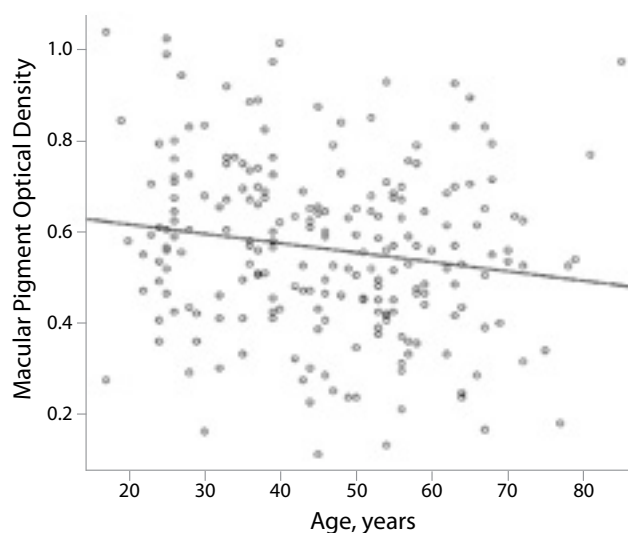
Although the gradual decrease of retinal exposure to blue light with age is protective, other, less helpful effects of aging are also at play.

Macular pigment—which is made up of carotenoids such as lutein and zeaxanthin—efficiently filters out short-wavelength radiation before it reaches the photoreceptors and RPE, providing a natural protection against blue-light damage.<sup>32,33</sup> Macular pigment molecules serve another beneficial role as free-radical scavengers. But, unfortunately, studies suggest that levels of macular pigment decrease with advancing age (Figure 8).<sup>34,35</sup>

The result is that, while less blue light reaches the retina in elderly eyes, the natural defenses and repair mechanisms simultaneously become less effective. The aging retina therefore remains susceptible to photochemical damage from blue light, even as its level of exposure drops.

### Link with AMD

AMD, a degenerative retinal disease that affects the photoreceptors, the RPE, Bruch's membrane, and the choroid, is a leading cause of legal blindness among people over age 65.<sup>36,37</sup> AMD is responsible for about half of severe visual loss (defined as visual acuity of 20/200 or worse) in Caucasian Americans over age 40.<sup>37</sup>



**FIGURE 8.** Age-dependent macular pigment optical density. (Figure adapted from Yu J, Johnson EJ, Shang F, et al. Measurement of macular pigment optical density in a healthy Chinese population sample. *Invest Ophthalmol Vis Sci.* 2012;53(4):2106-11.)

With the elderly population growing, AMD is rapidly becoming a major public health concern. By 2050, the number of Americans with early-stage AMD is expected to double from 9.1 million to 17.8 million.<sup>38</sup> Extrapolations from current trends indicate that the AMD population worldwide will grow to between 100 and 200 million people over the next 30 years.

Multiple factors increase a person's risk of developing AMD,

## BLUE LIGHT HAZARD

including age, tobacco use, genetic factors, and an antioxidant-deficient diet.<sup>39,40</sup> Blue light exposure, owing to its impact on lipofuscin accumulation and A2E-mediated phototoxic effects, has come to be considered another potential risk factor.

Several epidemiological studies have found evidence of a relationship between chronic sunlight exposure and AMD. The Beaver Dam eye study found that levels of sun exposure in the teen and early adult years were strongly associated with a higher risk of developing retinal pigment abnormalities and early AMD.<sup>41,42</sup> In the Chesapeake Bay Waterman Study, a group of subjects with advanced AMD had had high levels of blue light exposure over the preceding 20 years.<sup>43,44</sup> Recently, the European Eye (EUREYE) Study reported a significant association between lifetime blue light exposure and AMD in individuals with low dietary levels of antioxidants (including vitamins C and E, zeaxanthin, and dietary zinc).<sup>45</sup>

### Breakthrough Science

The potential connection between blue-light phototoxicity and retinal diseases such as AMD suggests that reducing blue-light exposure would be beneficial to long-term ocular health. Although research in animal models and in-vitro experimental set-

tings has generated substantial evidence that blue light can cause cellular damage to photoreceptors and RPE cells, the wavelengths within the blue-violet spectrum responsible for this damage have not been as precisely identified until now.

Eyes could be protected by simply blocking all blue light (as yellow “blue blocking” glasses aim to do), but this solution distorts color, has unwanted cosmetic effects, and eliminates the physiologically critical light in the chronobiological band. But selective blocking of the hazardous wavelengths (and just those wavelengths) required investigation to determine just what those wavelengths are.

To delineate the damaging bands within the blue-light spectrum, research scientists from Essilor partnered with the Paris Vision Institute (Paris, France) to create an in vitro model for the study of retinal phototoxicity.\*

\*Based in Paris and linked to Pierre & Marie Curie University, the Vision Institute (IDV) is considered as one of Europe’s foremost integrated eye condition research centers. It is here that 200 researchers and doctors and 15 manufacturers work together on discovering and approving new therapies and new preventive solutions, as well as compensatory technologies for sight impairment.

## COMMENTARY: Preventive Eyecare — Lens Technology Gets Specific

DIANA L. SHECHTMAN, OD, FAAO

The role of ultraviolet (UV) radiation in the pathogenesis of ocular conditions like cataract, pterygium, and UV keratopathy is well known. Most of the UV incident upon the eye is absorbed by the cornea and crystalline lens, and is thus associated primarily with conditions of the anterior segment.<sup>1</sup> On the other hand, high energy blue-violet visible light, lying just outside the UV band, typically passes through the cornea and lens.<sup>1</sup> Thus, this light is the highest energy visible light to reach and affect the posterior segment.

While it has been challenging to accurately measure and prove a causal link between age related macular degeneration (AMD) and long term retinal light exposure, there is evidence that long term sunlight exposure is one of the risk factors contributing to AMD.<sup>2</sup>

AMD can have a devastating effect on a patient’s vision and quality of life. Anti-VEGF therapy and AREDS-type supplements have been used to manage patients with AMD, but these options do not provide a cure or restore vision to its pre-morbid state. It would be far better to find effective ways to reduce the risk of developing AMD in the first place.

The need for good preventive measures is given urgency by the rapid growth of the elderly population and the prevalence of AMD within that population. In addition, exposure to high energy blue light is likely to increase significantly as people convert from incandescent and halogen lighting to compact fluorescent lights and LEDs, which produce a far higher proportion of blue light. In addition, the proliferation of digital screens in use today has caused an increase in our exposure to blue wavelengths. The impact of this increase is potentially concerning, though further studies are warranted.

Recently, research by Essilor in collaboration with the Paris Vision Institute has contributed to the growing body of evidence surrounding the mechanism of blue-light mediated retinal damage.<sup>3</sup> Their study isolated the specific narrow band of blue-violet light (435 nm ± 20 nm) that contributes to retinal pigment epithelium (RPE) cell apoptosis in an in vitro AMD model. Given the fact that blue light is still a necessity for color perception and physiological functions like the regulation of circadian rhythms, selectively blocking only the dangerous band(s) of blue light is critical. This dis-

covery, and the lens technology that enables it, may prove to be a public health breakthrough.

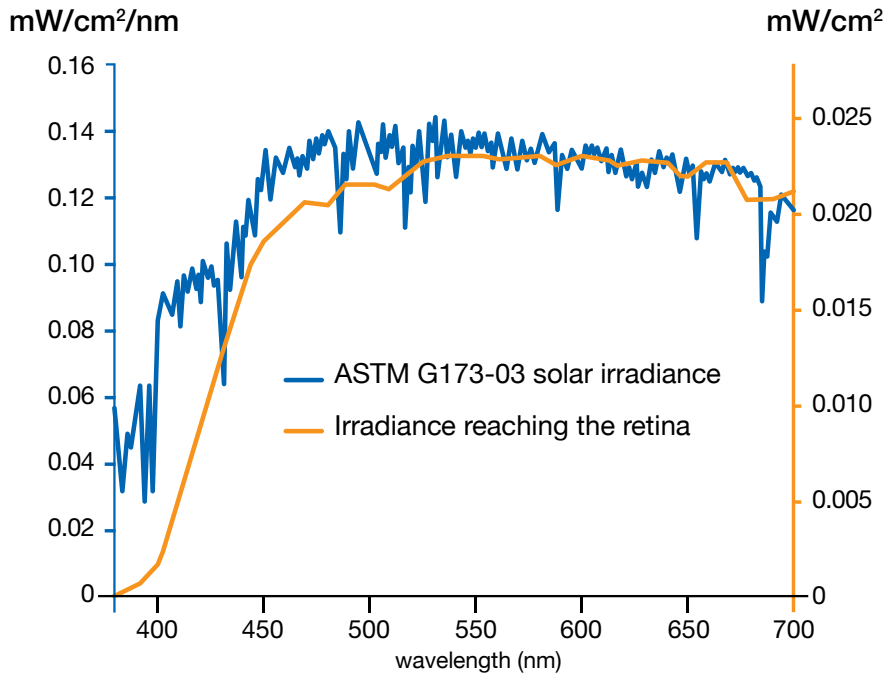
We already counsel patients about UV exposure and offer specific lenses and filters to help protect their eyes. Further research is necessary; but lenses designed to provide optimum vision, protect against UV, *and* selectively block the narrow band of blue-violet light implicated in RPE apoptosis could become an important element of preventive eye-care going forward.



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**FIGURE 9.** Calculated irradiances in the A2E experiment.

tral bands (across the range from 390 to 520 nm in 10-nm increments) with tight photometric control.

Before light exposure, the RPE cells were treated with A2E at different concentrations. (Because, again, A2E is a key photosensitive fluorophore in lipofuscin, A2E-loaded RPE cells are frequently used to model aging RPE cells.<sup>18,47,49,52,53</sup> Very recently, however, some authors have challenged the A2E model, proposing instead to measure lipofuscin directly. [Ablonczy Z, Higbee D, Anderson DM, Dahrouj M, Grey AC, et al. Lack of correlation between the spatial distribution of A2E and lipofuscin fluorescence in the human retinal pigment epithelium. *Invest Ophthalmol Vis Sci.* 2013 Jul 11.]) The A2E-containing cells were exposed to controlled doses of light in 10-nm bands at irradiance levels mimicking sunlight retinal exposure, and RPE cell damage was assessed by measuring cell viability, necrosis, and apoptosis (Figure 9).

**New Methods**

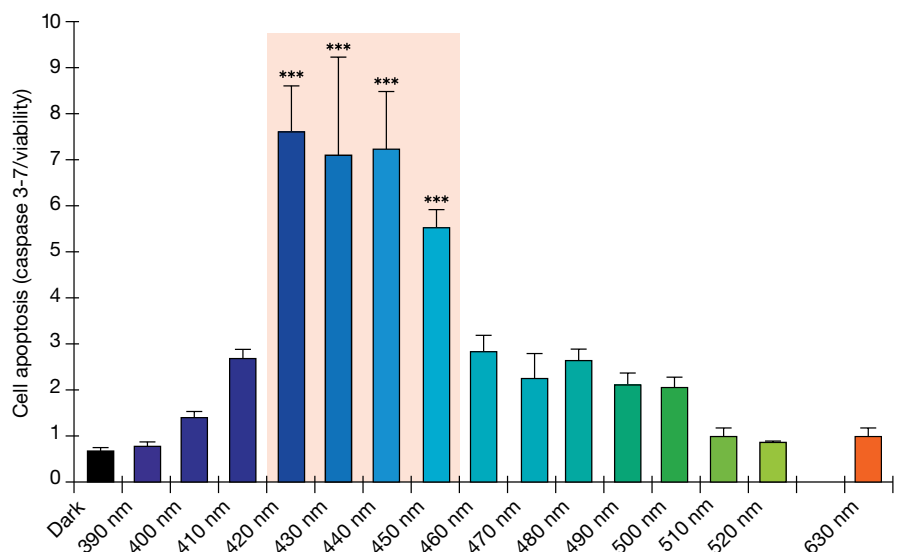
A large body of prior research had demonstrated that blue light causes phototoxic damage to RPE cells and is far more damaging to those cells than green or yellow-red light.<sup>46-49</sup> In addition, it had been determined that blue-light-induced RPE cell death is mediated by apoptotic, rather than necrotic, processes.<sup>46,47,50,51</sup>

These studies, however, had a number of methodological limitations. For example, the cells typically used for in vitro experiments were from immortalized RPE cell lines (rather than freshly harvested RPE cells), and the culture media were not always entirely free of visible light chromophores. Nor were the experimental light levels normalized to approximate actual physiological conditions. Most importantly, all studies prior to the joint study between Essilor and the Paris Vision Institute work used broadband blue light illumination and so were not able to define the specific toxic sub-band(s) within the blue-violet spectrum.

Knowing this, scientists from Paris Vision Institute and Essilor used their respective areas of expertise to develop improved experimental techniques and overcome the limitations of prior studies. Instead of immortalized cell lines, they employed primary cultures of swine RPE cells grown in a cell medium free of visible light-absorbing chromophores. In addition, they devised a unique illumination system that allowed them to normalize light irradiances to sunlight retinal exposure. They were able to expose the RPE cells to extremely narrow (10-nm) spec-

**Results**

The greatest damage followed exposure to the four 10-nm sub-bands within the blue-violet spectrum between 415 nm and 455 nm. In those test cells, morphological changes to RPE cells (cell rounding, loss of confluence, and decrease of density) were observed 6 hours after exposure (Figure 10). In addition to wavelength dependence, the toxic effect was A2E-dose dependent, with the greatest apoptosis rates occurring with 20 μM and 40 μM concentrations of A2E. In cells exposed to the narrow band



**FIGURE 10.** Phototoxic action (apoptosis) spectrum on A2E-loaded RPE cells and morphological changes of the RPE cells.

\*\*\**P* < 0.001 as compared to control cells maintained in the dark.

of blue-violet light centered on 440 nm, though, there was a significant increase in apoptosis, even with 12.5  $\mu$ M A2E, indicating the phototoxicity of those wavelengths.

The damage observed in the study was clearly apoptotic rather than necrotic. Irradiated RPE cells had necrosis rates no higher than those maintained in dark, irrespective of the A2E concentration, which is consistent with the experiments conducted in physiological light conditions.

### Significance of these Findings

The A2E concentration dependence seen here demonstrates that the photodamage to RPE cells in this test system was not due simply to the high photon energy of short-wavelength blue-violet light. Rather, this apoptotic cell death represents blue-light phototoxicity specifically mediated by the photosensitizer A2E. This is significant because it provides evidence that the test system can be used as an in vitro model of the suspected mechanism of cell death in AMD.

The key learning from this series of experiments is that blue-light phototoxicity to RPE cells appears to be concentrated in a narrow band of wavelengths centered on 435 nm  $\pm$  20 nm. For the first time, the toxic wavelength range within the blue-violet spectrum has been identified in physiological sunlight conditions using an aging RPE model.

The data further suggests that selectively attenuating the hazardous portion of the blue spectrum (wavelengths from 415 nm to 455 nm) may provide protection for the retina without significantly affecting the igRGCs, whose primary action spectrum lies between 465 nm and 495 nm. This is in contrast to broad filtration of blue light (“blue blocking”), which has the potential to affect the regulation of the pupillary light reflex and other critical physiological functions. The establishment of a narrow phototoxicity spectrum paves the way for developing new ophthalmic filters that deliver *selective* photoprotection.

## PREVENTIVE MEASURES

Given the probable role of blue-light phototoxicity in degenerative retinal diseases, selective photoprotection offers one potential means of helping eyes stay healthy longer. There may be added benefit to this in the world of blue-rich artificial light that is build-

## Crizal® Previncia™ No-Glare Lenses: Truly Selective Eye Protection

Crizal® Previncia™ No-Glare lenses with Light Scan™ represent the first application of new patent-pending technology that enables selective attenuation of harmful light – both UV and blue-violet – while allowing beneficial light to pass through and maintaining exceptional transparency at all other visible-light wavelengths. The goal is to enable patients to enjoy the best vision with significant protection against UV and high-energy blue-violet wavelengths.

Crizal® Previncia™ No-Glare lenses reduce the quantity of harmful blue-violet light (415 nm to 455 nm) reaching the eye by 20%\*. Unlike common yellow-tinted “blue blocking lenses,” Crizal® Previncia™ No-Glare lenses cause minimal color distortion—indeed these lenses are almost perfectly clear.

The efficacy of Crizal® Previncia™ No-Glare lenses has been demonstrated using the same A2E-loaded RPE tissue culture model used to discover the sub-band of blue-violet light that causes RPE apoptosis. When A2E-containing-RPE cells were exposed to white light that mimicked the solar spectrum, placing the new lens between the light source and the cells reduced cell apoptosis by 25% compared to no light filtering at all.<sup>60</sup> Designed to selectively block harmful light and maintain transmittance of visible light essential to color vision as well as critical chronobiological processes, Crizal® Previncia™ No-Glare lenses offer the most selective eye protection on the market today.

Crizal® Previncia™ No-Glare lenses also feature an Eye-Sun Protection Factor (E-SPF®) of 25, which means they provide 25 times more UV protection for the eye than wearing no lens at all. Integrating Essilor’s superior No-Glare technology, Crizal® lenses are easy to clean, resistant to smudges, scratches, dust, and water, and protect against distracting glare and reflections. Maintaining excellent transparency, Crizal® Previncia™ No-Glare lenses offer optimal color vision at all times.

\*Slight differences in attenuation may occur with different lens materials.

ing around us due to the growing popularity of energy-efficient compact fluorescent lamps and LEDs.

Because these new lighting sources are more cost-efficient, energy-efficient, long-lasting, and environmentally friendly than incandescent and halogen bulbs, they are quickly becoming the next-generation light sources. By 2016, traditional incandescent light sources will, by law, no longer be available for domestic lighting in Europe.<sup>3</sup> LEDs are also becoming progressively more popular in backlit mobile phone, tablet, television, and computer displays.

As LEDs and other blue-rich solid state light sources become more important in domestic and workplace lighting, and as people spend more and more time staring at TV, computer, and mobile phone screens, blue light exposure will gradually increase, and its ocular hazards may become more problematic.

## From Science to Solution

Efforts have been made to develop prophylactic and therapeutic methods to protect retinal cells from phototoxic damage. In cataract surgery, yellow intraocular lenses that block both UV and blue light (< 500 nm) have been introduced to reduce retinal phototoxicity in pseudophakic eyes; however, the clinical value of these lenses is debatable, as they block both hazardous wavelengths and those that most effectively activate the ipRGCs.<sup>54,55</sup>

The use of small-molecule compounds is also being investigated as a treatment method to modulate the visual cycle and reduce lipofuscin accumulation in RPE cells.<sup>56,57</sup> The most viable preventive approach, however, may simply be wearing spectacle lenses that are able to stop hazardous blue light from entering the eye.<sup>58,59</sup> Blue-light blocking glasses have existed for years and are recommended for patients with retinal diseases; but current lenses absorb a very large portion of the blue-light spectrum, distorting colors, reducing scotopic vision and possibly interfering with nonvisual ipRGC-controlled functions. Also, the absorptive technology makes the lenses appear yellowish (absorbing blue).

Based on the discovery of the precise spectrum of RPE-toxic blue light, Essilor has developed a new No-Glare lens, Crizal® Previncia™, a unique narrow-range blue light filter that selectively attenuates the hazardous portion of blue-violet light (415 nm to 455 nm) while remaining transparent to other wavelengths of visible light. Designed to reduce exposure to potentially harmful blue light, Crizal® Previncia™ No-Glare lenses also protect eyes from UV light coming through the front or reflecting off the back surfaces of the lenses. This new lens can benefit everyone by reducing exposure to the phototoxic wavelengths of blue-violet light.

## Optometrists and Eye Protection

There is scientific evidence to support the finding that high-energy blue light is harmful to the retina and that reducing exposure to the most toxic wavelengths of this light is likely to be beneficial.

Today, optical dispensing is becoming more doctor-driven, with optometrists no longer hesitant to discuss eyewear and make specific spectacle lens recommendations to patients in the chair. This is fortunate because the exam room is the ideal place to educate patients about the nature of blue light hazard and to explain how spectacle lens wearers can better protect themselves from it. In recommending selective filtering of phototoxic wavelengths, clinicians have an ideal opportunity to perform a truly beneficial function—protecting vision for a lifetime—even if the patient has simply come in for a refraction and new glasses.

This role will become ever more important as LED and compact fluorescent lighting find their way into more homes and workplaces—and as blue rich digital screens come to occupy even more of our days and evenings.

Crizal® Previncia™ No-Glare lenses, which cut the hazardous blue light in the 415 nm to 455 nm band by 20% and provide protection from back-side UV reflection, can be beneficial for patients at all ages. It is important for clinicians prescribing Crizal® Previncia™ No-Glare lenses to gain the support and commitment of their staff members, who can contribute tremendously to communication with patients. Once staff members understand the nature of blue light hazard and its association with ocular health, they can bolster the doctor's recommendation and help patients understand the importance of blue-light protection for the eye.

## CONCLUSIONS AND FUTURE DIRECTIONS

Certain wavelengths in the blue-violet range are now known to be detrimental to the retina, and cumulative blue-light damage is implicated in retinal disorders such as AMD. The most hazardous blue wavelengths for retinal pigment epithelium, as determined by the joint work of Essilor and the Paris Vision Institute, fall in the narrow band between 415 nm and 455 nm. This is relatively distinct from the spectral band that is responsible for critical physiological functions such as the pupillary light reflex and circadian entrainment.

For spectacle lenses to protect the retina, this means that in addition to protecting against UV wavelengths, attenuation of high-energy blue-violet light in the  $435 \pm 20$  nm band is of value. But for normal physiologic functioning, lenses must block this light without reducing transmission in the chronobiological spectral band.

Furthermore, patient acceptance may be limited when lenses are visibly colored and distort color perception, as is the case with most blue absorber lenses. To enhance vision and support color perception, lenses should offer high transmittance of all visible light wavelengths outside the UV and phototoxic blue bands.

Crizal® Previncia™ No-Glare lenses offer selective photofiltering and superior clarity of vision, taking blue blocking lenses and eye protection to the next level.

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## BLUE LIGHT HAZARD

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# BAD BLUE, GOOD BLUE, EYES AND VISION



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\_\_ **THE COLOUR BLUE INSPIRES THE ARTS**, blue vibrates through literature, but we really should be referring to blues: from Aragon's *Blue sun of dreams*, and Balzac's *Life as blue as a pure sky*, there is only a breath, a ray to tip us towards Gorki's *Blue fires of anger* or Bobin's *The blue of disasters seen through the window*. "Bad Blue v. Good Blue", there's the challenge and the focus of this latest issue of *Points de Vue*, which seeks to answer the new questions that have arisen from recent scientific discoveries and clinical observations linking the blue-violet fraction of the visible spectrum – 380 to 500nm – to the eye and vision:

- Is high energy blue harmful to ocular tissue?
- What more do we know today about the physiological roles of blue light?
- What would be the benefits for human health of suppressing some of the blue and what would be the risks of suppressing too much of it?
- Are we exposed more today to harmful blue, and if so, why?

**Significant progress has been made** since the mid-nineties in terms of physiopathological knowledge about the consequences of exposing the eye to various types of blue light.

**Previously, and since the advent of lasers** in the seventies, the scientific community and public authorities controlling radio- and photo-protection performed experiments on animals in order to establish the thermal and photochemical danger thresholds of light, mainly involving UV rays

and the anterior segment of the eye. This research also involved "high energy visible light", the blue-violet light renamed "blue light" for simplification, which is the light that potentially presents a danger of photochemical lesions in the retina. We know in fact that, except during childhood, ocular tissue filters out almost all UV rays and that it is indeed this "blue light" which is today incriminated in certain ocular pathologies.

**In the nineties**, progress made in cellular and molecular photobiology enabled exploration into which bands of visible light were the most harmful for the retina, which toxicity mechanisms were activated, distinguishing acute toxicity from chronic toxicity. This work was stimulated by the increased use of new intra-ocular implants that filter out blue, and also by the need to assess the risks to the retina of exploratory or eye surgery instruments. Acute toxicity is the consequence of exposure to high intensity light over a short period, and results in thermal destruction of the retina's cells and cell death by necrosis. Chronic toxicity is more insidious because photochemical mechanisms of oxidant stress lead to the accumulation of photo-sensitising components and oxidising reactive species (singlet oxygen, hydrogen peroxide, etc.) which, year after year, increase the danger to exposed cells from blue light and contribute to certain chronic ocular pathologies, such as AMD – Age-Related Macular Degeneration – or pigmentary retinopathies.

FIG. 1 | The topography and age relationship of lipofuscin concentration in the retinal pigment epithelium. - Wing G.L., Blanchard G.C., Weiter J.J.. IOVS (1978) 17(7) 601-7.

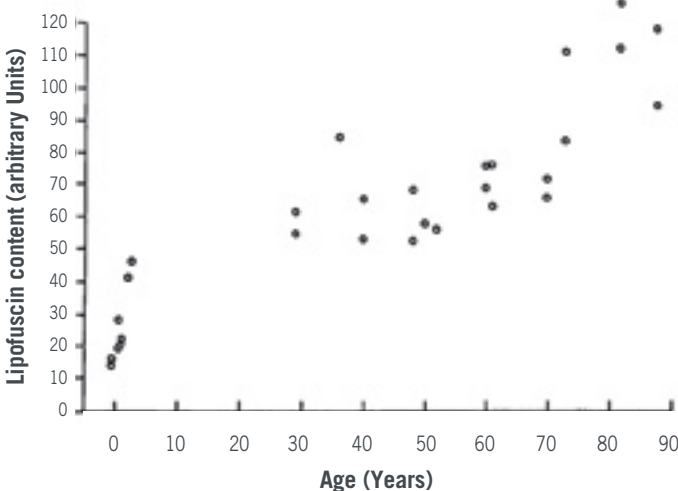
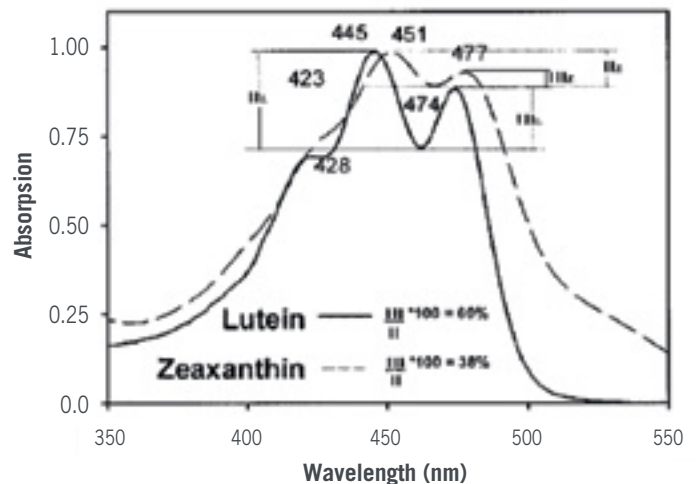


FIG. 2 | Spectra of lutein and zeaxanthin, in ethanol, illustrate the characteristic differences in the absorption properties of the two carotenoids - Landrum JT, Bone RA. Lutein, Zeaxanthin and the Macular Pigment. Arch. Biochem. Biophys. 2001 (385) 28-40.



→ From a clinical point of view, the correlation between exposure to blue light and the prevalence of AMD is difficult to establish. Nevertheless several epidemiological studies, including the “Beaver Dam Eye Study” have concluded that cumulative exposure to the sun increases the risk of AMD, and that it is more due to visible light than to UV rays<sup>[1]</sup>.

In terms of cells, the photoreceptors (cones and rods) and the retinal pigment epithelial cells (RPE), two groups closely linked to cells in the retina, have been identified as being the main cells involved both as contributors and victims to this oxidant stress and this chronic blue light phototoxicity, resulting in cell death by apoptosis (programmed cell death). The RPE is essential to photoreceptors because it supplies them with oxygen and nutrients and, in return, ensures phagocytosis of their external segments for each visual cycle, and the metabolic regeneration of the visual pigment (rhodopsin).

The dangers of blue light to photoreceptors have been demonstrated in animals. C. Remé and C. Grimm showed in 2000<sup>[2]</sup> in rats that blue light, unlike green, causes photoreversal of the whitening of photoreceptors; this rapid regeneration of the rhodopsin caused by high energy blue light leads to degeneration of the photoreceptors by apoptosis. Molecular mechanisms were explored further by M. Rozanowska<sup>[3]</sup> who showed a combined role played by rhodopsin and the 11-cis-retinal and 11-trans-retinal retinoids (“ATR” all-trans-retinal) the accumulation of which contributes to the phototoxicity mechanism on photoreceptors.

The action spectrum of light phototoxicity on RPE cells was studied by J. Sparrow and M. Boulton<sup>[4]</sup> who demonstrated the central role of lipofuscin accumulation in the amplification of photo-oxidation mechanisms, resulting in cell death by apoptosis. Death of the RPE leads, in turn, to the loss of photoreceptors, because they are inter-dependant. The granules of lipofuscin form in large numbers when the phagocytosis of the oxidised segments of photoreceptors is incomplete, which leads to cascades of inflammation and oxidant stress. Made of lipids and proteins, these granules contain a particularly photosensitising molecule, bisretinoid “A2E”, made from two ATR, which has an absorption peak in blue at around 440 nm, which explains the particular toxicity of blue light for the RPE, with a spectrum of action that does not follow the light energy level exactly. The collections of lipofuscin in the RPE increase with age, during childhood and then again after the age of 45 (fig. 1), as well as in pathological conditions such as AMD or pigmentary retinopathy. Moreover, with age, ocular diseases and bad diet, the natural mechanisms of retinal defence against oxidant stress are reduced: reduced “detoxifying” enzymatic activity (catalase, SOD, etc.), reduced fixing of the macular pigment in the centre of the retina, notably of lutein and zeaxanthin, which are absorbed from food, the maximum levels of absorption and protection of which are astonishingly close to the maximum toxic absorption of A2E.

Recently, a team of photobiologists from the Vision Institute in Paris (UPMC, Inserm, CNRS), Dr Serge Picaud and Dr Emilie Arnault, under the direction of Professor José-Alain Sahel, and in collaboration with Essilor, sought to narrow the spectrum of action of blue light phototoxicity on RPE cells, by putting the cells, for the first time, in chronic toxicity illumination physiological conditions, in stages of 10nm, taking account of the spectral ratios of the solar spectrum and of filtering by ocular media. They present their work here, for *Points de Vue*.

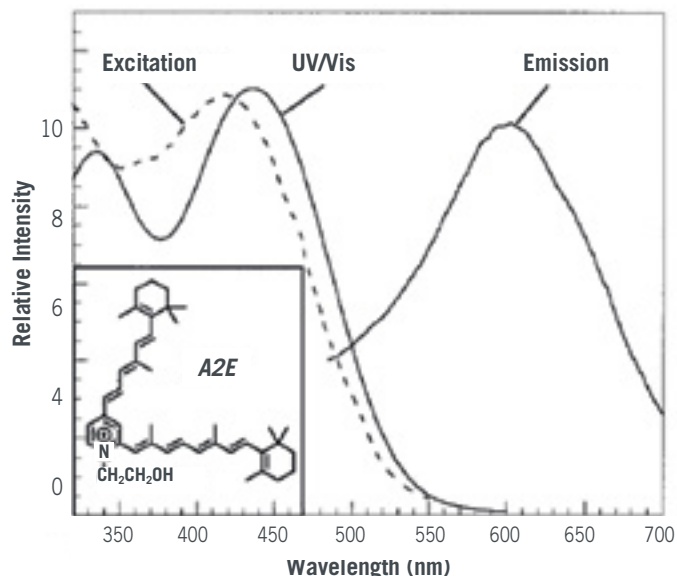


FIG. 3 | UV/Vis, excitation, and emission spectra of A2E in methanol. The absorbance spectrum had a major peak at 435 nm and lesser peak at 335 nm.

The excitation spectrum monitored at 600 nm emission, was similar in shape with a maximum at 418 nm. A 400 nm excitation wavelength generated a yellow emission centered around 602 nm. Inset, structure of A2E. Sparrow JR et al. IOVS 2000 (41) 1981-9

Thus, all the *in vitro* work done confirms the dangers of cumulative exposure to a certain blue light, *Bad Blue*.

But, in 2002, chronobiologists discovered a 3<sup>rd</sup> photoreceptor in the retina, which furthered the clinical knowledge of the eighties in terms of the extent and mechanisms of the eye's non-visual functions, modulated by a blue-turquoise band, *Good Blue*, centred at 480nm (ca. 465-495nm). This photoreceptor projects onto several non-visual areas of the brain, enabling resynchronisation of the so-called circadian physiological functions over the 24 hours of the Earth's rotation: sleep, vigilance, mood and body temperature are just a few examples of these functions, demonstrating the importance of not disturbing this *Good Blue*, if ever we were to seek to cut out all or some of the *Bad Blue*. Doctor Claude Gronfier (Inserm, Lyon) develops, in this issue of *Points de Vue*, the current level of knowledge of blue light and circadian rhythms.

*Bad Blue, Good Blue*, between “chagrin of Azure” (Louis Aragon, *Elsa's Eyes*) and “the magnificent radiation of a heavenly eye” (Victor Hugo, *The Rhine, Letters to a friend*), our eyes, our exposure to the new artificial lighting (see C. Martinsons in this issue), our vision of colours (see F. Viénot in this issue), our predisposition to eye diseases, or quite simply to glare (see B. Girard in this issue), our body, our rhythms, in short our whole physical and psychic life is influenced by light acting on our retinal and cortical sensors and, more specifically, by its proportions of *Good Blue* and *Bad Blue*. •

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# THE GOOD BLUE AND CHRONOBIOLOGY: LIGHT AND NON-VISUAL FUNCTIONS



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## INTRODUCTION

Over the past ten years there has been a wealth of discoveries in the field of chronobiology. Since the discovery of a new retinal photoreceptor in 2002 (melanopsin ganglion cells), shown to be involved in the synchronisation of the circadian clock, it is now clear that the eye is not for seeing only, it is also involved in a range of non-visual functions, directly stimulated by light. The mechanisms involved are mainly yet to be explored but all biological responses to photic stimulus show the way to clinical applications of light in a range of disorders and pathologies, from sleep to alertness, from cognition to memory and mood.

## LIGHT AND THE CIRCADIAN BIOLOGICAL CLOCK

The link between light and the internal biological clock was discovered in humans in 1980. The circadian clock (from the Latin *circa* "close to" and *dies* "day") is a physiological component that is essential to life since it has been observed in almost all the living organisms that have been studied, from prokaryotes through to humans<sup>[4]</sup>.

Two fundamental properties characterise the circadian clock<sup>[4]</sup>:

1. Its **rhythmic activity is endogenous**. Located in the *suprachiasmatic nuclei (SCN)* of the hypothalamus in mammals<sup>[7]</sup>, its circadian electric activity is supported by around ten *clock genes* whose cyclic activity is responsible for the near 24-hour rhythm of each of its neurons<sup>[9]</sup>.
2. Its **activity must be synchronised to 24 hours**. Its endogenous period is actually close to but slightly different from a 24-hour period.

Therefore, the clock has to be synchronised (reset in time) in order to enable its activity to be in phase with the solar day. In mammals, light is the most powerful clock synchroniser, and its effect takes place solely through the eye.

## FUNCTIONS CONTROLLED BY THE CIRCADIAN CLOCK

Lots of physiological functions work according to circadian rhythm. Figure 1 shows circadian control over several functions in humans. The clock acts like an orchestra conductor, enabling the expression of physiological activities at the right time. Alertness, cognitive performance, memory, body temperature and blood pressure are at their highest during day time (awake). On the contrary, secretion of the hormone melatonin, muscle relaxation and sleep pressure are at their highest during the night (sleep).

Many circadian biological activities have been discovered over the past 30 years, both in the periphery and at central level. Depending on the tissue, between 8 and 20% of the genome is expressed rhythmically via the endogenous clock.

The circadian system is involved in the control of cell division, apoptosis in cancer<sup>[10]</sup> and in the repair of DNA<sup>[11]</sup>. Because of this, these results can be used to understand how desynchronisation of the circadian system could be responsible for the increased prevalence of certain cancers in shift work<sup>[12]</sup>.

The importance of the circadian system and its synchronisation therefore appears to be crucial to human health.

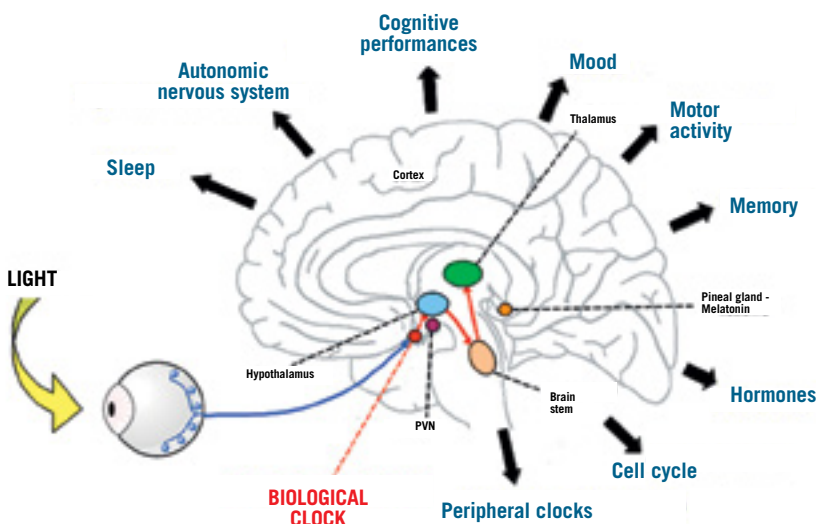


FIG. 1 | Diagram of the biological functions controlled by the circadian biological clock (non exhaustive list).

The structures indicated in colour are respectively in red: the suprachiasmatic nucleus, in orange: the pineal gland, in blue: the hypothalamus (containing the VLPO [ventrolateral preoptic area], known as the *sleep switch*), in beige: the brain stem (containing the ascending activator cortical pathway and the slow wave / paradoxical sleep *sleep switch*), in green: the thalamus (responsible for cortical activation and synchronisation of the EEG). (Modified diagram by Mignot *et al.* Nature 2002<sup>[3]</sup> and Gronfier *et al.* 2012<sup>[6]</sup>).

→ **THE CONSEQUENCES OF CIRCADIAN DESYNCHRONISATION**

In humans the importance of synchronisation is clear in symptoms of “jet lag” or in night work (20% of the population in industrialised countries). A lack of synchronisation of the clock is generally translated by a change in numerous physiological functions (sleep, alertness, cognitive performance, cardio-vascular system, immune systems<sup>[4,13,14]</sup>), the deterioration of neurocognitive processes (cognitive performance, memory) and a disturbance of sleep and alertness<sup>[15]</sup>. These changes are also found, chronically, in night workers, elderly patients, blind people, in certain psychiatric pathologies and in certain degenerative diseases of the central nervous system (Alzheimer’s and Parkinson’s disease<sup>[16]</sup>). Chronobiological disorders associated with these normal or pathological conditions have major socio-economic consequences since they can lead to a fall in the general state of health and to an increase in associated pathological risks. The French Society of Occupational Medicine has just published a report under the aegis of the High Health Authority (*Haute Autorité de Santé*) on the consequences of shift work, including recommendations for detecting them and ways in which to minimise them<sup>[17]</sup>.

**ENDOGENIC PROPERTY OF THE CIRCADIAN CLOCK**

In light conditions that are unsuitable for the synchronisation of the circadian system, the endogenous clock functions according to a rhythm that is no longer that of a 24 hour day. In this case it expresses its own endogenous rhythmicity (period). Just like a mechanical clock that has not been adjusted to time regularly, the circadian clock loses time or runs fast, depending on the individual (according to the length of the period of their own clock) in the absence of any synchronisation by the environment. This phenomenon, known as “free run”, is observed in blind people in whom the absence of any light means that the biological clock cannot synchronise to the 24-hour period<sup>[18]</sup>. This explains why about 75% of blind people complain that their sleep is not of good quality and consult their doctors for recurrent sleep disorders<sup>[19]</sup>. It should be noted that the length of the clock’s period is a highly precise individual characteristic. It does not vary with age in adults<sup>[20]</sup>, but is relatively flexible during childhood and adolescence (lengthening of the period in adolescence could explain in part the late-to-bed factor, or even disorder of the delayed phase type observed in the 15-25 age range<sup>[21]</sup>). Thanks to the use of strictly controlled experimental protocols<sup>[20]</sup>, it has been possible to demonstrate that the length of the clock period in humans is very close to 24 hours (24.2 hours on average<sup>[20]</sup>).

One of the direct impacts of the endogenous period in everyday life is the chronotype. Individuals with a short period (a fast clock) are generally those who go to bed early (morning chronotypes) whereas people who go to bed late (evening chronotypes) have a longer period (a slower clock)<sup>[22]</sup>.

**SYNCHRONISATION OF THE CLOCK**

Because the endogenous period is close to, but not exactly, 24 hours, the circadian clock must be constantly synchronised to 24 hours. In mammals it is light that is the most powerful synchroniser of the internal clock. The term *synchronisation* of the biological clock corresponds, just as with a wrist watch, to setting the time, whether the watch is running fast or slow, in order to get it back into phase with the environment. For an “evening” individual, whose endogenous period is 24 hrs and 30 mins, the clock has to be put forward by 30 minutes every day in order to be synchronised to 24 hours, if not it will be another 30 minutes late every day. On the other hand, in a “morning” person, whose period is 23 hrs and 30 mins, the circadian clock has to be delayed by an average of 30 minutes every day. Animals have different synchronisers, which are less efficient in humans. They are known as “non photic” synchronisers because they do not involve light. Eating and physical exercise have a synchronising effect on the human clock but this is not very strong. Studies carried out in the fifties had led researchers to believe that social synchronisers were more powerful than light in Humans<sup>[23]</sup>. We now know that this is not the case. The best proof that non-photoc synchronisers have, if anything, an extremely limited effect, has been obtained from the observation that the vast majority of blind people – with no perception of light – are in a state of non synchronised “free run”, despite a social life and activities set out according to the 24-hour period (work, going to bed / rising, eating meals, physical and intellectual activities, etc.). The hormone melatonin is the only non-photoc synchroniser for which the effect on the human circadian clock is without a doubt<sup>[24]</sup>. It should be considered as a priority approach in the treatment of “free run” in blind people.

**CIRCADIAN PHOTORECEPTION**

Until recently it was accepted that the cones and rods of the external retina were the only photoreceptors responsible for the transduction of light information to the endogenous clock. Studies carried out since the year 2000 in both humans and animals show that two retinal systems are involved in circadian photoreception (*fig. 2*):

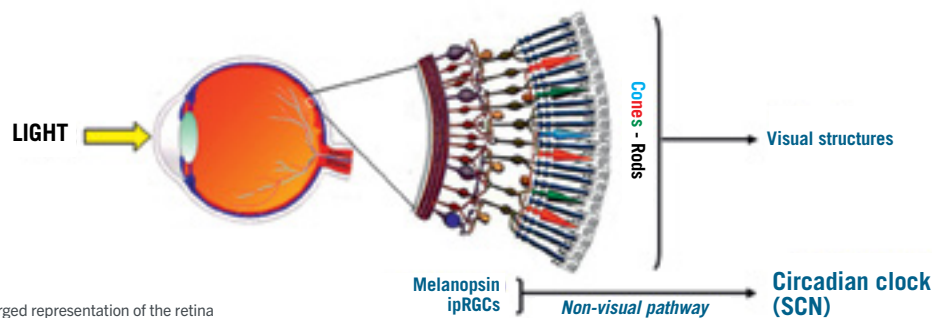


FIG. 2 | Diagram of the eye (section) with an enlarged representation of the retina (in the centre).

Surrounding light is perceived by the retina. The cones and rods project towards visual structures (perceptive vision). Melanopsin ganglion cells are involved in the regulation of biological rhythms via their projection towards the suprachiasmatic nucleus (modified image by webvision and Gronfier *et al.* [11]).

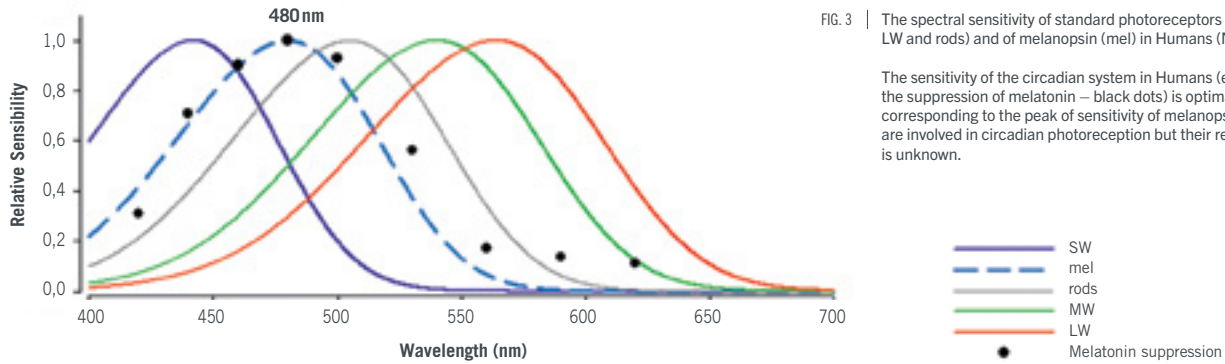


FIG. 3 | The spectral sensitivity of standard photoreceptors (cones SW, MW, LW and rods) and of melanopsin (mel) in Humans (Najjar et al.<sup>[21]</sup>).

The sensitivity of the circadian system in Humans (estimated by the suppression of melatonin – black dots) is optimal at ~480 nm, corresponding to the peak of sensitivity of melanopsin. Cones and rods are involved in circadian photoreception but their relative contribution is unknown.

— SW  
- - - mel  
— rods  
— MW  
— LW  
● Melatonin suppression

1. **The photoreceptors** involved in conscious vision (cones and rods).  
 2. **The intrinsically photosensitive** retinal ganglion cells: (ipRGC) involved in a large number of non-visual functions<sup>[25]</sup>. In the absence of these 2 systems, the circadian system is “blind” in rodents and functions in “free run”, expressing its endogenous rhythmicity<sup>[26]</sup>. It is currently thought that the light information responsible for synchronisation of the biological clock passes through the melanopsin ganglion cells, either by stimulating these cells directly or by stimulating them indirectly through cones and rods. Because of this fact, it is now considered that the eye is not used for vision only, but that it possesses both visual and non-visual functions (*fig. 2 and 4*). The two types of photoreceptors in the external and internal retina are phylogenetically and functionally different. Unlike cones and rods, melanopsin ganglion cells require high illuminances and show a peak of sensitivity at around 480nm (in all the mammals studied). These rhabdomeric type cells also show the property of bistability, which makes them virtually insensitive to *bleaching*<sup>[29]</sup>. These photoreceptors are currently the subject of a great deal of research, aimed at developing methods for treating certain chronobiological disorders (including disorders of the circadian rhythms of sleep and seasonal affective disorders), which could be faster and more efficient than the current methods which use fluorescent white lights<sup>[29]</sup>.

**The circadian system’s response to light depends on photic characteristics.** The effect of light on the clock *depends on the intensity of light and how long it lasts*. The more intense the light stimulus<sup>[30]</sup>, and/or the longer it lasts<sup>[31]</sup>, the greater the effect. For example, nocturnal exposure to light lasting for 6.5 hours leads to a delay of more than 2 hours in the melatonin rhythm when intense white light is used

(10000 lux)<sup>[32]</sup>. A stimulus given at the same time for the same length of exposure, with a light intensity of 100 lux, i.e. 10% of the maximum intensity tested, produces a delay of about 1 hour, i.e. 50% of the maximum observed<sup>[32]</sup>. Recent studies show that the circadian clock is actually particularly sensitive to low light intensities, and that exposure to a LED computer screen (between 40 and 100 lux) for 2 hours partially inhibits melatonin secretion, activates alertness, and delays the biological clock and sleep onset<sup>[33]</sup>.

The effect of the light *depends on its spectrum*. As shown in figure 3, the circadian system is at maximum sensitivity to a coloured light of between 460-480nm<sup>[34]</sup>. A monochromatic blue light (wavelength 480nm) can be as efficient on the circadian system as a fluorescent white light 100 times more intense (comprising 100 times more photons). This property is based on the sensitivity of melanopsin ganglion cells.

Finally, *the effect of light depends on the time at which it is perceived*. The phase response graph shows that the light to which we are exposed in the evening and at the beginning of the night (on average between 5pm and 5am) has the effect of delaying the clock, whereas light received at the end of the night and in the morning (on average between 5am and 5pm) has the reverse effect of advancing the clock<sup>[54]</sup>. It is this specific temporal sensitivity that explains the clock’s daily synchronisation under normal circumstances and its non-synchronisation in the presence of jet-lag and night work.

— LIGHT AND NON-VISUAL FUNCTIONS

Since the discovery of melanopsin ganglion cells in the retina 10 years ago, a range of non-visual, light-sensitive functions have been described. These functions involve anatomical pathways and cerebral structures →

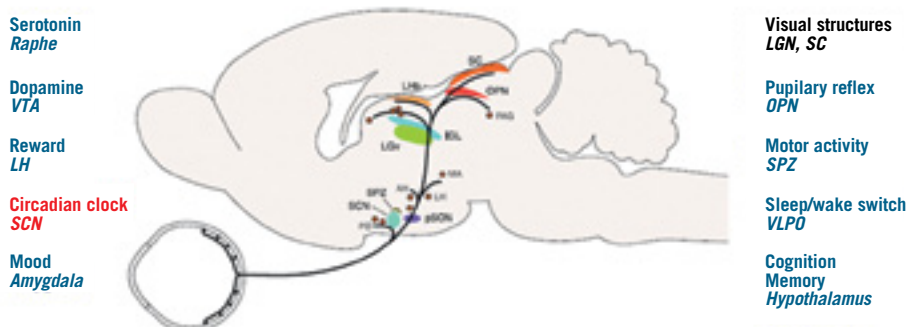


FIG. 4 | The retinal melanopsin ganglion cells project towards a range of structures involved in the regulation of the circadian system (SCN), pupil reflex (OPN), motor activity (vSPZ, IGL), sleep (VLPO) and alertness (LC). These projection pathways are the non-visual pathways of light. Modified diagram by <sup>[5,8]</sup>.

→ that are different to those involved in vision, and do not lead to the formation of images (fig. 4). Studies in animals<sup>[35]</sup> show projections of melanopsin ganglion cells towards structures involved in the regulation of biological rhythms, the regulation of alertness and sleep states, the regulation of locomotor activity, the pupil reflex, etc. In humans, studies show that melanopsin ganglion cells, via non-visual pathways, are involved in the effect of light on the resetting of melatonin phase<sup>[36]</sup>, the increase in alertness, body temperature and heart rate<sup>[37]</sup>, expression of the PER2 gene<sup>[38]</sup>, resetting of the rhythm of the PER3 gene<sup>[39]</sup>, the increase in psychomotor performances and EEG activity<sup>[40]</sup>, sleep structure<sup>[41]</sup>, and activation of cerebral structures involved in memory and mood regulation<sup>[42-51]</sup>. Light, via non-visual retinal projections, will therefore directly stimulate the cerebral structures involved in the control of alertness, sleep, mood and cognitive and psychomotor performances.

Before the identification of two anatomical pathways (visual and non-visual), it has been known since 1995 that some blind people who do not have any conscious visual perception can have a light-sensitive circadian system<sup>[52]</sup>. The visual system of these patients is blind, but their non-visual functions (including their circadian clock) are not blind and receive photic information. These cases are probably rare (very few individuals have been studied worldwide) and the majority of patients with ocular pathologies leading to partial or total privation of photic information have an increased prevalence of sleep and biological rhythm disorders (their circadian rhythms are most often expressed through "free run" and this clinical condition is associated with sleep disorders in over 75% of cases<sup>[19]</sup>). Nevertheless,

ophthalmologists should be aware of the eye's non-visual function and its importance in the synchronisation of the circadian system. In view of the risk of adding a blind circadian system (and the free-run symptoms with their associated treatments) to a defective vision, the non-visual sensitivity to light should be evaluated prior to enucleation of a blind patient.

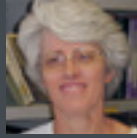
## CONCLUSIONS

In view of the importance of the circadian system synchronisation and the nature of the non-visual functions, light appears to be a biological requirement essential to health. It is predictable that light will be used in the future in the treatment of numerous normal or pathological conditions, in which a physiological malfunction will be corrected through activation of the eye's non-visual functions. •

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# PERCEPTION OF BLUE AND SPECTRAL FILTERING



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## INTRODUCTION

The sky is blue. Physicians give us an explanation for this: it is due to the preponderance of short wavelengths in the light diffused by the atmosphere. But why do we see it blue? Seeing the world in colour and identifying its characteristics requires processing of the image formed by the distribution of photons on the retina.

## 1. HOW IS THE COLOUR SENSE CREATED?

First we need to remember the various stages involved in how colour vision works. The photons reaching the retina are absorbed by photoreceptors: cones for daytime vision and rods for vision when the light is dim, and very often both cones and rods if light is slightly reduced. The photoreceptors generate a signal when they capture a photon, whatever the wavelength involved. Due to very extensive spectral sensitivity in the field of wavelengths, almost all the photoreceptors are able to absorb short wavelength photons. It is only the rate of absorption that differentiates them. So, "S" cones (improperly named "blue") are preferentially sensitive to short wavelengths of around 450nm, "M" cones ("green"), to medium wavelengths

of around 540nm, "L" cones ("red"), to around 570nm, and rods to around 507nm. However, the probability exists that, for example, a 450nm photon hitting the retina is absorbed by a photoreceptor other than an "S" cone.

Immediately on exit, the photoreceptors signals are recombined, and it is mainly contrast signals, of luminous or spectral origin, that enter the numerous visual paths in the retina. As for the retinal signals that head for the cortex, they are subject again to several recombinations, of variable importance, before resulting in the colour sense. In general, in these recombinations, signals from all the cone groups come into play, with variable importance. Colour is therefore an appearance attribute, constructed by our visual system. It is the tone that essentially characterises the colour of materials, and its definition is exceptionally stable within our natural environment. This phenomenon of relative stability is known as colour constancy.

**With regard to the effect of spectral filtering,** we note that: In practice, every group of photoreceptors can be stimulated at short wavelengths. An imbalance in the signals generated in cones can lead to a change in the contrasts perceived and a disturbance in colour perception which is not radical, however, as long as the three cone groups remain intact.

## 2. SPECIFIC CHARACTERISTICS OF BLUE VISION

In colour vision, blue, or more exactly the retinal pathway of signals issuing from the "S" cones, has a particular status. These signals contribute only slightly to luminous contrast at high spatial or temporal

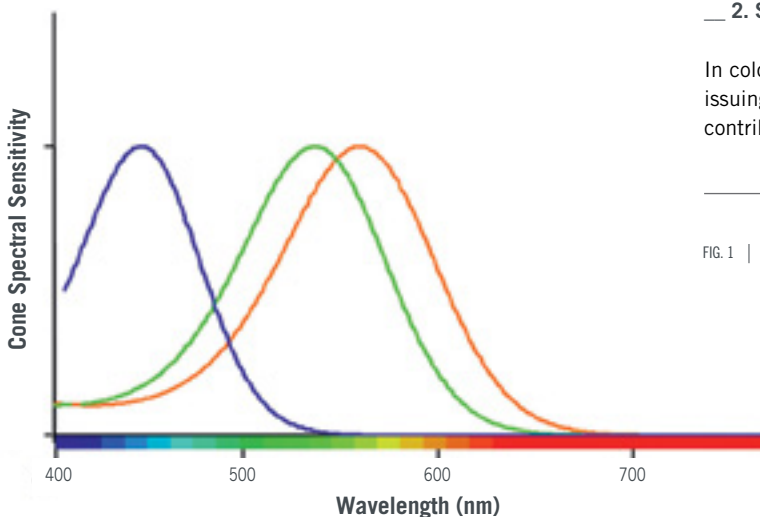


FIG. 1 | Spectral sensitivity of the three groups of retinal cones.

→ frequencies. Because of this fact, neither acuity nor sensitivity to flicker is based on these signals. We even speak of foveal tritanopia or small field tritanopia to indicate the reduction of colour vision due to the inability of “S” cones to process certain colour contrasts. On the other hand, “S” cone signals contribute massively to the distinction of colours and play an essential role in identifying shades of colours. For example the difference between yellow or white, or the distinction between warm white or cold white lights, is based on the response of “S” cones.

**In summary, in terms of spectral filtering:**

A strong reduction in signals from “S” cones should not affect acuity, but could lead to deterioration in the distinction of shades of colour and change colour sense.

But as long as a few “S” cone signals, even weak signals, pass through into the networks of retinal neurons, modifications to colour often go unnoticed.

**3. WHAT WOULD BE THE IMPACT OF A BREAK IN VISIBLE SHORT WAVELENGTHS?**

As long as the three groups of cones can maintain activity, colour vision, which is based on contrasts, is possible. So, everything depends on the position of the break in the visible spectrum.

A break at around 450nm, which leaves a gap at the entrance in “S” cones of almost 50% of the available photons, will have only a low impact on colour vision. Moreover, this is what happens naturally with ageing and cataract. The sky remains blue through until advanced old age. The effect of perceptive constancy, and in this case of “colour constancy”, stabilises the colours of materials in the environment, each in relation to the others, whatever the light variations.

If the break happens at around 500nm, a marked deterioration in the distinction of shades of colour is foreseeable in blue-green and purples, as well as for certain colour pairs such as yellow and white or dark blue and black. Acuity should be preserved. On the other hand, in night vision, the subject may suffer from a notable lack of light.

**CONCLUSION**

Any kind of spectral filtering leads to perception deficiency. Although colour distinction is always weakened, higher functions, that is to say the appearance and recognition of colours, are actually well preserved. In terms of colour, the visual response adjusts to the environment. As long as the light is polychromatic, the physiological adaptation capacities of humans compensate for a deficiency of light at source. •



FIG. 2 | Illustration of the difficulty in perceiving certain colour details that are based on a variation in the signal from “S” or “blue” cones. Whereas the surface occupied by the letters in the words “Points de Vue” is less than the surface area of the rectangle, the latter stands out more.

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# LIGHT EMITTING DIODES (LEDS) AND THE BLUE LIGHT RISK



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\_\_ THIS ARTICLE PRESENTS AN OVERVIEW OF THE KNOWLEDGE regarding the potential toxicity of light emitted by LEDs on the retina. Due to their high brightness and their emission spectrum containing a significant fraction of blue light, the so-called “blue light hazard” has been considered and studied for several years. Several independent studies carried out by health agencies have shown that the risk posed by LEDs used as general lighting sources is low, but cannot be neglected in the case of some sensitive populations, considering the increasing optical performances of LEDs and their fast mass market distribution.

**Traditional lighting sources** such as the well-known incandescent lamp and the compact fluorescent lamp are rapidly being replaced by products based on light emitting diodes (LED) (*fig. 1*). The so-called “solid-state lighting” (SSL) presents many advantages such as longer lifetime, reduced energy consumption and lower environmental impact. Many governments have therefore started to progressively ban older lighting technologies, paving the way for the massive usage of LEDs in the general lighting market. As a matter of fact, leaders of the lighting industry believe that over 90% of all lighting sources in the

world will be based on SSL products and LEDs by 2020. As any new and emerging technologies, SSL products should be proven to be at least as safe as the products they intend to replace. Furthermore, some unique properties of LEDs such as their compactness have generated many new lighting applications for which older technologies could not be employed. For instance, some kinds of toys and clothes now incorporate LEDs. The safety of products using LEDs should be assessed considering the interactions with the human body in existing and new ways of using them.

**The potential adverse effects** of optical radiation on the skin and on the eyes are known as photobiological hazards. LEDs currently used in lighting applications have the advantage of emitting a negligible amount of ultraviolet (UV) and infrared (IR) radiation<sup>1</sup>. The only photobiological hazards to consider when assessing the safety of LEDs are linked to visible light, and more particularly the blue part of the spectrum.

**Several health agencies such as ANSES<sup>2</sup> and SCENIHR<sup>3</sup>** have investigated and reviewed the scientific literature on photobiological hazards related to the use of LEDs. Two key features of LEDs have drawn the attention of experts:

- LEDs are very bright small sources of visible light, which can be glaring. Due to their high brightness, LEDs also have very high radiance →

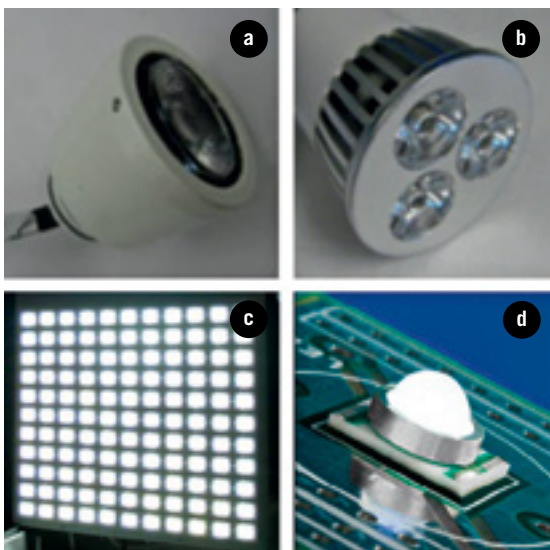


FIG. 1 | Photographs of several types of solid-state lighting products.

- a: Directional luminaire (spot light) using an LED.
- b: SSL lamp based on three LEDs and used to replace an incandescent lamp.
- c: Outdoor high power SSL luminaire using 121 LED modules.
- d: Typical single LED component, used in many SSL products. This type of LED consumes about 1 W of electricity and generates a luminous flux of about 100 lm. Its luminance can be as high as  $10^7$  cd/m<sup>2</sup>.

<sup>1</sup> As they emit negligible amounts of UV and IR, LEDs should not be expected to contribute to the onset of photokeratitis and cataract.

<sup>2</sup> Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (French National Agency for Food, Environmental and Work Safety).

<sup>3</sup> Scientific Committee on Emerging and Newly Identified Health Risks.

→ (a photometric quantity expressing the “concentration” of light), which in turn produces a high illuminance level upon the retina.

- The vast majority of white LEDs producing white light rely on a chip emitting blue light associated with layers of fluorescent materials (luminophores) to produce longer wavelengths. As a consequence, the emission spectrum of a white LED consists in a narrow primary blue peak and a large secondary peak in the yellow-orange-red part of the spectrum. The two peaks are separated by a region of very low emission in the blue-green part of the spectrum (*fig. 2*).

**\_\_ RISKS RELATED TO BLUE LIGHT**

Visible light on the retina can cause thermal damage and photochemical damage. The exposure levels needed to result in thermal damage on the retina cannot be met with light emitted by LEDs of current technologies. The photochemical risk is associated with blue light retinal illuminance. Due to the high brightness of LEDs, the retinal illuminance levels are potentially high and must be carefully considered. In general, the photochemical damage of the retina depends on the accumulated dose to which the person has been exposed, which can be the result of a high intensity short exposure but can also appear after low intensity exposures repeated over long periods. Blue light is recognised as being harmful to the retina, as a result of cellular oxidative stress.

Blue light is also suspected to be a risk factor in age-related macular degeneration (ARMD).

Retinal blue light exposure can be estimated using the ICNIRP<sup>4</sup> guidelines. A quantity called the blue-light weighted radiance  $L_B$  can be estimated as a function of the viewing distance and the exposure time. Maximum permissible exposure values (MPEs) were set by ICNIRP to provide limits for  $L_B$  as a function of exposure time.

For the past three years, blue light exposure data about LEDs have been provided by LED manufacturers and professional lighting associations but also by independent laboratories and governmental agencies.

It was found that the retinal blue light exposure levels  $L_B$  produced at a distance of 200mm from the user by blue and cold-white LEDs (bare LEDs and LEDs equipped with a focusing lens) exceed the MPE limits set by ICNIRP after an exposure time comprised between a few seconds for high power blue LEDs to a few tens of seconds for high power cold-white LEDs. As a consequence, the potential toxicity of some LED components viewed at short distances cannot be neglected. However, when the viewing distance is increased to one metre, the maximum permissible exposure time rapidly increases to a few thousands of seconds, up to a few tens of thousands of seconds. These very long exposure times provide a reasonable safety margin to assert that there is virtually no possible blue light retinal damage caused by LEDs at longer viewing distances (statement valid for state of the art LEDs at the time of writing).

Several classes of products and applications based on bare LEDs or LEDs covered by a focusing lens (collimator) are directly related to a potentially high level of retinal blue light exposure when short viewing distances are possible. Examples are (but are not limited to):

- Tests and adjustments of high power blue and cold white LEDs by operators in lighting manufacturing facilities or by lighting installers
- Toys using LEDs, given that the higher degree of transparency of the crystalline lens of children makes them more susceptible to higher blue light retinal exposures
- Automotive LED daytime running lights when activated near children and other sensitive subjects
- Some types of directional LED lamps sold for home applications. These lamps can be viewed from distances as short as 200mm

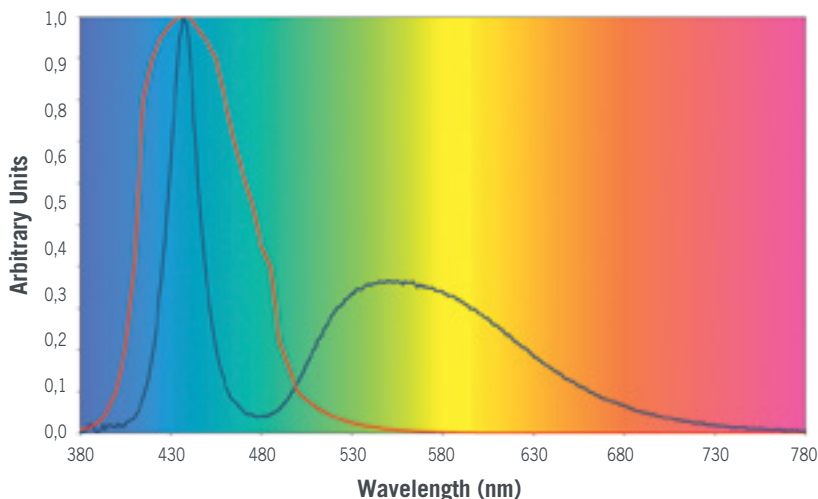


FIG. 2 | The blue curve represents the typical emission spectrum of a white LED. The blue peak reaches its maximum value at about 435nm.

It corresponds to the primary light generated by the LED semiconducting structure itself (the LED die). The secondary peak reaches a maximum value at 550nm (yellow colour) and is the secondary light emitted by luminophores excited by the blue light (fluorescence). The combination of the direct blue light and the yellow/red secondary light produces white color.

The red curve is a plot of the blue light retinal phototoxicity function. It reaches a maximum value at wavelengths corresponding to the blue light peak emitted by LEDs.

<sup>4</sup>International Commission for Non-Ionising Radiation Protection.

The conclusions drawn for single LED components or LED modules cannot be extended to all SSL applications because the photobiological safety of a final SSL product must be assessed independently of its LED components. As a matter of fact, the  $L_B$  value of an SSL product is generally very different from the  $L_B$  value of the LED components that it uses. For instance, a higher  $L_B$  can be obtained with a lamp using an assembly of low  $L_B$  LEDs. Conversely, a lower  $L_B$  can be obtained with a lamp using a diffuser in front of a high  $L_B$  LED. For all LEDs and products using LEDs, a photobiological blue light risk assessment must be carried out to determine whether or not the MPEs can be exceeded in the conditions of usage. Such risk assessments can be performed by test laboratories specialised in light sources photometry such as CSTB<sup>5</sup> and LNE<sup>6</sup> in France.

The main tool used to perform photobiological risk assessment is the CIE<sup>7</sup> S009 publication whose content was included in an international standard (IEC 62471) and other national standards (IESNA RP27, JIS C8159, etc.).

### \_\_ THE PHOTOBIOLOGICAL SAFETY STANDARD IEC 62471

This standard deals with the photobiological safety of lamps and devices using lamps and includes a classification of the light source in several risk groups. The standard considers all of the photobiological hazards that may affect the skin and the eye (thermal and photochemical hazards) from ultraviolet to infrared wavelengths. Four risk groups are defined: Risk Group 0 (RG0, no risk), Risk Group 1 (RG1, low risk), Risk Group 2 (RG2, moderate risk), Risk Group 3 (RG3, high risk). The risk group depends on the maximum permissible exposure time (MPE time) assessed at a given viewing distance.

### \_\_ RISK ASSESSMENTS METHODOLOGY

IEC 62471 defines two different criteria to determine the viewing distance. Light sources used in general lighting should be assessed at a distance corresponding to an illuminance of 500 lx. Other types of light sources should be assessed at a fixed distance of 200mm. For LED components, there is no ambiguity in the distance since LED components are not used per se in general lighting. In this case, IEC 62471 requires using the distance of 200mm. The application of the IEC 62471 measurement technique at 200mm leads to RG2 classification (moderate risk) for some high power blue and cold white LEDs.

However, the choice of the viewing distance in IEC 62471 is sometimes ambiguous and not realistic in the context of the real usage conditions. For instance, in the case of stage lighting (theatres, concert halls) where artists are exposed to an illuminance level higher than 500 lx. Applying the 500 lx criterion would underestimate the exposure while the 200mm criterion would largely overestimate it. In a more usual situation, directional household lamps fall under the 500 lx criterion, which corresponds to a typical viewing distance of a few metres. It is however quite common to have shorter viewing distances, as short as 200 or 500mm at home. Another example is street lighting where the illuminance level is much lower than 500 lx, typically a few tens of lx. Assessing the exposure to blue light emitted by a street lighting luminaire at the distance giving an illuminance of 500 lx is clearly not appropriate. A future revision of IEC 62471 should bring a more accurate definition of the distance at which the risk group is determined.

It is interesting to note that the strict application of CIE S009 and IEC 62471 to indoor LED lamps and luminaires lead to RG0 and RG1 classifications, similar to traditional indoor light sources (fluorescent lamps, incandescent and halogen lamps). Nevertheless, when the 200mm viewing distance is chosen, several measurement campaigns reveal that a small number of indoor LED lamps and luminaires belonged to RG2 while traditional indoor light sources (fluorescent and incandescent) were still in RG0 or RG1. This result shows that LED technology potentially raises the blue light risk in home applications where the viewing distance is not limited and light sources are accessible to children and other sensitive people. At the time of publication, the general public remains unaware of potential risks to the eye since no mandatory labeling system is currently in place for consumer SSL products.

The notion of a safety distance would actually be more appropriate to communicate to installers and to users, especially the general public. The safety distance of an SSL product would be the minimum distance for which the blue light hazard risk group does not exceed RG1. Measurement campaigns carried out by several laboratories showed that the vast majority of indoor LED lamps and luminaires have a safety distance of 200mm which is compatible with most lighting applications.

It is important to note that other widely used lighting sources, particularly high intensity discharge lamps used for outdoor lighting are in RG2 (moderate risk). However, these lamps are intended for clearly identified uses and can only be installed by professionals who should be aware of the safety distance required to limit the exposure.

### \_\_ OTHER LIMITATIONS OF IEC 62471 AND CIE S009 AND SENSITIVE POPULATIONS

The maximum exposure limits defined by the ICNIRP and used to define the Risk Groups in both IEC 62471 and CIE S009 are not appropriate for repeated exposures to blue light as they were calculated for a maximum exposure in one 8-hour day. They do not take into account the possibility of exposure over an entire lifetime. Neither CIE S009 nor IEC 62471 takes into account the sensitivity of certain specific population groups, which can be characterised by an accrued sensitivity to visible light:

- People having pre-existing eye or skin conditions for which artificial lighting can trigger or aggravate pathological symptoms
  - Aphakic (people with no crystalline lens) and pseudophakic people (with artificial crystalline lenses) who consequently either cannot or can only insufficiently filter short wavelengths (particularly blue light)
  - Children
  - Elderly people as their eyes are more sensitive to optical radiation
- The photobiological standards for lighting systems should be extended to cover children and aphakic or pseudophakic individuals, taking into account the corresponding phototoxicity curve published by the ICNIRP in its guidelines.

In addition to proven photochemical damage of the retina resulting from acute exposure to blue light, uncertainty still remains surrounding the effects of chronic exposure at low doses. These effects are still being investigated by ophthalmologists, biologists and optical scientists.

In France, the RETINALED project<sup>8</sup> is investigating the effects of chronic low exposure of rodents to light emitted by LEDs.

<sup>5</sup> Centre Scientifique et Technique du Bâtiment (French Technical and Scientific Research Center on Construction and Building).

<sup>6</sup> Laboratoire National de Métrologie et d'Essais (National Testing and Metrology Laboratory).

<sup>7</sup> Commission Internationale de l'Éclairage (International Commission on Illumination).

<sup>8</sup> The RETINALED project is carried out by INSERM, CSTB and ENVA. It is supported by ADEME (French Environmental and Energy Management Agency).

→ **Certain categories of workers** are exposed to high doses of artificial light (long exposure times and/or high retinal illuminances) during their daily activities (examples: lighting professionals, stage artists, etc.). Since the damage mechanisms are not fully understood yet, exposed workers should use appropriate individual means of protection as a precautionary measure (glasses filtering out blue light for instance).

## CONCLUSIONS

Due to their unique light emission properties, LEDs are currently on the verge of becoming the dominant lighting source of this century. However, the risks posed by these new sources of light are also rooted in their intrinsic characteristics: high optical output in a small package (producing a high radiance level) associated with a significant blue light emission. The combination of these two factors can potentially increase the risk of photochemical damage of the retina, in comparison with the incandescent lamp and the fluorescent lamp.

**Lighting industry leaders** are well aware of the photobiological safety of their products. Many lighting products using LEDs now emit warmer shades of white light (reduction of the blue light content in the spectrum) or use diffusers to reduce glare (reduction of the radiance). Most lighting products are found to present low risks or no risk at all for the general population when the viewing distance is equal to or greater than 200mm.

**However**, measurement campaigns carried out by independent agencies pointed out a few lighting products with significantly higher risk levels below a distance of one metre or more. At the present time, no mention is made by lighting manufacturers of a "safety distance". It is therefore impossible for the public to identify lamps or luminaires with a higher risk level.

**The blue light risk** assessment related to LEDs can be performed by test laboratories using the IEC 62471 standard which is not perfectly clear about the viewing distance to consider. In addition,

this standard does not consider sensitive populations such as children, aphakic, pseudophakic and elderly people, despite the fact that these populations are exposed to a higher level of blue light on the retina. The current knowledge of the mechanisms of blue light phototoxicity is far from being complete. The effects of chronic exposure and accumulated low exposure over very long periods of time are still an active subject of research. As far as LEDs are concerned, the better comprehension of the possible long term effects of the blue light on the retina is fundamental to guaranteeing that the "LED revolution" will not compromise our vision of the future. •

## BIOGRAPHY

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*From 2000 to 2007, he worked in the field of home automation for the HAGER Group. In 2007, he joined CSTB to head the Lighting, Electricity and Electromagnetism division.*

*He currently conducts research and consultancy work in the field of combined daylighting and artificial lighting in order to promote energy-efficiency in buildings while providing the best visual comfort conditions for users. His approach to lighting is put forward in the new French building energy code (RT 2012).*

*For the past four years, Christophe Martinsons has been leading laboratory measurement campaigns for French governmental agencies while working on independent studies concerning health and environmental aspects of solid-state lighting and LEDs.*

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INTERNATIONAL  
REVIEW  
OF OPHTHALMIC  
OPTICS

# Hazards of Solar Blue Light



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## INTRODUCTION

A retinal condition known as photoretinopathy occurs in people who have stared fixedly at the sun without adequate protection, usually for more than a few minutes (see references [\[1\]](#)).

Photoretinopathy is photochemical damage caused by visible light, especially in the wavelength region of approximately 400–500 nm (*Fig. 1*). Light in this wavelength region appears blue to the eye and therefore is called blue light.

According to the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [\[2\]](#) and the American Conference of Governmental Industrial Hygienists (ACGIH) [\[3\]](#), the hazard of blue light is generally measured by blue-light radiance. Blue-light radiance is obtained by weighting the spectral radiance of a light source against the blue-light hazard function (*fig.1*) and integrating this in the wavelength range of 305–700 nm. The maximum permissible exposure duration per day is calculated by dividing  $106 \text{ Jm}^{-2}\text{sr}^{-1}$  by the blue-light radiance. Thus, solar blue-light radiance should be known as a first step toward preventing sun-induced photoretinopathy.

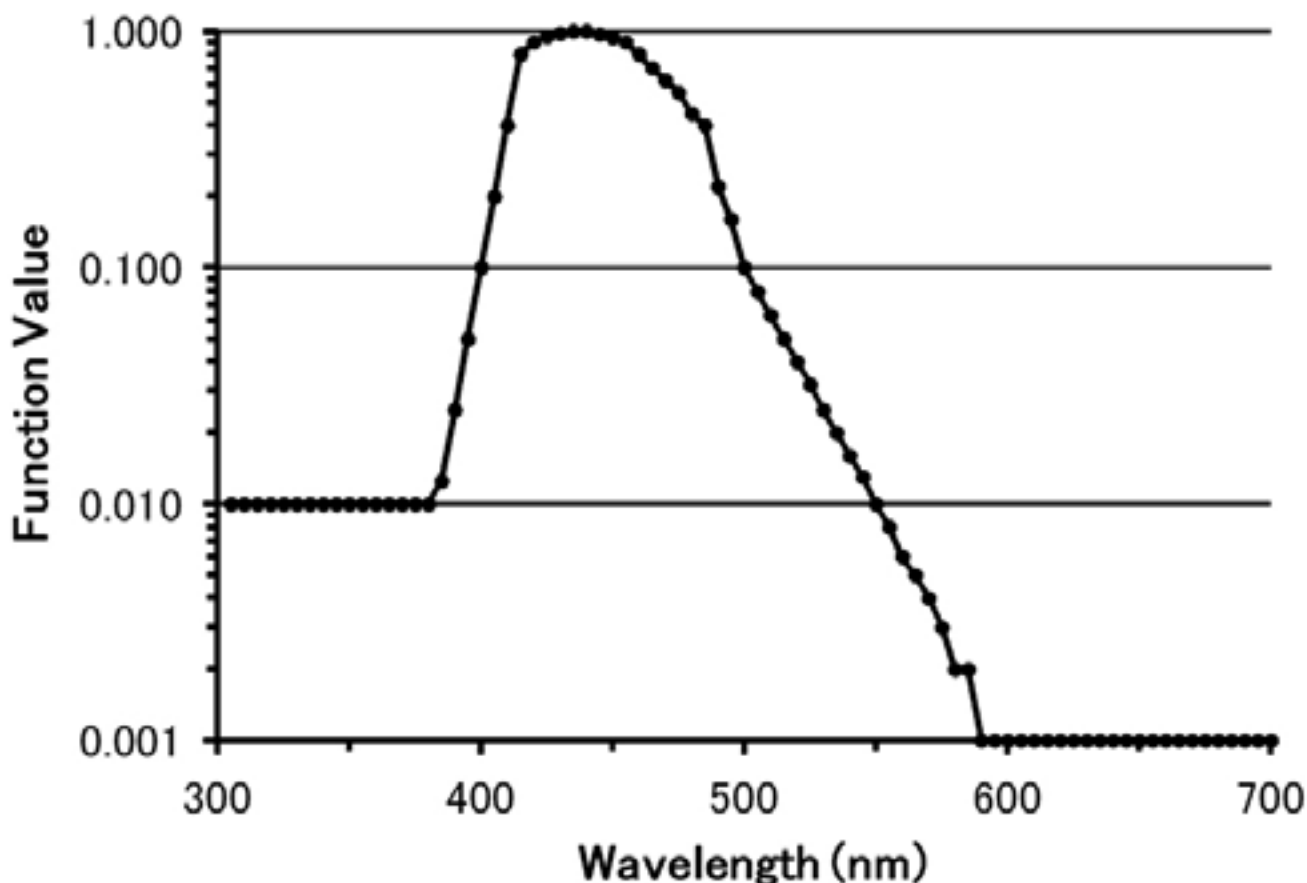


Fig. 1: Blue-light hazard function [2, 3]. The blue-light hazard function shows the relative effectiveness of optical radiation to produce photochemical retinal damage as a function of wavelength.

The intensity of sunlight observed on the earth's surface generally increases with solar elevation. As solar elevation increases, sunlight travels a shorter distance through the atmosphere to reach the earth's surface and therefore is less attenuated by atmospheric scattering and absorption. The intensity of sunlight is also expected to be influenced by temporary local atmospheric conditions such as clouds and dust. Thus, these factors should also influence solar blue-light radiance. In this study, solar blue-light radiance was determined for solar elevations up to almost 90° in summer in Ishigaki, Japan (latitude 24°20'N). The effect of solar elevation was studied using a mathematical model of atmospheric extinction.

## METHODS

Measurements were made on 10 consecutive days from 21 June (the summer solstice) to 30 June 2006 in Ishigaki from sunrise to sunset at 15-min intervals, except when the sun was completely invisible because of clouds. Since Ishigaki is a small remote rural island, urban atmospheric pollution is expected to be very low.

Spectral radiance in the wavelength range of 380–780 nm at 2-nm intervals was measured at the center of the solar disk with a measuring field of 0.125° (0.0022 rad) diameter by a spectroradiometer (PR-705, Photo Research Inc., 9731 Topanga Canyon Place Chatsworth, CA 91311-4135, USA). Two neutral density filters of about 1 % transmittance (ND-100, Photo Research Inc.) were attached to the aperture of the instrument, because solar radiance was too high to measure directly. Corrections for the spectral transmittance of the filters were made automatically by the instrument. The spectroradiometer was calibrated by the manufacturer prior to the

measurements. With the use of PC software (MyPlanet, Japan, Mitsunori Asami), the solar elevation was calculated from the geographic coordinates (longitude and latitude) of the measurement site and the date and time of each measurement.

The blue-light radiance at the center of the solar disk was obtained by weighting the measured spectral radiance against the blue-light hazard function and integrating it with respect to wavelength. In this case, the integration was started at 380 nm instead of 305 nm. This modification is acceptable, because the blue-light hazard function is very small in the wavelength range of 305–380 nm (Fig. 1) and therefore radiant energy in this range is expected to contribute little to blue-light radiance for white-light sources. For example, a simple calculation shows that the contribution of this wavelength range is only 1 % for light sources with a flat spectral distribution.

Data were corrected for the limb darkening of the sun. The central blue-light radiance obtained was multiplied by the ratio of the mean to central radiance at 450 nm of 0.755 [4] to obtain the blue-light radiance of the sun (i.e., the mean of the solar disk).

The blue-light radiance was then multiplied by (0.0093/0.011)<sup>2</sup>, because the sun subtends an angle of 0.0093 rad, which is less than 0.011 rad [2,3].

According to the ICNIRP [2] and ACGIH [3] guidelines, the maximum permissible exposure duration per day in seconds is obtained by dividing 106 Jm<sup>-2</sup>sr<sup>-1</sup> by the measured blue-light radiance in Wm<sup>-2</sup>sr<sup>-1</sup>.

The combined data on blue-light radiance versus solar elevation for all 10 days were compared with the prediction of a model of atmospheric extinction. Assuming that the optical density of the atmosphere that sunlight traverses to reach the earth’s surface is proportional to the amount of that atmosphere (air mass), the solar blue-light radiance observed on the earth’s surface depends on the solar elevation, as follows:

$$L(\gamma) = L_0 \exp(-kM(\gamma)), \quad (1) \text{ where :}$$

$\gamma$  = solar elevation;

$L(\gamma)$  = solar blue-light radiance observed on the earth's surface;

$L_0$  = solar blue-light radiance observed outside the atmosphere;

$M(\gamma)$  = air mass, which is normalized to 1 at 90°;

and  $k$  = extinction coefficient per unit air mass.

The air mass is approximated as follows [5]:

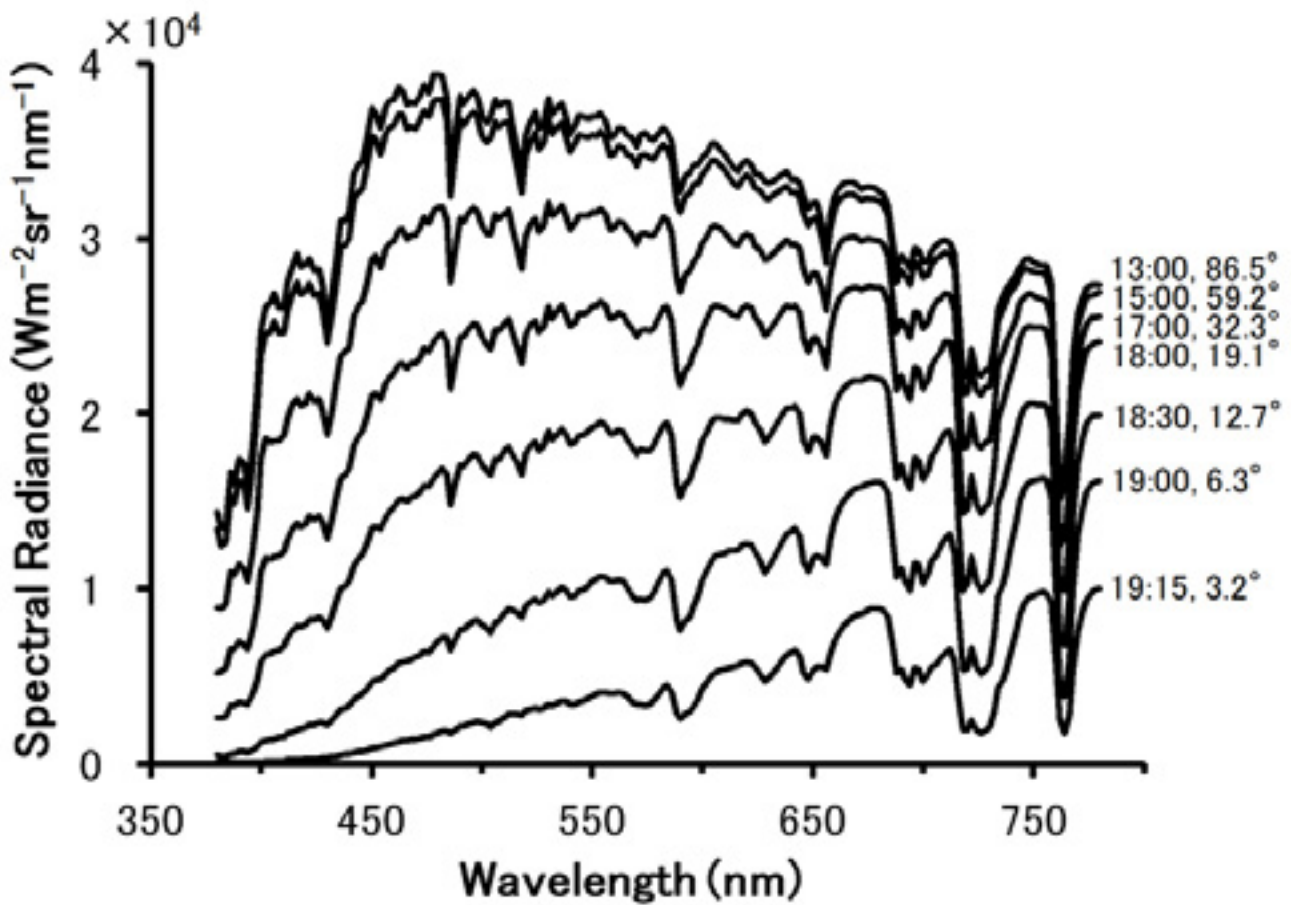
$$M(\gamma) = \frac{1.002432 \cos^2(90^\circ - \gamma) + 0.148386 \cos(90^\circ - \gamma) + 0.0096467}{\cos^3(90^\circ - \gamma) + 0.149864 \cos^2(90^\circ - \gamma) + 0.0102963 \cos(90^\circ - \gamma) + 0.000303978} \quad (2)$$

The data were least-squares fitted to eqn (1) with  $L_0$  and  $k$  as parameters under the constraint that the solar blue-light radiance measured is lower than that predicted by the model. This constraint was imposed because the solar blue-light radiance may actually be reduced by temporary local atmospheric conditions such as clouds and dust. Fitting was performed using the solver add-in in spreadsheets software (Microsoft Excel).

## RESULTS AND DISCUSSION

A total of 461 measurements were made of the solar spectral radiance on 10 consecutive days.

Although the overall intensity of sunlight varies greatly from measurement to measurement, the spectral features remain basically unchanged (*fig.2*).



*Fig. 2: Solar spectral radiance measured on 23 June 2006. The time and solar elevation at which the measurement was taken are indicated for each line.*

The solar blue-light radiance and the maximum permissible exposure duration per day were calculated for each measurement of the solar spectral radiance, according to the ICNIRP [2] and ACGIH [3] guidelines. The solar blue-light radiance generally increases from sunrise to about noon and then decreases toward sunset, but it varies when the sun goes behind a cloud, as shown by the sharp valleys in *fig.3*. The solar blue-light radiance also fluctuates to some extent, even when no clouds are seen in front of the sun, probably due to invisible moisture or dust in the atmosphere.



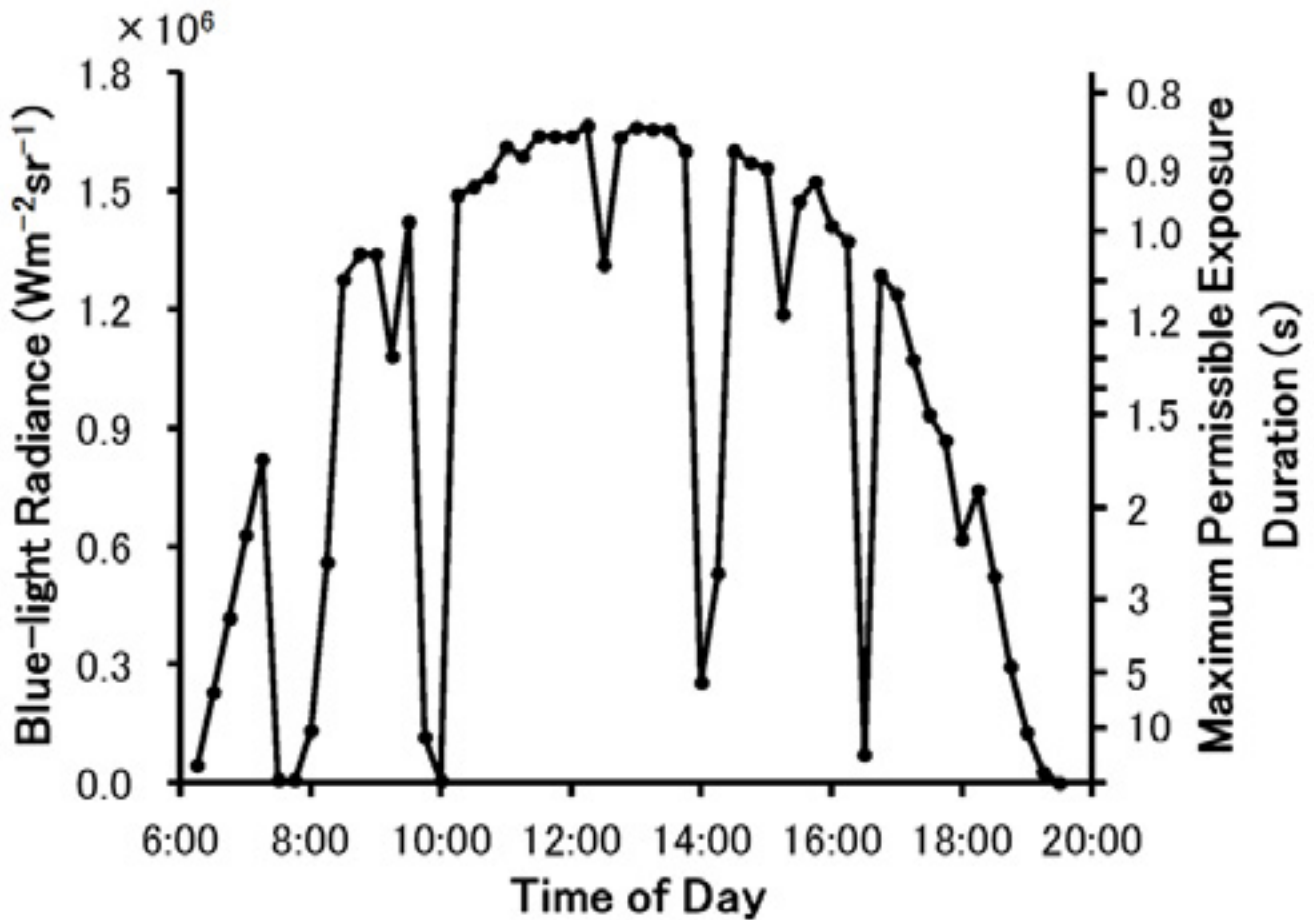


Fig. 3: Solar blue-light radiance measured on 22 June 2006, plotted against time of day. The maximum permissible exposure duration per day can be read from the right-hand scale.

The blue-light-radiance data for all 10 days are shown in fig. 4 as a function of solar elevation. Higher blue-light radiances are associated with higher solar elevations. The solar blue-light radiance ranges from  $8.39 \times 10$  to  $1.71 \times 10^6$   $\text{Wm}^{-2}\text{sr}^{-1}$  with the median  $1.31 \times 10^6$   $\text{Wm}^{-2}\text{sr}^{-1}$ . The maximum exposure durations per day corresponding to the maximum and median blue-light radiance are only 0.82 s and 1.07 s, respectively, meaning that viewing the sun can be very hazardous. In fact, it is not unusual to view the sun for more than these maximum exposure durations in everyday situations such as scanning the sky for a scenic view. Thus, it is necessary to avoid viewing the sun directly except at very low solar elevations.

Data on blue-light radiance versus solar elevation were well fitted by eqn (1) (fig.4), indicating the validity of this model. The best-fit parameters are  $L_0 = 2.26 \times 10^6$  and  $k = 0.272$ . Thus, the maximum solar blue-light radiance at each solar elevation and the corresponding maximum permissible exposure duration per day can be calculated as,

$$L_m(\gamma) = 2.26 \times 10^6 \exp(-0.272M(\gamma)) \quad (3),$$

$$t_{\max}(\gamma) = 0.619 \exp(0.272M(\gamma)) \quad (4)$$

where  $L_m(\gamma)$  = maximum solar blue-light radiance at solar elevation  $\gamma$ ;  
and  $t_{\max}(\gamma)$  = maximum permissible exposure duration per day at solar elevation  $\gamma$ .

Eqns (3) and (4) are of practical importance, because the maximum hazard at any time and place can be evaluated by calculating the solar elevation from the geographic coordinates, the date and the time and substituting it into these equations. This knowledge can be used when discussing

measures or strategies to prevent sun-induced photoretinopathy.

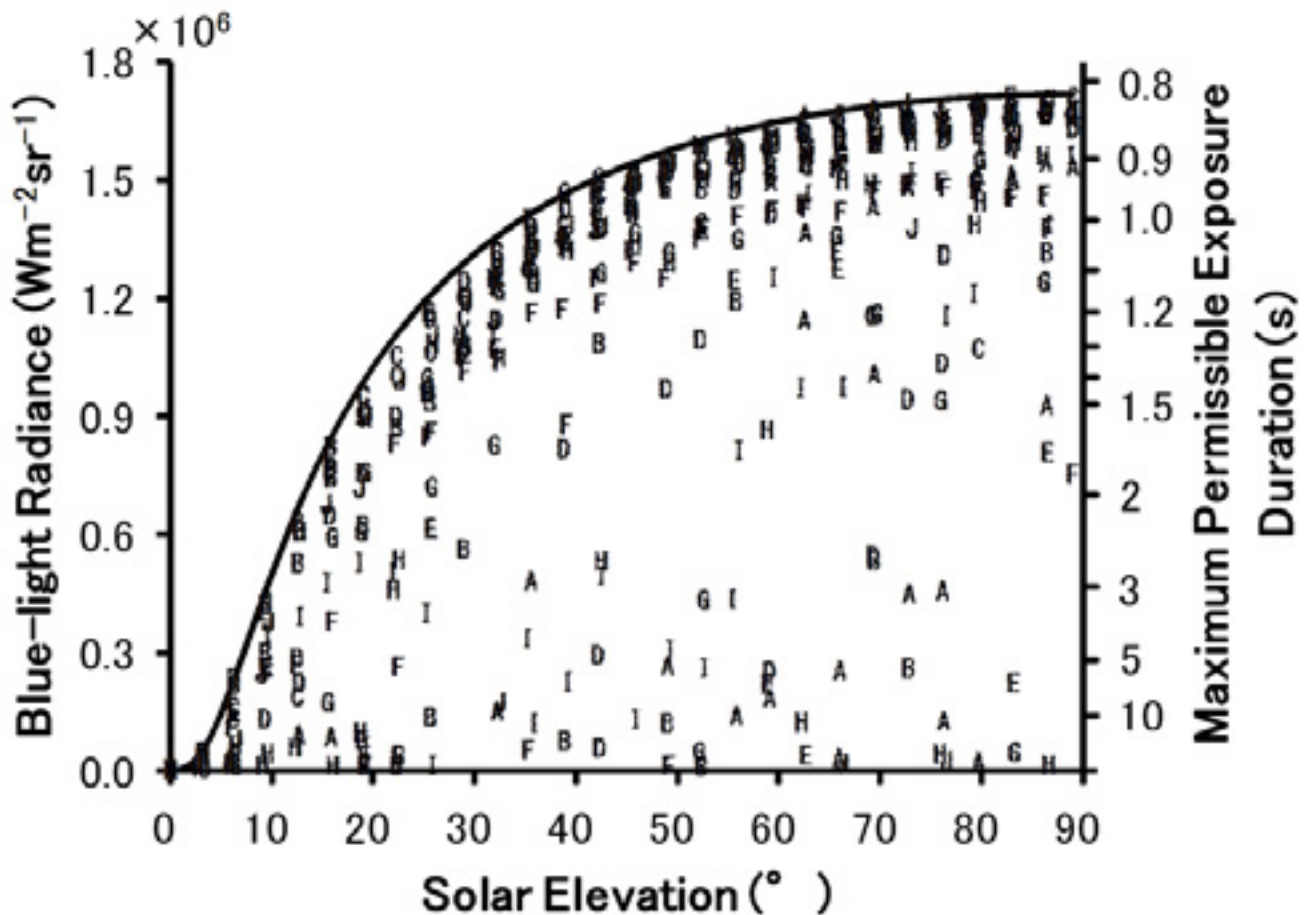


Fig. 4: Solar blue-light radiance plotted against solar elevation. The letters A-J represent data for 10 days, respectively, and the line represents the prediction of the best-fit model. The maximum permissible exposure duration per day can be read from the right-hand scale.

## CONCLUSIONS

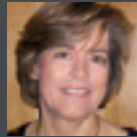
This study demonstrates that the sun is generally very hazardous to view. It is necessary to avoid viewing the sun directly except at very low solar elevations.

This study also presents a mathematical model to predict the maximum hazard at each solar elevation and the corresponding maximum permissible exposure duration per day. This knowledge is important when discussing measures or strategies to prevent sun-induced photoretinopathy.

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# PHOTOSENSITIVITY AND BLUE LIGHT



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\_\_ **PHOTOPHOBIA IS THE PAINFUL SENSATION** felt by a patient on exposure to light. It is responsible for the reflex closing of the eyelids, which protects the retina from too much exposure to light rays, and particularly the sun's rays, due to the phototoxicity of light on the chorioretinal layers.

Photosensitivity occurs only within the spectrum of visible light. This sensorial information can be exacerbated and in this case we then refer to it as photophobia. Some diseases cause photophobia and it is seen as one of the symptoms. The most common diseases of this type affect the integrity of the eye or vision paths, such as corneal lesions, traumatic corneal ulcers, corneal abscesses or superficial punctate keratitis, which are common in all dry eye syndromes. Uveitis may also be mentioned here, along with retrobulbar neuropathy or extra-ocular conditions such as migraine or meningitis.

## \_\_ SPECIALISED GANGLION CELLS

Photophobia originates in specialised ganglion cells known as "ipRGCs" (intrinsically photosensitive retinal ganglion cells). At the current stage of research we do not yet know whether these cells sub-divide according to the wavelength presented. These ipRGCs are located in the retina's layer of ganglion cells. At the outset their axons take the same path as all the retinal nerve fibres and head towards the optic nerve. Their specific path has only recently been discovered, and is called the *non-visual path* of the optic nerve, which arrives at the posterior section of the thalamus or pulvinar<sup>[6]</sup>. These *non-visual paths*, individualised using the techniques of Diffusion MR tractography provide an anatomo-physiological basis for the pain engendered by light. There are also nerve connections between the pulvinar and the nucleus of the trigeminal nerve which can explain photophobia in all ocular lesions that stimulate the ophthalmic branch of the trigeminal nerve. After direct connection by the optic nerve to the pulvinar, the route of the *non-visual path* connects the cortex, both visual (Brodmann occipital areas 18, 19, 20), parietal (association area, Brodmann area 7), frontal and pre-frontal. The connections of this *non-visual path* interact with motor and sensorial paths (olfactive). This *non-visual path*, activated by photic stimulation, acts on the excitation limit of the trigeminal neurones in the lateral posterior and posterior nucleus of the thalamus (rat) increasing the feeling of pain to light exposure in migraine. A functional IRM study<sup>[8]</sup> has also shown an increase in pulvinar activity during central cerebral sensitisation (migraine), thus explaining photophobia. The pulvinar is divided into four areas, three of which (medial, superior and inferior) concentrate visual information<sup>[3]</sup>. The pulvinar is therefore a major centre for the integration

and modulation of sensorial inputs, particularly those conveyed by the ipRGCs and the *non-visual path* which itself has connections with the suprachiasmatic nucleus (SCN), the habenula, the pineal gland, the intergeniculate leaflet (IGL) and the olivary pretectal nucleus (OPN). The latter is connected to the ciliary ganglion and to the Edinger-Westfal nucleus which is involved in photo-dependent pupil reflexes.

## \_\_ THE TOXICITY OF BLUE LIGHT

To protect itself from the harmful effects of high energy light radiation, nature has established numerous filters. A, B and some C ultraviolet rays, which have even higher energy than blue light, do not reach the retina because they are halted by the ozone layer, then the cornea and the crystalline lens. On the other hand, the various radiations of the visible spectrum of light do reach photoreceptors. The blue light wavelength has the most high-energy. It is located at between 400 and 510nm. It includes violets, indigo-blue and cyan (*fig. 1*). Blue light is absorbed by the yellow pigments of the crystalline lens (*fig. 2*), which gradually appear as age progresses (*fig. 3*) and in the retina by pigments, rhodopsin, lipofuscin and the macular pigments (lutein, zeaxanthin, meso-zeaxanthin). The photochemical reaction is responsible not only for phototransduction but also for the formation of free radicals during

Light energy:  
 $E \text{ (eV)} = h$   
 $(\text{Hertz}) = 1/ \text{ (nm)}$

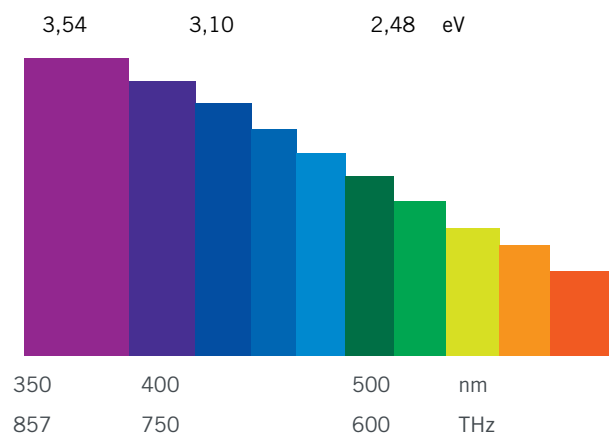


FIG. 1 | Photon energy depending on wavelength, within the visible light spectrum.

→ oxidative phenomena. These free radicals, which are ionic unstable, are toxic directly on cellular membranes and intracellular metabolites, causing a slow-down in retinal metabolism, non-renewal of the external articles of photoreceptors and their apoptosis. Photophobia is the retina's final protection against their oxidative phenomena, blocking the input of light by means of a blepharospasm (blinking) reflex.

Results in literature are still contradictory in stating the trigger role played by blue light in the genesis of AMD (fig. 4) and cataract, but a certain number of articles come down in favour of this hypothesis. The generations of yellow crystalline lens implants, which block out blue light, are the results of these scientific hypotheses. The debate is still open, but optical filters which block both UV and blue light are still more efficient. Blue light is however of major importance to the body, in addition to better scotopic perception by means of stimulation of the rods, there is also regulation of the circadian cycle and mood regulation<sup>[5]</sup>. Melanopsin, the retinal pigment that absorbs blue, with an absorption peak of 480nm, controls the diurnal cycle via the *non-visual path* that stimulates the pineal gland directly as well as the secretion of melatonin<sup>[7]</sup>. Changes in serum melatonin levels are responsible for sleep cycles and mood (photodependent or seasonal depression).

**Photosensitivity is a natural phenomenon** that gives humans their diurnal behaviour, with regulation of the internal biological clock. The ipRGCs mediated by the *non-visual path* control hormonal circadian cycles, sleep and mood. Photophobia triggers retinal protection against light energy and more particularly blue light, which has the most high-energy and is responsible for irreversible cellular lesions with apoptosis of the photoreceptors during photochemical mechanisms that release toxic oxidative residues. •

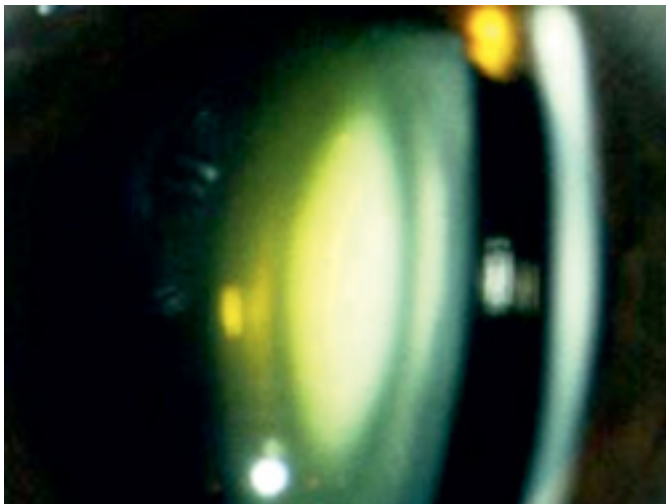


FIG. 2 | Natural ageing of the crystalline lens; cortical nuclear cataract.

Transparent at birth, the crystalline lens is gradually loaded with yellow pigments through the product of oxidation of the tryptophan and protein glycosylation; cataractogenic role of short wavelengths in the case of nuclear cataract: attenuation, followed by non perception of blues and violets. Protective role of the retina?

FIG. 3 | Light absorption in a phakic or pseudophakic patient.

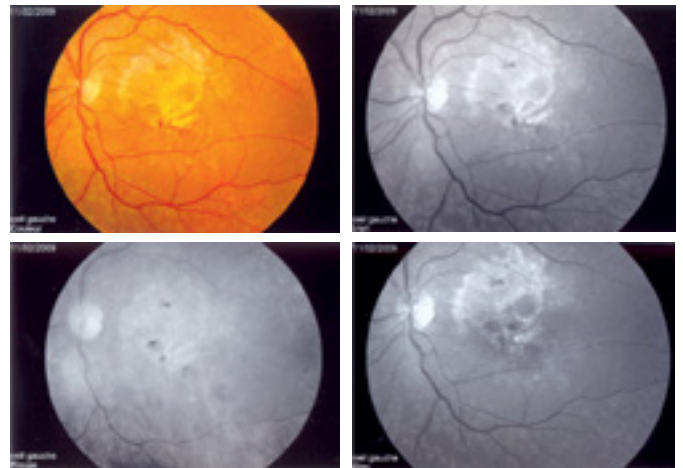
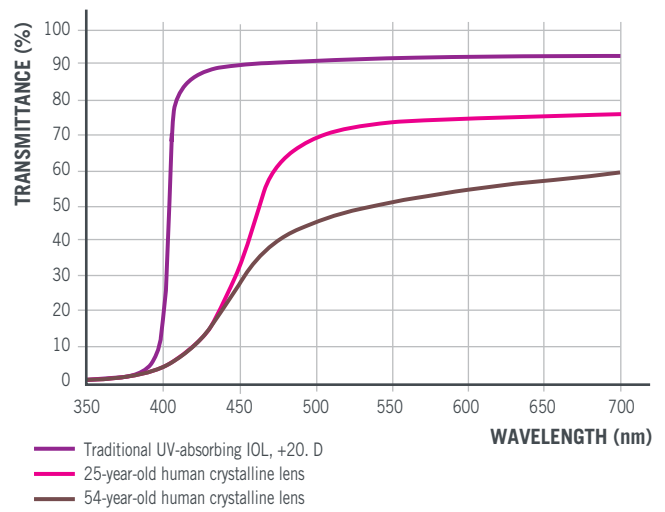


FIG. 4 | AMD.

Change in the pigmentary epithelium; cicatricial fibrogliar appearance. Atrophy of the photoreceptors. Accumulation of lipofuscin and cellular deterioration products caused by the oxidative mechanisms of phototransduction.

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# NEW DISCOVERIES AND THERAPIES IN RETINAL PHOTOTOXICITY



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## INTRODUCTION

Age-related Macular Degeneration, AMD, is one of the major causes of visual impairment in industrialised countries, along with diabetic retinopathy and glaucoma. In the United States, AMD is considered to be the cause of 54.4% of visual impairments and 22.9% of cases of blindness<sup>[1]</sup>. It is estimated that in 2010, 9.1 million Americans aged over 50 presented early-stage AMD<sup>[2]</sup> and that this number is set to double by 2050, to reach 17.8 million. At least 12% of the American and European populations aged over 80 is affected by advanced AMD<sup>[3-5]</sup>. Amongst risk factors for AMD identified in literature, sunlight is indicated as being a factor that can cause cumulative damage to the retina. The highest energy portion of the visible spectrum, at between 400nm and 500nm, also known as blue light, is incriminated here. Ophthalmic appliances already claim to offer protection against blue light. Spectacle lenses or intraocular implants mostly contain high-pass filters that absorb a wide band of blue light. However, such unselective filtering can lead to maladjustment of the eye's visual and non-visual functions. Colour perception is disturbed, scotopic vision is limited and the body clock of wake/sleep cycles, which is controlled by certain wavelengths of blue light, is potentially thrown out of kilter. The limited specificity of the filtering mechanisms in existence is due to a lack of information concerning the relative toxicity to the retina of each wave length within the visible spectrum. This is the reason why Essilor International and the Vision Institute went into partnership in 2008 in order to define the harmfulness of blue light to the retina more clearly and develop more selective, protective filtering lenses.

## LIGHT: A RISK FACTOR FOR AMD

Since the causes of AMD are currently poorly identified, there are no efficient preventive and curative solutions. Numerous epidemiological studies demonstrate a large variety of potential risk factors. Although the first proven factors are age<sup>[5]</sup>, tobacco consumption<sup>[5-8]</sup> and lack of carotenoids<sup>[9]</sup>, light is also being blamed as probably playing a part in the prevalence of AMD<sup>[10-14]</sup>. One of the characteristics of AMD is the appearance of sub-retinal deposits known as drusen<sup>[15,16]</sup>. These deposits are made up of lipofuscin, a product of the deterioration of the external segment of the photoreceptors and of the visual pigment. Lipofuscin, because of its photosensitising characteristics, is thought to be involved in the retinal damage caused by exposure to light.

## BLUE LIGHT: HOW DANGEROUS IS IT FOR THE RETINA?

In the retina, light is mainly absorbed by the visual pigments contained in the external segments of the photoreceptors. The visual pigments of vertebrates are made up of a transmembrane protein, opsin, combined with a vitamin A derivative 11-cis-retinal. In the rod photoreceptors, this visual pigment is rhodopsin.

Most ultraviolet radiation is naturally filtered by ocular tissues located in front of the retina, particularly the cornea and the crystalline lens<sup>[17,18]</sup>. The most energetic light that reaches the retina is therefore mainly blue light, at between 400nm and 500nm. Because of its high energy level, it induces and accelerates photochemical reactions and cellular damage via the production of radical species that are highly reactive in the presence of oxygen. In particular, the toxic potential of blue light on the external retina acts at two cellular levels: photoreceptors and the cells in the retinal pigment epithelium.

In the rod photoreceptors, absorption of a photon by rhodopsin causes isomerisation and the release of the 11-cis-retinal as all-*trans*-retinal. Free all-*trans*-retinal is not only toxic as a reactive aldehyde, it also presents strong sensitivity to blue light<sup>[19,20]</sup>. Under moderate light exposure conditions, the all-*trans*-retinal is recycled continuously into 11-cis-retinal by the cells of the retinal pigment epithelium and does not cause any danger to the cell. When exposure to light happens over a longer or more intense period, the all-*trans*-retinal accumulates and its activation by blue light may be the cause of oxidative stress which damages the cellular components of the photoreceptors. This oxidative stress is normally compensated for by the presence of the numerous antioxidants in the retina. However, with age and certain genetic and environmental factors, such as tobacco consumption or a diet that is low in antioxidants, anti-oxidative defences are reduced<sup>[21,22]</sup> and can no longer compensate for the stress caused by prolonged or intensive exposure to blue light.

The function of the cells in the retinal pigment epithelium is to ensure renewal of the external segment of photoreceptors. They eliminate the distal part of them by ingestion, or "phagocytosis", whilst the growth of these external segments occurs continuously<sup>[23]</sup>. When the external segments are too damaged by oxidative stress, their membrane components are difficult for the retinal pigment epithelium to break down. Intracellular digestion is then incomplete and generates an accumulation of residual granular bodies, in the form of lipofuscin. The granules of lipofuscin contain a large amount of polyunsaturated fat, a target for oxidation. The lipophilic extract of lipofuscin contains a potential photosensitiser, which forms a triplet excited state with a maximum of absorption in blue at 440nm<sup>[24,25]</sup>. One of the components of lipofuscin, A2E, has been identified as being involved in the photosensitising nature of the lipid residue. The energy of the triplet state is sufficient to be transferred and react with oxygen in the blood.

Photoactivation of the lipofuscin granules by blue light then generates reactive oxygen species (superoxide, hydrogen peroxide, lipid hydroperoxides and malondialdehyde)<sup>[26, 27]</sup>. When the number of these species exceeds the cellular defence capacity, the retinal pigment epithelium cells die by apoptosis. Deprived of these support cells that provide their energy supply, the photoreceptors deteriorate in turn, contributing to the loss of vision diagnosed in patients suffering from AMD.

**In conclusion**, the suggested mechanism by which light is involved in the appearance and progression of AMD may happen at two levels: on the one hand in photoreceptors *via* absorption of blue light by rhodopsin and then in the near ultraviolet blue by the all-trans-retinal, and, on the other, in the retinal pigment epithelium *via* absorption of blue by lipofuscin.

#### \_\_\_ THE LIMITATIONS OF EXISTING STUDIES

The toxic effects of visible light and blue light in particular on the retina have already been demonstrated experimentally on cellular<sup>[28-30]</sup> and animal<sup>[31]</sup> models of degenerative retinal pathologies. However, the studies performed to date have not enabled characterisation of the respective toxicity of each wavelength. Also, they suffer from certain limitations. In fact comparisons of results are difficult from one study to another because units fluctuate between energetic and visual units. Also, the illumination systems used are not calibrated on the illumination of the light sources existing in our environment, whether natural (the sun) or artificial (neon, LED, halogen, etc.) and therefore do not reflect true conditions of exposure to light. Finally, none of the illumination systems used to date enables step by step definition of the toxic spectrum of light on the cells of the retina. The only recurrent information is that the highest toxicity levels are contained within the spectral interval [400nm; 500nm].

#### \_\_\_ THE CONTRIBUTION MADE BY THE VISION INSTITUTE AND ESSILOR INTERNATIONAL

The objective of this contribution was, in partnership with Essilor International, to establish a photobiology laboratory at the Vision Institute, to enable us to define precisely the specific toxicity on the retina of each wavelength in the blue section of the visible spectrum. The first action taken involved the development of a cellular illumination system. This enabled the production of visible wavelengths of very narrow bandwidths and at given illumination in order to model the desired luminous spectrum. The light source to which we are the most exposed and which is the most intense is the sun and the work was therefore carried out using, for each wavelength, radiation values relative to the sun's spectrum.

The second direction for work involved development of a model of cultured cells, reproducing *in vitro* the degeneration of retinal cells, as observed in AMD, with the presence of a lipofuscin component: A2E.

#### \_\_\_ EQUIPMENT AND METHOD

The system of illumination that has been developed is a multi-wavelength generator used to illuminate the cells being cultured inside an incubator. The light source comprises a set of light-emitting diodes (LEDs), each connected to the incubator and the cells by means of optical fibres. The range of wavelengths covered extends from 390nm to 520nm in bandwidths of 10nm (*fig. 1*). The whole unit can thus, with each optical fibre, restrict illumination to 10nm of the spectrum arriving in the retina.

In order to model the accumulation of lipofuscin in the retina, cells cultured in pig's pigmentary epithelium were treated with various concentration of A2E, one of the components of lipofuscin (*fig. 2*). These cells were then exposed to a light bandwidth of 10nm

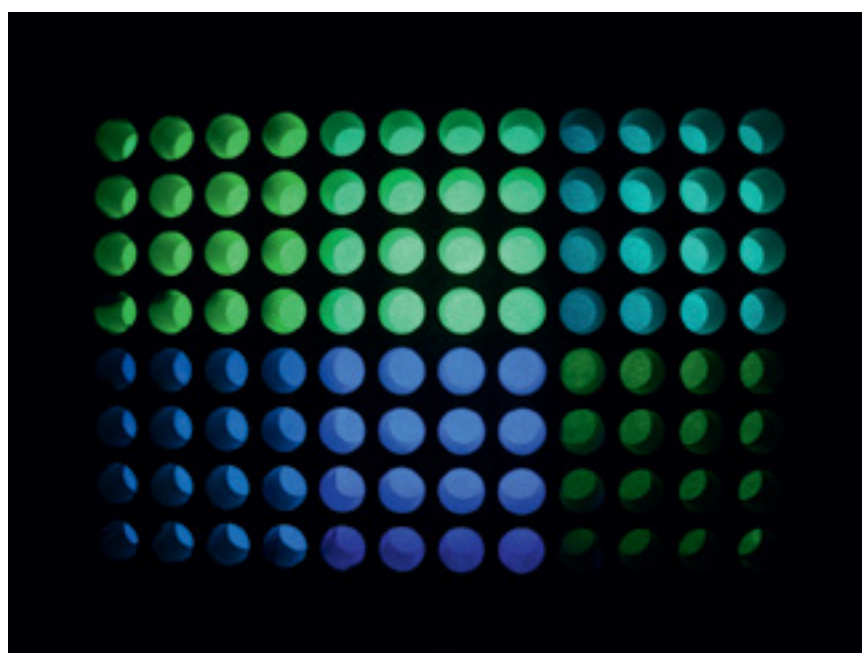


FIG. 1 | View from above of a cell culture plate lit by various wavelengths, from 390 to 520nm.

→ for 18 hours. Six hours after exposure, the effects of the light on the cells were characterised according to three parameters: the percentage of live cells, apoptotic activity of the cells and the percentage of cells undergoing necrosis.

## RESULTS

Quantification of live cells shows that exposure to light leads to cell death only when the cells have been treated with A2E (fig. 3). This phototoxicity is shown by activation of an enzyme, caspase-3, which is involved in programmed death processes (apoptosis). On the other hand, we did not observe any cell necrosis under these experimental conditions. Our results also show that the greater the concentration of A2E, the greater the toxic effect of light. These results demonstrate that an A2E dose-dependent effect exists, and therefore probably one of lipofuscin too, in induction of phototoxicity. This can be related to the influence of age in AMD, because it has been observed that drusen and lipofuscin accumulate with age and are present in greater quantities in elderly patients suffering from AMD<sup>[15,16,32,33]</sup>.

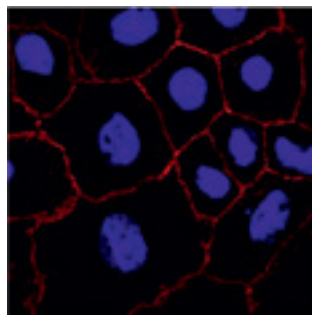
## CONCLUSION AND PROSPECTS

The joint work carried out by the Vision Institute and Essilor International has resulted in the establishment of an experimental process using a cellular model of AMD to define the precise spectrum of sunlight toxicity on the retina. These results provide information of capital importance in terms of the need to be protected from highly specific blue light wavelengths. It is important to note that these wavelengths are also present in variable proportions in the various sources of artificial light (neon, LED, xenon, halogen, etc.) and that the potential effects of lengthy exposure should not be neglected. This project supplies elements of understanding of the physiopathological processes taking place in AMD, with the possibility of therapeutic or preventative solutions for this major pathology. This type of therapeutic solution could be extended to other retinal pathologies involving oxidative stress processes leading to degeneration of the photoreceptors, such as pigmentary retinitis and Stargardt's disease. The association of the respective skills of the Vision Institute in terms of the cellular biology of the retina, and of Essilor International in optics was essential in setting up this innovative ophthalmological project. •

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### Non-treated cells



### Cells + A2E

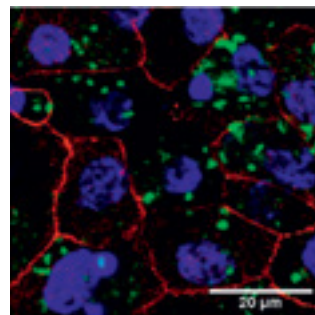
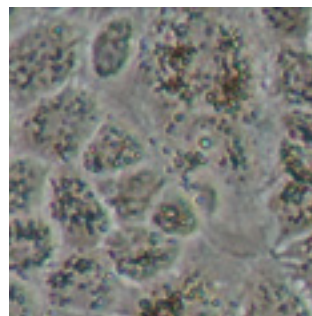


FIG. 2 | Pig's retinal pigment epithelium cells with or without treatment with A2E, one of the components of lipofuscin.

The cells' nuclei are visible in blue and inter-cellular junctions are coloured red. On the left the A2E internalised by the cells is visible by autofluorescence in green when it is illuminated with blue light.

### Dark



### Light

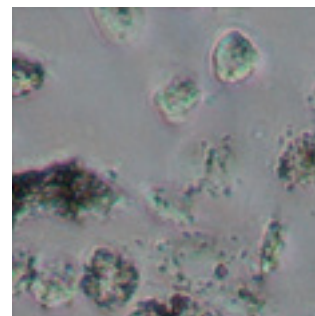


FIG. 3 | Pig's retinal pigment epithelium cells treated with A2E kept in the dark or exposed to light. On the left the cells kept in the dark are healthy because they are hexagonal in shape and will join to each other (at confluence).

On the contrary, exposure to light (on the right) causes cell death, visible from their rounded shape and reduced density.

# UNDERSTANDING RISKS OF PHOTOTOXICITY ON THE EYE

Certain portions of the light spectrum can be detrimental to ocular health and lead to accelerated eye ageing and diseases. With an influx of modern short wavelength light sources on the market, the human eye is susceptible to greater exposure to these lights.

Prof. John Marshall, Professor of Ophthalmology at University College London, recipient of the Junius-Kuhnt Award and Medal for his work on AMD, sheds some light on phototoxicity risks and the need for prevention for *Points de Vue*.

## PROFESSOR JOHN MARSHALL

University College London

***Points de Vue:* Professor Marshall, could you describe some of the research areas you have been involved with over the years that are linked to vision and light?**

**Prof. John Marshall:** I started in vision back in 1965, when I was given a PhD grant with the Royal Air Force to investigate the potential damaging effects of lasers on the retina. At that time we needed to have a much better understanding of how light interacted with the retina and what mechanisms could potentially damage it. Collectively our work together with some German and American teams developed a data base that formed the basis for the international codes of practice to protect individuals against the potential damaging effects of lasers. It also extended into the potential damaging effects of incoherent light. These data were also incorporated into the codes of practice used by large international organizations such as the World Health Organization (WHO), the United Nations environmental programme and the International Red Cross.

### KEYWORDS

UV, blue light, photo toxicity, laser, cataract, AMD, Retinitis Pigmentosa, RP, IOL, Crizal® Previa® prevention

After looking at the effects of the acute intense light I became very interested in the effects of chronic irradiation with incoherent light such as sunlight and commercial and domestic light sources in the UK. Our subsequent research showed that the retina was most sensitive to short wavelength visible radiation in the blue region of the spectrum and strangely the cones were more vulnerable than the rods in diurnal animals. Previous data which has confused a lot of the literature was derived from experiments on rats and mice that have predominantly rod retina and as a consequence showed damage to rods.

***Subsequently, was your transition into studying the effects of incoherent light, away from lasers, more of a personal interest?***

Originally it was personal interest because light is light, whether generated within a laser or an incandescent bulb. Light sources emit photons. I was interested in the interaction between photons and biological tissue, and how photons gave rise to the sensation of vision. Eventually I got interested in how excessive exposure, whether high level, high power or prolonged periods of exposure, had



## interview



the potential to damage the visual system. From the evolution standpoint our eyes were designed to have roughly 12 hours of light and roughly 12 hours of dark, something that modern lifestyles have changed considerably.

**From your personal point of view, do you think changes in illumination have had an impact in this regard?**

Yes, because for thousands of years the only light source under man's control was fire found in systems such as burning braid, oil lamps or candles. The next progression in the series was gas lighting, which was also essentially fire. However, all of these sources created heat and a lot of light meant a lot of heat. It wasn't until the advent of the incandescent bulb in the mid-1800s that we had daylight levels of illumination at any time of night or day. Further, with the advent of fluorescent lighting in the 1940s, we could have high light levels without significant actual heat. Unfortunately unlike incandescent bulbs, which produced light mainly towards the red end of the spectrum, fluorescent lighting had emissions in the blue and ultra violet regions. At present, due to environmental concerns of conservation of energy, we are seeing

compact fluorescent and LED lights in the market in the name of energy saving, but again these produce ultraviolet and blue light. There should have been much more consultation with the biological vision community before these biologically unfriendly sources were introduced. It is only now that a committee has been formed to consider the unexpected health hazards of such devices. The dermatologic and ophthalmic community could have told the manufacturers that such potential health hazards were certainly not unexpected.

**What do you expect the impact of this new form of low energy lighting to be now and in the future?**

Researchers on skin have already expressed some concern over ultraviolet and high-intensity blue, increasing the chances of skin problems from commercial and domestic lighting. My concern would be that **any short wavelength radiation involves high-energy photons and can exacerbate the ageing process in our eyes** in a manner similar to how excessive sunlight exposure during your lifetime can lead to ageing effects such as wrinkly skin. Certain wavelengths may well implicate an accelerated ageing process leading

**“Any short wavelength radiation involves high-energy photons and can exacerbate the ageing process in our eyes.”**

to an earlier onset of cataract and could also exacerbate other age-related conditions such as age-related macular degeneration. They represent environmental risks factors to which we really do not need to expose ourselves, as incandescent bulbs had illuminated our homes satisfactorily for a hundred years.

#### Are there any calls to government agencies on the dangers of this new push for low energy light bulbs?

In my opinion there should have been a committee of experts assessing the health hazards of low-energy lighting before they became available in the marketplace and certainly before incandescent bulbs were banned! Unfortunately this is closing the door after the horse has bolted. It should have been more important to consult the relevant experts before making important policy decisions in order to avoid a potential downstream problem.

#### How does this phototoxicity act on ocular tissue?

High-energy photons in the presence of oxygen give rise to reactive oxygen species that are potentially dangerous for cells. Light damage to the skin is minimised by the surface cells of the skin being constantly replaced by cells from deeper layers, thus simplistically the system is renewed approximately every five days. By contrast the cells that line the inside of the eye, the retina, are in essence an outgrowth of the brain and therefore like all neurons incapable of dividing. The rods and cones have to absorb light and are in the presence of high levels of oxygen. They have developed a mechanism whereby the light-sensitive portion of the cell is constantly renewed on a daily basis. Every hour of every day approximately three to five new light-sensitive membranes are manufactured and every morning on awakening rods lose approximately 30 old membranes to a layer of cells called the retinal pigment epithelium (RPE). Cones lose their old membranes about every four hours during our sleep period.

Over a human lifetime, the RPE cells that also don't nor-

mally divide have to contend with huge amounts of degraded biological material. From one's mid-thirties onwards, the RPE cells get progressively clogged with toxic products. At a later stage these waste products lead to further changes between the RPE cells and their underlying blood supply. This sequence of buildup of age-related waste products generated by an attempt to protect the light-sensitive cells against the damaging effects of light throughout a lifetime is the biggest risk factor in age-related macular degeneration (AMD). More light stress produces more debris, and has the potential to accelerate the ageing process. We certainly need some exposure to blue lighting in order to balance our biological well-being and stop us becoming affected by seasonally adjusted disorder (SAD). However this is a requirement for longer wavelength blue light and there is no advantage associated with short wavelength blue light or ultraviolet.

#### So to expand on this point, do you see a difference in phototoxicity between the bands within the blue portion of the spectrum?

Yes, the longer wavelengths of blues are the blues we need to keep happy and prevent ourselves from getting SAD. **It's the blue light near the ultraviolet and the blue indigo violet that are the most harmful and the wavelengths that we**

**ought to get rid of.** Not all wavelengths cause concern. Only short wavelength photons are individually capable of producing photochemical events, and these tend to be from the short wavelength blue end of the visible spectrum down through the ultra

violet. From the red end of the visible spectrum up through the infrared, photons do not have enough energy by themselves to produce photo chemical damage and here damage results by large concentrations of them arriving in tissue, causing vibrational modes which are heat.

**“I think the scientific base is pretty incontrovertible, short wavelength visible radiation is more harmful than long wavelength visible radiation.”**

## interview

**Could you elaborate on the particular ocular conditions that you have some concern about?**

Many patient groups that suffer from conditions where the photoreceptor cells or light sensitive cells are most vulnerable have been advised in the past to wear protective eyewear which typically looks “reddish” or “brownish” and such devices filter out harmful wavelengths whilst letting in the useful wavelengths required for vision. Large patient groups such as those with Retinitis Pigmentosa (RP) would be an example of a disease group that benefits from such protection.

**Would you contend that from your personal belief that protective eyewear would be useful for people who are in early stages of any other ocular condition?**

Several clinicians would advise patients in the early stage of AMD to wear peaked hats and to wear protective eyewear as well. The big problem is that patients do not get good advice currently as to which protective eyewear is going to be helpful; they are merely instructed that the device blocks 100% of ultraviolet, but usually they are given no information on how much blue is transmitted.

**What role do you think clinical practice could play in prevention of the ocular problems you've described linked to blue-violet light?**

**I think the scientific base is pretty incontrovertible: short wavelength visible radiation is more harmful than long wavelength visible radiation.** It should be remembered that we do not have any short wavelength photoreceptor cells, blue cones, in our foveas and that the macular region of the retina is protected by the presence of a yellow pigment thus blue plays no role in high acuity vision. We all suffer with foveal tritanopia and as a consequence we lose nothing by filtering out short wavelength blue in terms of our visual life. There is some resistance to wearing highly pigmented protective eyewear because many individuals don't like walking around in bright yellow or brown lenses. This is why **I think the current innovation from Essilor is quite interesting, because these lenses (Crizal® Previncia®) are apparently transparent, and also reflect blue from the surface while absorbing**

**the ultraviolet.** This innovation is pretty interesting, because they now offer protection without being stigmatised for aesthetics.

**Would you suggest that this innovation would be a useful correction that an eye care professional could deliver to a younger patient?**

I think it's extremely useful because wearing protective eyewear is similar to wearing sun cream. It won't do any harm and probably it will do a lot of good over the course of one's lifetime.

**Earlier, you mentioned the shifts in internal lighting historically over the last hundred years. Do you see the more recent changes as a cause of concern?**

Yes, both in terms of domestic and commercial lighting. Although lighting companies are working very hard to try and get rid of potentially harmful wavelengths, they've not been successful so far. The light sources they have produced with filters to filter out the harmful radiation are significantly more expensive compared to the light bulbs in our homes. In terms of fluorescent tubes, there is one sodium line which is almost 40% of the blue light hazard and accounts for less than 8% of the light, but they can't get rid of it, because it facilitates lower costs and ease of manufacture.

**What do we need to do to bring a level of public awareness around blue light and its potential harmfulness?**

It would be very helpful to bring optometrists and eye care professionals up to date and to make sure they are in full possession of the basic knowledge. They would then be in a position to help their potential clients. Specifically in the field of the cataract surgery, we remove the natural yellow lens and implant a plastic intra-ocular lens; now virtually all intraocular lenses have UV block, and in recent years many IOL companies have introduced lenses with blue blocking or blue attenuating filtration. This is because when you remove the crystalline lens, the retina gets exposed to even more light damaging blue light and ultraviolet.

**The benefits of the yellow sort of blue filter IOLs have been raised with the ophthalmologist community. What are your thoughts on this?**

In Europe, the proportion of IOLs having blue filters varies from country to country; the highest ratio of blue blocking lenses is in France, where I believe 70% of the lenses have yellow filtration. It is less in many other countries. In the UK, ophthalmologists sometimes prefer clear lenses over blue blocking ones. They would like to see more established evidence of the benefits of blue blocking. There is mixed opinion on the subject, although experimental evidence does point in that direction. It comes down to education at the end. The mindset of ophthalmologists is progressively moving, but these things take time. When it comes for me to have my cataracts removed, I will certainly have a blue-filtering IOL implanted. •

Interviewed by Andy Hepworth

**BIO**

**Professor John Marshall**  
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Professor John Marshall is the Frost Professor of Ophthalmology at the Institute of Ophthalmology in association with Moorfield's Eye Hospital, University College London.

He is Emeritus Professor of Ophthalmology at King's College London, Honorary Distinguished Professor University of Cardiff, Honorary Professor the City University and Honorary Professor Glasgow Caledonian University.

Primarily, he has concentrated his research on the inter-relationships between light and ageing, the environmental mechanisms underlying age-related, diabetic and inherited retinal disease, and the development of lasers for use in ophthalmic diagnosis and surgery.

He invented and patented the revolutionary Excimer laser for the correction of refractive disorders.

He also created the world's first Diode laser for treating eye problems of diabetes, glaucoma and ageing.

Professor Marshall has been the recipient of several awards: the Nettleship Medal of the Ophthalmological Society of the United Kingdom, the Mackenzie Medal, the Raynor Medal, the Ridley Medal, the Ashton Medal, the Ida Mann Medal, the Lord Crook Gold Medal, the Doyné Medal of the Oxford Congress, the Barraquer Medal of the International Society of Cataract and Refractive Surgery and the Kelman Innovator Award of the American Society for Refractive and Cataract surgery. More recently in 2012 he received the Junius-Kuhnt Award and Medal for his work on AMD.

Professor Marshall has authored over four hundred research papers, 41 book chapters and 7 books.

**“Wearing protective eyewear is similar to wearing sun cream. It won't do any harm and probably it will do a lot of good over the course of one's lifetime.”**



**KEY TAKEAWAYS**

- Photons interact with biological tissue and may potentially lead to ocular health hazards.
- The red end of the visible spectrum up to the infrared can generate heat, while short wavelength photons can produce photochemical damage and accelerate ocular ageing process.
- Short wavelength blue-violet may exacerbate age-related macular degeneration (AMD) and UV radiation can potentially lead to earlier onset of cataract.
- Not all wavelengths cause concern. Long wavelength blue light is needed to balance biological well-being and Seasonally Adjusted Disorder (SAD).
- Selective photo-protection (filtering UV and short blue-violet light) is a necessity for eye health in the long term.
- Crizal® Previncia® lenses selectively filter UV and the bad part of the spectrum while allowing good blue light to pass through. They maintain perfect transparency.

# THE ROLE OF BLUE LIGHT IN THE PATHOGENESIS OF AGE-RELATED MACULAR DEGENERATION


Blue light exposure is one of the modifiable risk factors involved in the pathogenesis of Age-Related Macular Degeneration (AMD). Several studies have evaluated the relationship between light exposure and AMD, as well as clinical trials evaluated the visual function effect of blue filtering IOLs versus conventional IOLs. However, the authors encourage further clinical trials to assess the preventive filtering effect of ophthalmic lenses, particularly those with narrow bandwidth filters, in the development and/or progression of AMD.



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## KEYWORDS

AMD, neovascularization, blue-violet light, IOL, lipofuscin, rhodopsin, chromophore, RPE cells, photoreceptors, photopigment, photoreactivity, Crizal® Previncia®

**A**ge-related Macular Degeneration (AMD) is the most common cause of blindness in the elderly population in developed countries and accounts for 8.7% of all the blindness worldwide.<sup>1, 2, 3</sup> In the future, the prevalence of AMD is likely to increase as a consequence of exponential population aging. The early stages of AMD are characterized by yellowish deposits (drusen) and/or pigmentary changes of retinal pigment epithelium (RPE) but without overt functional loss of vision. In advanced stages of AMD, there is dysfunction and death of photoreceptors secondary to an atrophic (geographic atrophy, GA) and/or a neovascular (choroidal neovascularization, CNV) event leading to irreversible loss of central vision.

The early stages of AMD, compared to its later stages, affect a significantly larger proportion of the population and increase the risk for visually significant advanced AMD by 12- to 20-fold over 10 years.<sup>4</sup> There have been significant advances in the management of neovascular AMD and the introduction of anti-angiogenesis therapy can now prevent blindness and in many cases restore vision.<sup>5, 6</sup> However, the treatment modalities are expensive and not available to patients in many countries.<sup>7, 8</sup> Therefore, identification of modifiable risk factors that may inform disease prevention programme is of priority. This review evaluates the long held belief that blue light exposure has a role in the pathogenesis of AMD.

**Light is necessary for vision but it can damage the sight organ itself** – a property that has long been recognized. The human retina is exposed to the “visible component” of the electromagnetic spectrum from 400 to 700 nm and some short wavelength infrared because ultraviolet radiations

are naturally filtered by ocular tissues located in front of the retina, particularly the cornea (295 nm) and the crystalline lens (less than 400 nm). Therefore, high-energy visible light, the blue-violet light renamed “blue light” for simplification, between 400 and 500 nm wavelength reaches the retina.

**Blue light may damage the retina** in a number of ways involving different chromophores and cellular events; however, retinal damage by photo-

chemical mechanism is most likely to be of relevance in the development

of AMD. Photochemical reactions occur in normal ambient conditions and involve a reaction between energetic photons and an absorbing molecule in the presence of oxygen leading to the generation of reactive oxygen species (ROS) that are highly toxic to the retina.

**Short-term exposure (up to about 12 hours)** to relatively intense blue light, referred to as “blue light hazard”, can produce damage at the level of

RPE in primates.<sup>9</sup> The dependence of this type of damage on the oxygen concentration and on the level of various antioxidants to reduce the light damage confirms its oxidative nature. Furthermore, lipofuscin in the RPE is the most likely chromophore for this type of damage because lipofuscin is a potent generator of ROS,<sup>10</sup> and more importantly, the action spectra for photochemical damage to the RPE correspond to the aerobic photoreactivity of the lipofuscin.<sup>11</sup> The key component likely to contribute to lipofuscin’s photoreactivity is A2E (N-retinylidene-N-retinylethanolamine), a photosensitizer that has been demonstrated to produce ROS, trigger RPE cell apoptosis and lead to RPE cell death.<sup>12, 13</sup>

**Long term exposures (typically 12-48 hrs)** to less intense exposures produce damage at the level of the photoreceptors. The photopigments absorb the blue light and acts as photosensitizer resulting in photoreceptor damage. It is believed that deep blue light is 50-80 times more efficient at causing photoreceptor damage than green light due to rhodopsin photo reversal.<sup>14</sup> Blue light promotes the photoisomerization of all-trans-retinal

FIG. 1 | Retinal degeneration: a new model of blue-light induced damage  
Light microscopy photographs (magnification x400).  
Trichrome Masson staining of sagittal section of retina 14 days after blue light exposure. Approximately four rows of photoreceptor nuclei remaining and inner and outer segments were disrupted (Iris Pharma, France).

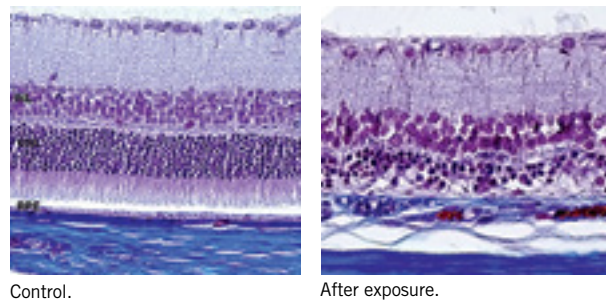


TABLE 1 | List of studies that have evaluated the relationship between light exposure and Age-Related Macular Degeneration (AMD)

PRINCIPAL INVESTIGATOR (YEAR OF PUBLICATION)	TYPE OF STUDY	SAMPLE SIZE	TYPE OF AMD	ASSESSMENT OF LIGHT EXPOSURE	CONCLUSION
Taylor H.R. <i>et al.</i> (1992)*	Cross-sectional	838	Late AMD (GA+CNV)	Blue light exposure at leisure and working time for the previous 20 years	High levels of exposure to blue and visible light in late life may play a role in the pathogenesis of late AMD (OR: 1.35, 95%CI: 1.0-1.81)
Cruikshanks K. J. <i>et al.</i> (1993)* Beaver Dam Eye Study	Population-based	4926	Early AMD	Time spent outdoors in summer	The amount of time spent outdoors in summer was associated with an increased risk of early AMD (OR: 1.44, 95%CI:1.01-2.04)
			Late AMD (GA+CNV)	Leisure time spent outdoors in summer	The amount of leisure time spent outdoors in summer was significantly associated with neovascular AMD (OR, 2.26; 95% CI, 1.06 to 4.81) and GA (OR: 2.19; 95% CI 1.12 to 4.25)
Darzins P. <i>et al.</i> (1997)	Case-control	409/286**	Any type of AMD (early+GA+CNV)	Annual sun exposure	Sun exposure was relatively greater in control subjects than in cases with AMD ( $p < 0.01$ )
Delcourt C. <i>et al.</i> (1997) POLA study	Population-based	2584	Early AMD	Annual ambient solar radiation	A decreased risk of early AMD was observed in subjects exposed to high ambient solar radiation (OR:0.73, 95%CI:0.54-0.98)
			Early AMD	Leisure time sunlight exposure	A decreased risk of early AMD was observed in subjects with frequent leisure time sunlight exposure (OR:0.8, 95%CI: 0.64-1.00)
Tomany S.C. <i>et al.</i> (2004)* Beaver Dam Eye Study	Population-based	3684	Early AMD	Leisure time spent outdoors aged 13-19 years and aged 30-39 years	Significant associations were observed between extended exposure to the summer sun and the 10-year incidence of early AMD (RR:2.09; 95%CI:1.19-3.65)
Khan J.C. <i>et al.</i> (2006)	Case-control	446/283**	Late AMD (GA)	Sun exposure index (per unit increment)	No associations between late AMD (GA) and sun exposure or related factors were observed ( $p = 0.44$ )
			Late AMD (CNV)	Sun exposure index (per unit increment)	No associations between late AMD (CNV) and sun exposure or related factors were observed ( $p = 0.29$ )
Hirakawa M. <i>et al.</i> (2007)	Case-control	148/67**	Late AMD (GA+CNV)	Facial wrinkle length (direct correlation with sunlight exposure)	Significantly more facial wrinkling was found in patients with late AMD ( $p = 0.047$ , OR: 3.8; 95% CI: 1.01 - 13.97)
			Late AMD (GA+CNV)	Facial hyperpigmentation (direct correlation with sunlight exposure)	Less facial hyperpigmentation was observed patients with late AMD ( $p = 0.035$ , OR: 0.3; 95% CI 0.08 - 0.92)
Vojnikovic B. <i>et al.</i> (2007)	Population-based	1300	Any type of AMD (early+GA+CNV)	Exposure of sunlight	Significant correlation was observed between chronic exposure to sunlight and prevalence of any type of AMD
Plestina-Borjan I. <i>et al.</i> (2007)	Cross-sectional	623	Any type of AMD (early+GA+CNV)	Mean daily exposure (in hours) to solar radiation	A positive relationship was observed between long-term sunlight exposure and increased risk of any type of AMD
Fletcher A.E. <i>et al.</i> (2008)*	Population-based	4753	Late AMD (CNV)	Blue light exposure	Significant associations were found between blue light exposure and neovascular AMD in patients with lowest antioxidant levels (OR:1.09,95% CI:0.84-1.41)

\* significant and positive association \*\* no. of controls; GA: Geographic atrophy; CNV: Choroidal neovascularization; OR: Odds ratio; RR: Relative risk; CI: Confidence interval

that leads to the regeneration of rhodopsin and an increase phototransduction signaling in turn leads to photoreceptor apoptosis. Photoreceptor damage may also take place from liberation of ROS by all-*trans*-retinal, which is a well-known photosensitizer.<sup>15</sup>

**Blue light damage increases substantially with aging and may play a role in the pathogenesis of AMD.**

Phototoxicity contributed by lipofuscin increases substantially with age because of substantial increase in the concentration of photoreactive elements. Past studies have shown that aging significantly increased the potential for blue light hazard by nine-fold over a life span. Lipofuscin is of particular importance because of several reasons: first, the chronology of lipofuscin accumulation within RPE cells is coincident with the de-

velopment of AMD;<sup>16</sup> second, *in-vivo* autofluorescence studies have shown that degenerative changes in the retina corresponds with the areas of highest autofluorescence;<sup>17</sup> thirdly, RPE cells are retained throughout life and their repair system operates at a molecular level and this type of closed-system is more prone to ROS induced damage.<sup>18</sup>

TABLE 2 | Randomized clinical trials evaluating visual function using blue filtering IOLs versus conventional IOLs

PRINCIPAL INVESTIGATOR (YEAR OF PUBLICATION)	TYPE OF STUDY SUBJECTS	SAMPLE SIZE (N° OF EYES)		VISUAL FUNCTION	CONCLUSION
		BLUE FILTERING IOL	CONVENTIONAL IOL		
Yuan Z. <i>et al.</i> (2004)	Healthy	30*	30*	Colour vision, contrast sensitivity	Blue filtering IOLs are preferable over conventional IOLs in preserving spatial contrast sensitivity and cause less photophobia and cyanopsia in the early postoperative period
Marshall J. <i>et al.</i> (2005)	Healthy	150	147	Photopic, scotopic & colour vision	No significant difference between blue filtering IOLs and conventional IOLs in terms of visual performance
Raj S.M. <i>et al.</i> (2005)	Congenital color blind (partial red-green)	30	30	Colour vision	No significant difference between blue filtering IOLs and conventional IOLs in terms of visual function in subjects with congenital partial colour blindness
Rodriguez-Galiero A. <i>et al.</i> (2005)	Diabetes	22	22	Colour vision, contrast sensitivity	Blue filtering IOLs improved color vision in the blue-yellow chromatic axis in diabetic patients
Kara-Júnior N. <i>et al.</i> (2006)	Healthy	56	56	Photopic & colour vision	No significant difference between blue filtering IOLs and conventional IOLs in blue-yellow perception
Vuori M.L. <i>et al.</i> (2006)	Healthy	25	27	Colour vision	No significant difference between blue filtering IOLs and conventional IOLs in color vision
Muftuoglu O. <i>et al.</i> (2007)	Healthy	38	38	Photopic, scotopic & colour vision and contrast sensitivity	No significant difference between blue filtering IOLs and conventional IOLs in terms of visual performance
Landers J. <i>et al.</i> (2007)	Healthy	93	93**	Colour vision, contrast sensitivity	No significant difference between blue filtering IOLs and conventional IOLs in terms of visual performance
Schmidinger G. <i>et al.</i> (2008)	Healthy	31*	31*	Colour vision, contrast sensitivity	No significant difference between blue filtering IOLs and conventional IOLs in color contrast sensitivity
Kiser A.K. <i>et al.</i> (2008)	AMD	22	22	Photopic, scotopic & colour vision	No significant difference between blue filtering IOLs and conventional IOLs in scotopic vision but detection of navy colour may be impaired
Wirtitsch M.G. <i>et al.</i> (2009)	Healthy	48*	48*	Colour vision, contrast sensitivity	Blue filtering IOLs negatively affect contrast acuity and blue/yellow foveal threshold when compared with conventional IOLs
Kara-Junior N. <i>et al.</i> (2011)	Healthy	30	30	Photopic, scotopic & colour vision and contrast sensitivity	No significant difference between blue filtering IOLs and conventional IOLs in terms of visual performance
Espíndola R.F. <i>et al.</i> (2012)	Healthy	27	27	Photopic, scotopic & colour vision	Contrast sensitivity was better under mesopic conditions with conventional IOLs; however, no significant difference was observed between blue filtering IOLs and conventional IOLs in terms of color vision

Blue filtering intraocular lens (IOLs) refer to Alcon SN60AT except \* corresponding to Hoya UV AF-1 and \*\* corresponding to other conventional IOLs

Several studies in the past have evaluated the role of blue light on the development of AMD (Table 1). A study by Taylor *et al.* on 838 watermen of the Chesapeake Bay demonstrated that patients with advanced AMD had significantly higher exposure to blue or visible light over the preceding twenty years.<sup>19</sup> Similarly, the Beaver Dam Eye Study observed that visible light rather than UV light might be associated with AMD.<sup>20</sup> Furthermore, the EUREYE study found a significant association between blue light expo-

sure and late neovascular AMD in individuals having the lowest antioxidant levels.<sup>21</sup>

Recently, a systematic review and meta-analysis included fourteen studies that evaluated the association between sunlight exposure and AMD. In this review article, twelve out of fourteen studies identified an increased risk of AMD with greater sunlight exposure, six of which reported significant risks. The pooled odds ratio was 1.379 (95% confidence interval 1.091 to 1.745). The

subgroup of non-population-based studies revealed a significant risk (odds ratio 2.018, confidence interval 1.248 to 3.265,  $p=0.004$ ). The authors concluded that individuals with more sunlight exposure are at significantly increased risk of AMD.<sup>22</sup> It is important to note that epidemiological studies evaluating light exposure and risk of AMD have several limitations. The pathogenesis of AMD is very complex and lifetime light exposure cannot be measured accurately. Also, there are notable dif-



difficulties in such studies that depend on the patients' own recall about cumulative exposure to blue light. Moreover, other factors including variability in genetic susceptibility or diet may obfuscate the true relationship between light exposure and AMD.

The nature of the blue light induced damage is dependent not just on the photoreactivity of a variety of chromophores but also on the capacity of the defense and repair systems. One of the defense systems that deserve special mention is macular pigment (MP). MP is composed of two dietary carotenoids, lutein (L) and zeaxanthin (Z), and has peak concentration within the central 1-2 degrees of the fovea.<sup>23</sup> MP carotenoids are natural protective filters attenuating short-wavelength light prior to photoreceptor light capture with absorbance spectra ranging from 400 to 500 nm (lutein = 452 nm; zeaxanthin = 463 nm). It is therefore particularly effective at reducing the potentially damaging effect of lipofuscin whose photoreactivity peaks at 450 nm<sup>11</sup> in elderly population. MP acts, uniquely as an antioxidant, both passively and actively, the former mechanism being dependent on its ability to limit photo-oxidative damage by filtering short wavelength light at a pre-receptorial level and the latter mechanism attributable to its capacity to quench ROS.<sup>24, 25</sup>

**Implantation of blue-light filtering intraocular lens (IOLs)** following cataract surgery may have the potential to protect the retina from oxidative damage secondary to blue light and slow the progression of AMD. In experimental studies, these IOLs have been demonstrated to significantly reduce the death of RPE cells from light induced damage mediated by lipofuscin fluorophore A2E.<sup>26</sup> Furthermore, blue light filtering IOLs may provide addi-

tional visual benefit for AMD patients because blue light is selectively scattered by the ocular media and its attenuation has been associated with improvements in contrast sensitivity and a reduction in glare sensitivity.<sup>27</sup>

There have been theoretical speculations about the potential negative ramifications of filtering blue light. Blue light provides 35% of scotopic vision, 53% of melanopsin, 55% of circadian and 32% of s-cone photoreception. Blue light filtering IOLs eliminate 27-40% of incident blue light depending on their dioptric power.<sup>28</sup> The decrease in blue light photoreception therefore may result in impairment of color vision, scotopic vision, and circadian rhythm. Several randomized clinical trials have been conducted to compare visual performance using blue filtering IOLs and conventional IOLs in healthy volunteers and in patients with AMD (Table 2). The results from these trials suggest that there are no clinically significant effects on various measures of visual performance, including color vision, photopic and scotopic sensitivities and contrast sensitivity with blue filtering IOLs.<sup>29</sup> Also, given the great improvement in light transmission achieved simply

**“In the future, well-designed clinical trials should be undertaken to evaluate the effect of blue light filtration in the development and/or progression of AMD.”**

by removing the cataract, it seems unlikely that blue filtering IOLs cause any significant disruptions to the circadian rhythm. However, there is a current lack of evidence that demonstrates that blue filtering IOLs have any effect on AMD. No randomized prospective studies have been conducted to prove claims of macular protection against progressive disease.

Furthermore, a recent study in animal model suggested that the 415-455 nm spectral range might be the most damaging light for patients at risk of AMD.<sup>30</sup> The authors suggest that filters in this narrow bandwidth would not occlude light in the 460-500 nm range, not only essential for color vision but also for circadian rhythm regulation mediated by melanopsin-sensitive retinal ganglion cells. However, it remains to be evaluated if new selective ophthalmic filters in the defined bandwidth could provide macular protection in patients at risk of AMD.

Similarly, another proposed option is to use eyeglasses that attenuate short-wavelength light in bright environments for effective photo-protection. Crizal® Previncia® No-Glare clear lenses represent the first application of new patent-pending technology

**“Blue light may damage the retina  
in a number of ways involving different  
chromophores and cellular events.”**

that enables selective attenuation of harmful light, both UV and blue-violet, while allowing beneficial light to pass through and maintaining exceptional transparency at all other visible-light wavelengths. The goal is to enable patients to enjoy the best vision with significant protection against UV and high-energy blue-violet wavelengths. The advantage of eye-glasses (c.f. IOLs) lies in the fact that there is freedom to remove sunglasses for optimal scotopic and circadian photoreception, if necessary.

**In summary**, there is persuasive theoretical and experimental evidence suggesting that blue light exposure may damage the retina and possibly play a role in the pathogenesis of AMD; however, there is a paucity of clinical evidence to support this notion. In the future, well-designed clinical trials should be undertaken to evaluate the effect of blue light filtration, particularly those with narrow bandwidth, in the development and/or progression of AMD. •

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## KEY TAKEAWAYS

- Blue light provides 35% of scotopic vision, 53% of melanopsin, 55% of circadian and 32% of s-cone photoreception. Yet blue-violet light may damage the retina.
- The nature of the blue-violet light induced damage is dependent on the photoreactivity of a variety of chromophores and on the capacity of the defense-repair systems.
- A systematic review and meta-analysis indicates that people with more sunlight exposure are at significantly increased risk of AMD.
- However, individual patients' cumulative exposure to blue-violet light is complex to measure. Several other individual factors involved in AMD pathogenesis can vary, including genetics, diet, etc.
- Implantation of blue-light filtering intraocular lens (IOLs) following cataract surgery may have the potential to protect the retina from oxidative damage secondary to blue light and slow the progression of AMD.
- Blue light filtering IOLs eliminate 27-40% of incident blue light depending on their dioptric power.
- It remains to be evaluated if new selective ophthalmic filters in the defined bandwidth could provide macular protection in patients at risk of AMD and/or patients operated from cataracts.

# The Benefits and Dangers OF BLUE LIGHT

By Christian Sotty

The blue light region in the visible light spectrum has captured the interest of scientists due to its role in non-visual biological mechanisms such as regulation of the circadian cycle. This part of blue light can have a positive impact on health, and it ranges from 465 to 495 nanometers (nm) (Blue-Turquoise light).<sup>1</sup> However, in the range of 415 to 455 nm (Blue-Violet light), it has been established that light induces a high level of mortality in the retinal pigment epithelium (RPE) cells.<sup>2</sup> Blue light (also known as high energy visible light) ranges from 380 nm to 500 nm. It is emitted by both natural (sun) and artificial light sources, such as LED lighting.

## Synchronizing our biological clock

Light, and in particular “good” blue light, also known as “chronobiological light,” regulates our individual circadian rhythm. We need to reset our biological clocks daily in order to synchronize our biological rhythm. Our clock transmits to a number of parts of the body, such as the liver, muscles, heart, kidneys and other organs. All biological functions need to work at the right moment, and because our biological clock drives this particular rhythm, it ensures particular functions are active at the right time.

“Light acts on the retina through the action of specific cells—melanopsin-containing ganglion cells—which are different from the cones and rods that are the photoreceptors used in vision,” said Claude Gronfier, INSERM (French Institute of Health and Medical Research) chronobiology researcher. “When these ganglion cells are activated by blue light, they transmit a nerve signal that runs along the optic nerve and, rather than activating the visual structures in the brain, activates non-visual structures such as our internal circadian clock. So it’s exposure to light that resets the time on the biological clock.”

## Blue light and AMD

Recently, it has been shown that exposure to light contributes to the early occurrence of

age-related macular degeneration (AMD).<sup>3</sup> *In-vitro* experiments on porcine cell cultures point specifically to blue light, which is more energy intensive. Macular pigments are natural filters for these wavelengths. Unfortunately, pigments don’t accumulate well in the retina as we age or when disease starts.

“It’s essential to combine several approaches to help explain the pathophysiological impact of light on the retina and the part played by these effects on retinal conditions,” said Serge Picaud, INSERM director of research at the Paris Vision Institute.

“This multidisciplinary aspect was one of the challenges of a recent project in which we tried to determine toxic wavelengths in the visible spectrum. Our main aim was to calculate the relative quantity of light reaching the retina in each wavelength. We measured the toxicity of these relative irradiances using an AMD porcine cell model.

“The work enabled us to define the most phototoxic spectral bands against this cellular model,” he said. “Optics specialists from Essilor took part in the project to help us design optical devices to calculate retinal light irradiances and to manipulate concepts involving light, while researchers from the Paris Vision Institute brought their knowledge of vision and their know-how in experimental biology as applied to the retina. It was important to be able to draw on the results to establish preventive strategies designed to limit the initial development or further progress of visual pathologies.”

## 10-nm illumination bands

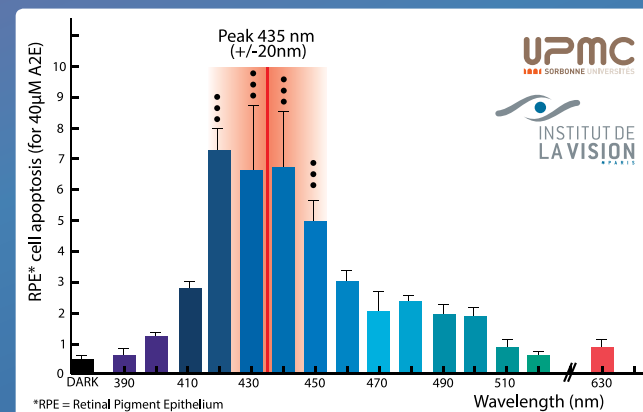
The blue light spectrum is very wide, rang-

ing in broad terms from 380 to 500 nm. It was important to target the blue wavelengths that were most harmful and control the illumination values used to expose the cells to light.

“We produced an illumination device that allowed us to convey light on very restricted, narrow wavelengths—and we split the visible light spectrum into 10-nanometer bands,” said Emilie Arnault, photobiology project manager in the Translational Systemic and Therapeutic Biology of Vision department at the Paris Vision Institute. “Each band was guided by an optic fiber toward a cell incubator. This allowed us to split the visible light spectrum and precisely control the degree of illumination for each wavelength. We were able to produce intensities of illumination in proportion to those of the solar spectrum for each 10 nm band.”

All of these elements confirm the importance of the research currently conducted to accurately describe the wavelengths of blue light: we need to be able to distinguish good from bad clearly so that we can then develop a sophisticated filtering system to address the harmful effects of one while retaining the positive effects of the other.

## RPE Cell Death per Wavelength<sup>2</sup>



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## **II. BLUE LIGHT AND DIGITAL ENVIRONMENT**

# THE DIGITAL ENVIRONMENT AND ASTHENOPIA

The incidence of asthenopia is steadily increasing. The main culprit is the increasingly varied and intensive use of digital displays. This dual trend, however, is far from being a foregone conclusion. The observations and ideas for preventive solutions presented below were expressed during an interview with Dr. Marcus Safady, an ophthalmologist practicing in Rio de Janeiro and the 2013-14 president of the SBO - Sociedade Brasileira de Oftalmologia (Brazilian ophthalmology society).



**Dr. Marcus Safady**

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Marcus Safady graduated in medicine in 1980 from Universidade Federal do Rio de Janeiro.

Ophthalmologist with the Associação Médica Brasileira in 1984.

Teacher of the ophthalmology specialization course of Sociedade Brasileira de Oftalmologia.

Head of the glaucoma department of Hospital Federal de Bonsucesso, Rio de Janeiro.

Currently chairman of the Sociedade Brasileira de Oftalmologia (S.B.O.).

**Points de vue: What are Brazilian ophthalmologists seeing during consultations?**

**Dr. Marcus Safady:** We are seeing more and more patients suffering from asthenopias in our practice. Nowadays, symptoms such as dry eyes, red eyes, eye strain sensations, blurred near vision, headache, peri-, intra- or retro-ocular pain, and glare sensations are extremely common. The origins of these symptoms may be refractive (uncorrected or poorly corrected), accommodative or muscular, and clinicians must consider their true cause to treat them effectively.

**KEYWORDS**

Asthenopia, eyestrain, postural fatigue, glare, headache, dry eye, contrast perception, adaptation, comfort, posture, digital displays, ergonomics, e-reading, digital devices, connected life, computer, smartphone, tablet, Essilor® Eyezen™, ophthalmic lenses, protocol, eye examination.



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### What correlation do you see between asthenopia and digital displays?

If the patient is properly corrected and presents no particular abnormality in binocular vision, asthenopia symptoms are generally related to external causes. Foremost among them is the intensive use of digital devices, now ubiquitous in our daily lives. When we work in front of a screen our eyes blink less often, resulting in dryness of the ocular surface. The effort of accommodation and convergence is also more sustained due to the increased proximity of multiple displays (e.g. the smartphone and tablet are used at closer distances than the computer). Our eyes make an effort to focus and converge on more or less pixelated targets, whose quality and contrast vary, while remaining exposed to high screen brightness levels. The light emitted is characterized by a predominant dazzling white light that peaks in the blue at short wavelengths. An ophthalmic impact is unavoidable.

**“Asthenopia symptoms are generally related to external causes correlated with the ubiquitous use of digital devices in our daily activities.”**

### Does this type of disorder affect some populations more than others?

These displays exacerbate existing visual defects and also affect those who do not wear glasses. Studies show that 60% to 90% of people using digital displays have more or less troublesome symptoms of eye disorders, regardless of their visual correction. Ophthalmic consultations reveal this problem in adults, children and adolescents. In fact, young people, who often keep their eyes glued to video games, cell phones and computers all day long, even at school, are a particularly vulnerable population.



Photographer © João Salamonde / joaosalamonde.com.br

**“Displays exacerbate existing visual defects and also affect those who do not wear glasses.”**

#### **What are the most common solutions and recommendations?**

Patients may not be aware of the causes. When they consult, they usually come in for a refractive problem. They complain of eyestrain and subjective symptoms. Ophthalmologists need to be attentive and play an active role in the fight against this very real scourge. Recommendations are simple: a good visual examination (including visual acuity, binocular vision and accommodation), a refractive correction, ergonomic advice (i.e.

best practices for the use of digital devices) and the prescription of a treatment (i.e. eye drops to relieve ocular dryness) or a preventive solution such as appropriate ophthalmic lenses.

#### **How is treatment for this problem handled in Brazil?**

In Brazil, as in the other countries, eye problems related to the ubiquity of digital displays are widespread. Vision care professionals are increasingly aware and a "standard" protocol is beginning to emerge. It is organized into four





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**“Young people, who often keep their eyes glued to video games, cell phones and computers all day long, even at school, are a particularly vulnerable population.”**

main points and is potentially very beneficial for the patient. First point: increasingly frequent consultations with age, arriving finally at an annual rate (eye check once a year). Second point: ergonomic advice (on posture, lighting, rest, etc.) to avoid exacerbating the problem. Third point: better lubrication of the ocular surface, simply by blinking more frequently or via artificial tear solutions. Finally, the fourth and central point of the prevention plan for asthenopia related to digital device use involves the prescription of ophthalmic lenses adapted to the specificities and pervasiveness of digital displays.

#### **What are the desired characteristics for these preventive lenses?**

They are two in number. The first is the provision of additional refractive power at the bottom part of the lens to relieve the eye's accommodative effort. A few fractions of additional diopter are invaluable when working for hours in front of a digital display. The second is the presence of a filter blocking blue light and the glare effect: a selective anti-reflective treatment reduces screen brightness and blocks harmful blue light.



Photographer © João Salamonde / joaosalamonde.com.br

**“The central point of the prevention plan for asthenopia related to digital device use is the prescription of ophthalmic lenses adapted to the specificities and pervasiveness of digital displays”**

The perfect ophthalmic lens must combine both features to fight effectively against asthenopia generated by digital device use.

**These characteristics seem to be consistent with the ophthalmic lens offer called Eyezen and designed by Essilor research centers?**

Absolutely!



#### KEY TAKEAWAYS

- Intensive use of digital displays increases the incidence of asthenopia.
- The problem affects all age groups and as many people not wearing glasses as those with visual defects.
- In Brazil, an easy-to-use four-point protocol is helping to fight effectively against this type of disorder.
- Glasses combining additional refractive power in the bottom part of the lens and a blue light filter are the main preventive solution prescribed for asthenopia related to digital device use.

# WILL “DIGITAL VISION” MEAN A BLURRY FUTURE?

Research points to the growing use of digital devices. In parallel, myopia is at epidemic levels in countries around the globe. Taking the longer view, this epidemic could have a negative impact on the lives of the myopic people, especially as they age, and will increase the economic burden that poor vision creates on the world around us.



**Maureen Cavanagh**

President of the Vision Impact Institute,  
USA

In 2014, Maureen Cavanagh accepted the role of president of the Vision Impact Institute. She joined Essilor in 2005 and has held various executive leadership positions within the company. Cavanagh has extensive experience in vision healthcare, having worked for Johnson & Johnson's Vistakon and Spectacle Lens divisions before joining Essilor. Cavanagh earned her bachelor's degree from Bridgewater State University. She is a long-time member of the Optical Women's Association and has received numerous industry awards of distinction, including the OWA Pleiades Award in 2015 and Jobson's Most Influential Women in Optical 2012.



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## KEYWORDS

digital devices, digital screens, digital media, digital vision, connected life, computer, smartphone, tablet, socio-economic impact, myopia, shortsightedness, myopia epidemics, impaired vision.

## Myopia widespread and growing; links to near vision demanding tasks and small digital screens

It's been reported that of the approximately 7 billion people in the world, more have access to a mobile phone than a toothbrush.<sup>1</sup>

That astonishing statistic speaks to the power and pervasiveness of digital communication and information. Millions of people on this earth can use the technology to text or make a phone call, yet may not have running water and electricity in their residences.

Let's admit that there is a hypnotic quality to the digital screens that inhabit our lives. Follow someone into an elevator as they are absorbed in what they're reading on the phone. Stop to watch people on a busy street corner, exiting an office building or on public transportation – it's a safe bet that a large number will have a smartphone or other digital device in their hands.

We are turning more and more of our daily routine over to our digital devices. From getting the news, to paying for coffee, to receiving directions to reminding us of appointments – digital devices have become the personal assistants for 21st-century lives.

We are living multi-screen lives and are more productive because of it. However, have we stopped to consider how spending so much time squinting at small screens is impacting our vision? Eye health professionals are increa-

singly worried about “digital vision” and the consequences resulting from spending so much time focused on small screens. In addition to failing eye sight, there are the related health issues and socio-economic impacts to consider. While users aren’t abandoning their digital screens, eye health professionals should be aware how to better advise them to be productive and retain their healthy vision.

**Myopia increasing in Asia**

In parallel, we observe a rise of myopia in developed and developing nations worldwide. It’s at epidemic levels. Eastern Asia, Europe and the United States have all seen a dramatic increase in the number of people who are experiencing shortsightedness.

Myopia is an elongation of the eyeball. While not being able to see distances can be frustrating, even dangerous when driving, it can be corrected with spectacles, contact lenses and refractive surgery. However, high myopia has been associated with a higher risk for ocular disorders, including retinal detachment and glaucoma.

According to researchers, rates of myopia have doubled, even tripled, in many eastern Asia countries during the past 40 years. Hong Kong, Singapore and Taiwan have experienced rate increases hovering around 80 percent. Professor Kathryn Rose of the University of Technology Sydney and Ian Morgan with the Australian National University mentioned the prevalence of myopia in East Asia as ranging from 82% to 96% depending on age groups and countries.<sup>2</sup> Published studies confirm those figures:

LOCATION	PERCENTAGE OF MYOPIA	AGE GROUP	YEAR OF THE STUDY
Seoul	96.5%	19 yo	2010 <sup>3</sup>
Taiwan	86.1%	18-24 yo	2010 <sup>4</sup>
Guangzhou, China	84.1%	17 yo	2007 <sup>5</sup>
Singapore	81.6%	17-29 yo	2009-2010 <sup>6</sup>

Since 1963, Chinese students have participated in a daily routine designed to relieve eye fatigue. While seated at their desks, they massage the pressure points around their eyes. It doesn't seem to be working. Rates of myopia have been soaring in Chinese cities, nearing almost 90 percent in places.<sup>2</sup>



CHILDREN

## Direct Costs of Myopia in Teenagers

In Singapore, where an estimated 74% of teenagers are myopic, a 2008 study calculated the direct costs of myopia for teenagers and their families to be \$25 million.



Source:

Singapore Quek et al. "Prevalence of refractive errors in teenage high school students in Singapore". *Ophthalmic Physiol Opt* 2004 24.

### Myopia prevalence in Europe

European countries have been experiencing the impact of digital vision and myopia as well. The European Eye Epidemiology (E<sup>3</sup>) Consortium has done an extensive study of meta-data associated with eye health research which estimates that refractive error affects more than half of the continent's adult population – myopia being the leading type with 227.2 million people based on 2010 population estimates. Based on this study, the prevalence of myopia suggests that about 20.1 million Europeans are therefore at higher risk for associated complications such as retinal detachment.<sup>7</sup>

The E<sup>3</sup> study also shows that younger people are more affected by myopia than their parents. According to the study, about one-half of younger Europeans are affected. After analyzing the data, the study uncovered that overall levels of myopia have increased about one-third for adults born after 1940 as compared to those born before that year.

In a news release about a King's College London research project, Katie Williams from the university's Department of Ophthalmology, said, "We knew myopia was becoming more common in certain parts of the world – almost 8 in 10 young people are affected in urban East Asia – but it is very interesting to find that the same pattern is being seen here in Europe. This has major implications for the future burden from this eye disease which can threaten sight in older age, particular in very shortsighted people."

The same rise in myopia is happening in the United States. The American Academy of Ophthalmology estimates that the current rate of myopia has risen to 40 percent from 25 percent in the 1970s.<sup>8,9</sup>

### Link between myopia and education

Another interesting finding in several research studies is the association between level of education and the incidence of myopia. The research suggests that the more educated the person – regardless of where they live – the more likely they are to suffer from shortsightedness.

**“Eye health professionals are increasingly worried about “digital vision” and the consequences resulting from spending so much time focused on small screens”**

GLOBAL POPULATION

Corrected Vision Could Save Millions Per Year

The total economic cost of myopia in adults over 40 years old in Singapore is estimated to be approximately \$755 million per year.



Source: The Economic Cost of Myopia in Adults Over 40 Years in Singapore, Oct. 2013.  
www.visionimpactinstitute.org



This is significant because it points to lifestyle factors as having a role in the rise of myopia.

The E<sup>3</sup> analysis of studies, which looks at more than 60,000 people, shows that the rate of myopia is about twice as much higher in people with college degrees compared to those whose education stopped with primary school.<sup>9</sup>

One of the studies included in the E<sup>3</sup> analysis was what is known as the Gutenberg Health Study from the University Medical Center in Mainz, Germany. By examining 4,685 people ranging in age from 35-74 without cataracts or refractive surgery, the results show that myopia increases as education increases.<sup>9</sup>

LEVEL OF EDUCATION	PREVALENCE OF MYOPIA
No high school or other training	24 percent
High school or vocational school graduates	35 percent
University graduates	53 percent

The question is then natural: Is there a link between myopia development and the use of digital devices? Although

no study has shown a direct link, it has been shown that when using handheld video games, children adopt a closer working distance which in turn may favor Myopia onset and progression.<sup>7</sup> Indeed, near work behavior appears to be highly linked to myopia prevalence. Epidemiological studies showed that higher amount of near work results in a high prevalence of myopia in children.<sup>10,11,12</sup>

**The digital vision “antidote”**

This rapid rise in myopia is alarming, especially as it affects younger people the most. Are we raising a global generation that will suffer from poor vision throughout their lives?

There is research that indicates that sunshine can be an antidote to digital vision. An Australian research project from 2003-2005 shows that time spent outdoors in natural light significantly affected the presence of myopia in children.<sup>13</sup> Longer time of outdoor activity, such as sports and leisure activities, were associated with more hyperopic refractions and lower myopia rates in the 12-year-old students studied. Those who combined longer time of near work with shorter time of outdoor activity

**“In addition to failing eye sight, there are the related health issues and socio-economic impacts to consider”**

**“With the increased use of digital devices and rising rates of myopia, an annual exam is the best way for parents to have poor vision diagnosed – and then corrected as needed – in their children.”**

had the least hyperopic mean refraction, while the students who combined low levels of near work with high levels of outdoor activity had the most hyperopic mean refraction. The lowest odds for myopia were found in groups reporting the highest levels of outdoor activity.

Chinese schools are testing various methods to improve that country’s myopia epidemic. Some schools are experimenting with transparent classrooms – the walls and ceilings are constructed of see-through material to allow for as much light as possible – to determine if that helps improve the students’ eyesight.

Other schools are forcing children to be outside more during the day and away from near vision demanding tasks including small digital screens. Students are sent outside during lunch and recess with the doors locked to keep them there.<sup>14</sup>

The role of sunlight in our eye health is not completely understood as of yet. A theory suggests that the healthy wavelengths on the blue light spectrum from the sun (the good blue) releases dopamine in the retina which would

prevent the eyeball from elongating, thus preventing from myopia. These wavelengths are also protective to vision and other health functions. And the cumulative effect of the damaging wavelengths of blue-violet light (the bad blue) has been linked to retinal cell death, and possibly to AMD. The sources such as artificial light (cold LED), computer screens and handheld devices are rich in harmful blue-violet light and may source potential risks.

In addition to good old-fashioned outdoor playtime for children, the importance of an annual eye examination by a trained vision professional can’t be over emphasized. With the increased use of digital devices and rising rates of myopia, an annual exam is the best way for parents to have poor vision diagnosed – and then corrected as needed – in their children.

**Promising research**

Promising researches from specialized centers in Australia and China do offer hope. The Vision Cooperative Research Center (Vision CRC) is a partnership between the Brien Holden Vision Institute at the University of New South Wales and the University of Houston College of Optometry.



**“Let’s not give up the digital devices, but let’s be sure to take care of users’ eye health while advising both an annual comprehensive eye examination and frequent breaks from “digital vision” to take in a longer view.”**

It has announced a new technology that slows the progression of myopia in children. Vision CRC has been conducting large-scale clinical trials in Australia and China designed to control in participating children the position of the central and peripheral retinal image points. Therefore, corrective lenses can be made to control myopic progression by changing the retinal image position at the periphery without affecting the image at the center of the retina. Professor Brien Holden (1942 - 2015) has been quoted saying, “What we need are treatments that effectively slow the progress of myopia which will significantly reduce the prevalence of high myopia. A reduction in the rate of myopia of 33% could produce a 73% reduction in myopia above 5.00 D.”<sup>15</sup>

To strengthen research on myopia, Essilor International and the Wenzhou Medical University in China, opened in 2013 a joint research laboratory: the Wenzhou Medical University-Essilor International Research Center (WEIRC).

“What makes it all the more important is that the link between the severity of myopia and the risk of associated conditions is exponential. Slowing the development of myopia by only 50% reduces the risk of conditions that can lead to blindness (retinopathy, retinal detachment, etc.) by a factor of 10,” explains Dr. Björn Drobe, Essilor Group Researcher and Associate Director of WEIRC.

The laboratory works on three different approaches. The first is to gain a clearer understanding of the mechanisms that cause children to develop myopia. The second focus for research relates to the predictability of myopia, and more particularly involves a study conducted with a group of 1,000 children from urban and rural environments. Lastly, the laboratory is working to identify new ways of controlling the development of myopia through a clinical trial involving 210 children.

“Ultimately, the new knowledge gained will enable us to make our products more effective in terms of slowing the development of myopia with offerings that are suitable for all children and are attractively designed, as well as enabling the development of innovative solutions to counter the myopia pandemic,” summarizes Dr. Björn Drobe.

#### **Socio-economic impact of myopia**

Impaired vision is the most common disability in the world, affecting 4.3 billion around the globe.<sup>16</sup> The good news is that 80 percent of those impairments can be avoided or cured. However, that much vision impairment comes with a price tag.

While the global direct socio-economic impact of myopia hasn’t been determined yet, the effect of poor vision on the global economy is well documented. A 2012 review by the Boston Consulting Group and Essilor found that:<sup>17</sup>

- Approximately 33 percent of the world’s working population has uncorrected vision problems that result in a \$272 billion loss of productivity to businesses globally.





- Poor vision slows the education of school-aged children, resulting in academic under-achievement and risk of reduced adult literacy. In fact, 30% of children worldwide need vision correction and don't have it.
- Impaired vision is associated with 60 percent of driving accidents around the world.
- Globally, poor eyesight multiplies by seven the risk of falls and hip fractures in the elderly.

The National Medical Research Council of Singapore commissioned a study on the economic cost of myopia. In 2009, the mean annual direct cost of myopia for school-aged children in Singapore was \$148 (U.S. dollars), with the median cost at \$83.33 (U.S. dollars) per student.<sup>18</sup> It also showed that the cost of refractive surgery equaled the cost of buying and wearing contact lenses for 10 years. Beyond the cost for children, with a myopia rate of 39% in adults over 40, a 2013 study estimates the total cost of myopia for this population to be approximately SGD\$959 (USD\$755) million per year in Singapore.<sup>19</sup>

#### What it means for the future

Research has indicated that myopia is rapidly rising in East Asia, Europe and the United States, especially among younger people. And research points to factors other than genetics, such as behavior and environment, as causing this epidemic. Is the common denominator among these the time spent using digital devices at near?

The global use of these devices is only going to grow as we

increasingly rely on them to connect with friends, get our news, make financial transactions, and simply make our lives easier and more productive. As a planet, we spend 3 billion hours a week playing video games.<sup>10</sup> That means that we will spend more time in "digital vision" mode - fixated on small glowing screens using our eyes for near vision more often.

#### There will be consequences.

Yes, the majority of myopia cases can be corrected with spectacles, contact lenses or refractive surgery. And the research centers such as Vision CRC and WEIRC, as well as the technology development, give us hope for a better-seeing future. However, with so many young people dealing with shortsightedness, as they age the cost and impact of poor vision is likely to increase from such things as loss of productivity,<sup>21,22</sup> motor vehicle accidents, falls, and social isolation. Add to that the significant increased risk people with high myopia have for related vision diseases.

Let's not give up the digital devices, but let's be sure to take care of users' eye health while advising both an annual comprehensive eye examination and frequent breaks from "digital vision" to take in a longer view. •



## KEY TAKEAWAYS

- An epidemic of myopia is circling the globe, with Eastern Asia, Europe and the United States seeing rising rates of shortsightedness, especially in young people.
- Research shows that there is a link between education level and myopia rates – those with more education are more likely to be myopic.
- Corresponding to the increase of myopia is also an increase in near vision demanding tasks including the use of small digital devices as people rely on them more not only to communicate, but also to access news, information and entertainment.
- “Digital vision” will likely have a socio-economic impact on the world, especially as young people with myopia grow older.


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# DIGITAL EYE STRAIN IN THE USA: OVERVIEW BY THE VISION COUNCIL\*


With its annual survey, *Hindsight is 20/20/20: Protect Your Eyes from Digital Devices*<sup>1</sup>, The Vision Council monitors usage trends related to digital displays and their impact, as regards both eye strain and exposure to blue light. The report's 2015 edition highlights the growing pervasiveness of digital displays in the United States and the stakes in raising awareness of the actors involved in the visual health sector like the general public.



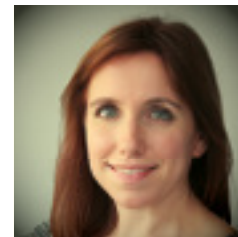
 **Mike Daley**  
Chief Executive Officer (CEO),  
The Vision Council, USA


Mike Daley began his optical career as an instructor with Ferris State University in 1975. He joined Essilor in 1976. With consolidated skills in sales, marketing, technical services, laboratory operations, he served as the President of Varilux Corporation (1989-1995). After 32 years with Essilor, he retired in 2008 as the President and CEO of the Lens Division of Essilor of America. Throughout his career, he has been recognized by his peers and has served in a leadership position for an impressive number of optical organizations including National Academy of Opticianry (NAO) Hall of Fame; Prevent Blindness America, Board of Directors; AOA Optometric Charity Board; SoloHealth Board of Directors; The Vision Council of America, Board of Directors, and past Vice Chairman. He holds Ferris State University Honorary Doctorate (2006).



 **Dr. Dora Adamopoulos**  
Medical advisor, The Vision  
Council, OD in Alexandria, USA

Dr. Adamopoulos graduated as a Doctor of Optometry from the New England College of Optometry in 1998. During her last few academic years, she had the opportunity to sharpen her clinical skills through a series of rotations in different types of medical settings on the East Coast. After graduation she worked in the private practice arena, treating and managing ocular pathology in a geriatric population. Today, she devotes her expertise to welcome and treat patients suffering from dry eyes, allergies, diabetes, cataracts and glaucoma. Involved in the development of visual health in the United States, she collaborates with the Vision Council as medical advisor.



 **Erin Hildreth**  
Marketing and Communication  
Manager, The Vision Council, USA

Erin Hildreth has great past experience in communication, marketing and education. She served as the Education Manager for the Health Industry Distributors Association (HIDA), coordinating and providing contents for trainings. She led several editorial projects including advertising, content management and online development. Today, she is responsible for marketing and communication at The Vision Council. She develops and implements programs that educate consumers about eyewear trends, lens technology and health aspects. Keeping strong focus on eye health benefits, she works on UV awareness, protection and prevention necessity (including digital eye strain), aging and low vision.

## KEYWORDS

displays, posture, ergonomics, e-reading, digital devices, connected life, Internet, new technologies, computer, smartphone, tablet, e-book, e-reader, TV, console, connected lifestyles, blue light, LED, digital eye strain, visual health, eye health.



\* The Vision Council  
Serving as the global voice for vision care products and services, The Vision Council represents the manufacturers and suppliers of the optical industry. The Council positions its members to be successful in a competitive marketplace through education, advocacy, consumer outreach, strategic relationship building and industry forums.

**“FROM THE MOMENT PEOPLE GET UP UNTIL THE TIME THEY GO TO BED AGAIN – INCLUDING WHEN THEY ARE EATING, EXERCISING AND READING – THEY ARE USING ONE DIGITAL DEVICE AFTER ANOTHER AND THUS EXPOSING THEMSELVES TO RISKS RELATED TO PROLONGED EXPOSURE TO LIGHT EMITTED BY SCREENS”**

**M. DALEY**

**Digital eye strain is more than a reality; it is a public health priority in the United States.** This is the warning published by The Vision Council\*, which has just released its latest survey on this issue: *Hindsight is 20/20/20: Protect Your Eyes from Digital Devices*<sup>1</sup>. The document is based on an analysis of 9,749 questionnaires completed by a representative sample of adult U.S. residents. Its aim is to determine the broad outlines of behavioral changes with respect to digital displays, be they smartphones, tablets, computers, laptops or other electronic devices, such as game consoles. This state of play confirms the trend that has emerged in recent years: *“From the moment people get up until the time they go to bed again – including when they are eating, exercising and reading – they are using one digital device after another and thus exposing themselves to risks related to prolonged exposure to light emitted by screens,”* sums up Mike Daley, chief executive officer of the Vision Council.

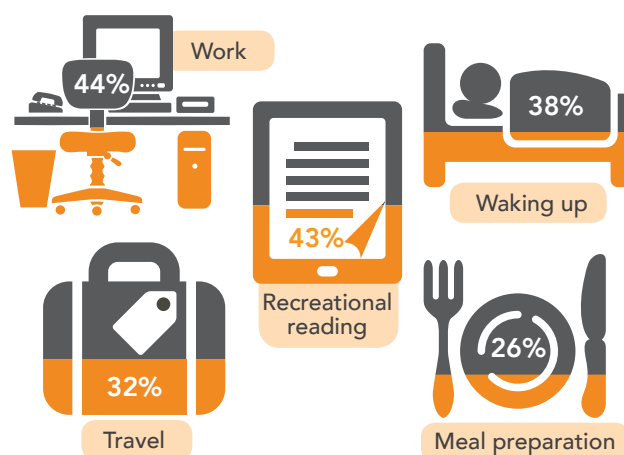
In concrete terms, **more than 95% of American adults spend at least two hours a day in front of a screen and almost three out of ten spend over nine hours.** Even though people working on computers are the most concerned by a potential “overdose”, **the study stresses that one child out of four is exposed to screens over three hours a day.** These constantly increasing figures can be explained by both new societal patterns (i.e. a decrease in physical activity, an increase in passive

consumption and paperless contacts, etc.) and options made possible through innovation. *“Digital technologies offer ever increasing options and opportunities to simplify consumers’ daily lives. This growing trend is not likely to be reversed any time soon. Nor are the related ophthalmic problems,”* Daley predicts.

#### **Screens as a source of eye strain**

The main effect of prolonged exposure (greater than two hours per day) to light emitted by screens is digital eye strain. Described as a passing discomfort, it manifests itself in different forms with symptoms such as red, dry or irritated eyes, blurred vision, pain in the neck, shoulders or back, headache, etc. *“We blink 18 times a minute on average. However, staring at a screen for an extended period can result in less frequent blinking that could dry or even irritate the eyes”<sup>2</sup>,* Erin Hildreth reminds us. The Vision Council’s marketing and communication manager relates that a recent study<sup>3</sup> concluded that employees

#### **Activities Associated with Digital Device Use:**



**Kids (Born 1997 - 2014)**



**23.6%** Nearly one in 4 kids spend more than 3 hours a day using digital devices.

**22%** of parents say they are very concerned about the potential harmful impact of digital devices on developing eyes.

**Millennials (Born 1981 - 1996)**



**37.4%** Nearly four in 10 millennials spend at least nine hours on digital devices each day.

**68%** Nearly seven in 10 report symptoms of digital eye strain.

**84%** Most millennials own smartphones.

**57%** Nearly six in 10 millennials take their smartphones to bed and use them as alarm clocks.

working all day on a computer could present physiological changes of the lacrimal system similar to those found in dry eye syndrome. *“This is not surprising when one considers that the work environment is often characterized by multiple or split screens, small fonts, poor posture and LED or fluorescent lighting.”*

**The blue light paradox**

In addition to eye strain, overexposure to digital displays is linked to the issue of blue light. Eye doctor and medical advisor to the Vision Council, Dora Adamopoulos, recalls that *“a great deal of research is currently underway to determine its precise impact on the eyes and vision. One thing is certain: the blue-violet spectrum (415-455 nm) is particularly harmful<sup>4</sup>. It penetrates deeply*

*and causes photochemical reactions likely to damage retinal cells, with a cumulative effect. The retina cannot be replaced; its alteration therefore leaves the eye vulnerable to harmful light and environmental factors, thereby increasing the risk of early development of ophthalmic disorders, such as AMD.”*

However, blue light is not an enemy that must be fought at all costs. The blue-turquoise spectrum participates in the regulation of natural circadian rhythms (i.e. sleep-wake cycles) among other things, and stimulates the pupillary reflex and such cognitive functions as alertness, memory and emotion regulation. *“Blue light is both unavoidable and indispensable. So it is important to understand its repercussions on the organism and vision, and be familiar with the tools and recommendations for minimizing exposure, particularly from digital displays,”* the expert advises.

**“ A QUESTIONNAIRE HANDED OUT PRIOR TO A CONSULTATION CAN HELP TO CLARIFY AT WHAT DISTANCE EACH SCREEN IS BEING USED, HOW THE OFFICE IS ORGANIZED, THE MOST COMMON POSTURAL POSITIONS ASSUMED AND SO ON, AND THIS INFORMATION CAN THEN SERVE AS A BASIS FOR DISCUSSING PROBLEMS AND POSSIBLE SOLUTIONS ”**

**E. HILDRETH**

## Gen X (Born 1965 - 1980)



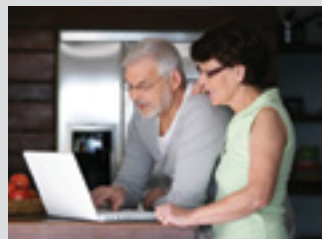
**32%** Nearly one-third of Gen X spends at least nine hours on digital devices each day.

**63%** Six in 10 Gen Xers report symptoms of digital eye strain.

**48%** Gen Xers own more tablets or e-readers compared to other age groups.

More likely than the other two groups to use digital devices for work and recreational reading.

## Boomers (Born 1946 - 1964)



**26%** One in four boomers spend at least nine hours on digital devices each day.

**57%** Experience fewer symptoms of digital eye strain than millennials and Gen Xers do.

**81%** of Boomers are more likely to own a TV compared to other age groups.

Source : 2014 Vision Watch data

### Digital childhood and myopia

Prevention and protection are equally important for both adults and young people, who now use computers and smartphones in all aspects of their schooling and social life. The latest *Digital Eye Strain* report points to intensive screen use and a lack of data on the medium-term consequences. *"The phenomenon is recent, so it is impossible to foresee the impact of emitted light on children's eyes. But in our opinion, myopia is one the main risks that must be evaluated,"* Erin Hildreth hypothesized. *"The causes of myopia are related to a combination of genetic and environmental factors, and since the pervasiveness of digital devices stimulates ocular accommodation at very close reading distance, this could well be part of the problem."* The Vision Council therefore calls for vigilance and a complete eye exam every year to ensure the best possible development of children's eyes. *"A professional can evaluate symptoms or visual disorders resulting from the use of digital devices and suggest solutions and make recommendations,"* she affirms. However, this approach comes up against one of the main findings of the study: **the majority of parents are not worried about the effect of the digital environment on their offspring.** 15% of respondents place no limits on the amount of time spent in front of screens, and 30% are not concerned about the potentially harmful impact of digital devices on the development of the visual system.

### Think and act "awareness"

This finding of disregard for risk highlights one of the major challenges of the Vision Council's action: public awareness. Its CEO confirmed this focus: ***"For us, education is the key. The transmission of information about the nature of digital eye strain, including risks***

***related to exposure to digital displays and especially how to fight them, should be a major focus for mobilizing our sector."*** To optimally publicize the issue, The Vision Council is diversifying its strategy and seeking to strengthen its communication in schools and during 'key' events: film releases, TV marathon broadcasts, new technology launches, or international trade fairs, including the celebrated CES (Consumer Electronics Showcase), an unmissable event for new technology fans. This is a good way to reach a large number of users and instill in them a desire to safeguard their eye health. And to facilitate the assimilation of prevention, the organization is relying on its flagship slogan: "20-20-20". Every 20 minutes, look 20 feet in front of you (approximately 6 meters) for 20 seconds. This rule is easy for both adults and children to remember and use. *"The Think About Your Eyes campaign (www.thinkaboutyoureyes.com) is also a great way to inform people about the benefits of an annual ophthalmic examination,"* adds Daley, who sees in consumers' appetite for connected information an excellent opportunity to use these media, including websites and social networks, and connect with other industry players about the importance of eye health in the digital environment.

**“WE HAVE A DUTY TO EXPLAIN TO CONSUMERS THAT THEY DO NOT HAVE TO LIVE WITH DISCOMFORT OR PAIN WHILE USING DIGITAL DEVICES. CUSTOM GLASSES, WITH OR WITHOUT CORRECTIVE LENSES, CAN ALLEVIATE OR PREVENT SHORT-TERM SYMPTOMS AND PROTECT AGAINST LONG-TERM DAMAGE.”**

**D. ADAMOPOULOS**

#### **Vision professionals and new preventive measures**

**Eye care professionals have a big responsibility – and a good opportunity – to lead the fight against the deleterious effects of digital displays.**

In addition to the development of new health and technical solutions, Erin Hildreth encourages *“ophthalmologists, optometrists and opticians to adopt simple and pragmatic measures to help their patients in their everyday activities.”* Some ideas and recommendations include: promoting continuing education and keeping abreast of the latest findings in this area; taking an interest in public opinion and consumer perceptions; taking charge of consultations by systematically interviewing patients about their use of digital devices and finding out not only what type of devices are being used, but also how they are used and for how long. *“A questionnaire handed out prior to a consultation can help to clarify at what distance each screen is being used, how the office is organized, the most common postural positions assumed and so on, and this information can then serve as a basis for discussing problems and possible solutions,”* she suggested. This should be accompanied by some key preventive recommendations.

#### **Preventive recommendations for the users of digital displays**

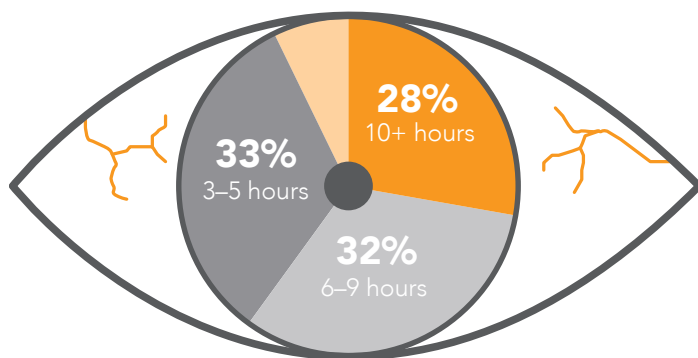
- 1) Design your work space in such a way as to alleviate external stressors, with ideal lighting, an “eye-gonomic” setting (ergonomics for the eyes) and good posture.
- 2) Increase character size in relation to the device used.
- 3) Observe the 20-20-20 rule. Every 20 minutes, look 20 feet in front of you (about 6 meters) for 20 seconds.
- 4) Consult a health professional on a regular basis to obtain counseling and prescriptions for **ophthalmic lenses designed for multiple screen use.**

#### **The importance of prevention**

Advances in ophthalmic optics have already made possible a wide range of options for lenses capable of reducing glare and filtering out blue light. These two indispensable options to optimize visual comfort while using digital displays should encourage opticians to add them to prescriptions to more

closely meet their clients' needs. "Many manufacturers also offer multifocal lenses for people who need to relieve eye strain and correct both near and far vision," Dora Adamopoulos added. The medical advisor feels that "the optical/ophthalmic industry must continue to engage in research and development for new products, but also educate the community of vision care professionals and the general public. We have a duty to explain to consumers that they do not have to live with discomfort or pain while using digital devices. **Custom glasses, with or without corrective lenses, can alleviate or prevent short-term symptoms and protect against long-term damage.**"

### Time spent in front of digital devices:



**63%** of adults do not know that electronics emit high-energy visible or blue light

SOURCE: The Vision Council reports on digital eye strain, 2012 & 2013

It is more important than ever to disseminate this message, inasmuch as scientific advances are increasingly confirming the link between digital displays, eye strain, age-related eye diseases and the importance of prevention and protection.

"The new digital era is more stressful on our eyes and we must all adapt accordingly, professionals and users alike. The optical/ophthalmic industry has already identified the major issues raised by digital devices and during the last several years, we have witnessed a boom in innovation capable of reducing disorders related to the light emitted by screens. These products and technologies do much more than protect our eyes: they improve the quality and precision of our vision," Mike Daley concluded. •



### Some key figures

- In 2015, 69% of American adults use a smartphone and 42.5% a tablet or e-book reader on a daily basis, versus 45% and 26% respectively in 2012.
- 60.8% spend more than five hours a day in front of a screen.
- 31.9% do not make any effort to reduce symptoms of digital eye strain.
- 72.5% are not aware of the potential damage caused by overexposure to blue light and do not know that digital displays emit blue light.
- 22% of parents say that they are concerned by the impact of digital device use on their children's vision.
- 30.6% of the same parents allow children to use digital devices for over three hours daily despite their concern.



### KEY TAKEAWAYS

- Americans (both adults and children) are spending more and more time in front of digital displays on all types of devices.
- Disorders and risks related to light-emitting screens (i.e. eye strain and retinal pathologies) are either unrecognized or underestimated by the general public, the majority of whom neglect prevention and protection.
- Simple solutions exist to fight against digital eye strain and overexposure to blue light.
- The Vision Council recommends following the 20-20-20 rule (every 20 minutes, take a 20 second break while looking 20 feet away) and using ophthalmic lenses designed for screen use.
- Vision care professionals all have a role to play in terms of advocacy, awareness-raising and counseling.

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# THE CHALLENGES OF DIGITAL VISION IN A MULTI-SCREEN WORLD

In this new digital era, there are new risks for user eyes and new challenges for vision care professionals. Ten experts, optometrists, ophthalmologists and researchers have addressed this broad topic and offer us their experience and thoughts in the form of verbatim comments. This overview has been divided into three main thematic areas: risks and prevention, professional practices, and projections and expectations.

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Optometrist – Darwin, Australia

**Berenice Velázquez**   
Behavioral Optometrist, Mexico

## 1. RISKS AND PREVENTION

What effects do digital displays have on health? The main risks, whether they are known, suspected or potential, primarily concern vision, but may also affect other functions. Experts are reassuring however: good visual hygiene, regular eye exams by professionals, appropriate optical solutions and enhanced public awareness provide effective prevention.

### Impact of digital displays on vision

***“Our visual system is biologically designed for distance vision. Near vision is only an accommodation reflex that helps us quickly identify objects close at hand. Our eyes are not designed to stare at screens for hours on end.”***

José de Jesús Espinosa Galaviz

### KEYWORDS

digital devices, connected vision, multi-screen environment, computer, smartphone, tablet, video games, blue light, ametropia, emmetropia, digital displays, posture, digital tools, connected life, eye strain, vision health, prevention, visual hygiene, accommodative effort, asthenopia, headaches, sensitivity to the light, diplopia, sleep, cortisol, melatonin, ergonomics, protection, child, myopia.



**“OUR VISUAL SYSTEM IS BIOLOGICALLY DESIGNED FOR DISTANCE VISION. OUR EYES ARE NOT DESIGNED TO STARE AT SCREENS FOR HOURS ON END.”**

**JOSÉ DE JESÚS ESPINOSA GALAVIZ**

*“A reduction in the frequency of blinking during screen use increases the severity of such symptoms as dry eye or irritation and blurred vision. **Smartphone users tend to hold their phones very close to the face, thus requiring an intense accommodative effort causing eye strain or headaches.**”*

Sebastian Marx

*“In such rapidly developing cities as Singapore, we see **concomitant growth in the number of people working in offices and cases of asthenopia, sensitivity to light, transient diplopia and so on.**”*

Koh Liang Hwee

*“No clinical study to date has demonstrated that overexposure to digital displays is the cause of early macular degeneration. **However, blue light emissions are a reality and over time we are bound to see a clinical impact.** Concerning the increase in cases of myopia, various studies point to the possible influence of digital displays used at ever closer distances. **We still need to understand why certain subjects develop myopia and others don’t, even among twins.**”*

Sebastian Marx

*“**The increase in ophthalmic disorders is linked to the proliferation of screens and the time spent watching them:** in the classroom (from primary school to postgraduate courses, including tablets, computers, electronic tables, etc.), but also at all ages via the social networks, television and e-books, which are becoming increasingly popular.”*

Helen Summers

*“**The main risk for the younger generation is myopia, perhaps not true myopia, but rather an ‘accommodative spasm’ (i.e. near point stress according to Skeffington), since the human eye and brain were not designed for extended near vision.**”*

Aravind Srinivasan



**Consequences beyond vision**

*“In the medium and long term, digital displays affect people in different ways. **The impact is not solely ophthalmic.** The symptoms are varied, suggesting both physical disorders (neck and back pain, etc.) and psychological disorders (fatigue, irritability, poor concentration, memory problems and so on).”*

Aravind Srinivasan

*“**Overexposure to blue light emitted by screens can disrupt the secretion of melatonin and thus affect the quality of sleep.** Eye strain can also have an effect on productivity and lead to other disorders, such as stress, anxiety or mood swings.”*

Koh Liang Hwee

*“Ever more pervasive video gaming is associated with player immersion and strong screen flicker. These two situations can eventually stimulate systemic and endocrine functions, resulting in elevated cortisol levels. **The main repercussions have been found to affect sleep, behavior, mood, motivation and learning.**”*

Helen Summers

**Preventive solutions**

*“Consumer awareness campaigns are an important means of highlighting the risks and symptoms related to digital displays and offer an opportunity to stress the need for **regular eye exams.**”*

Aravind Srinivasan

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**“OVEREXPOSURE TO BLUE LIGHT EMITTED BY SCREENS CAN DISRUPT THE SECRETION OF MELATONIN AND THUS AFFECT THE QUALITY OF SLEEP.”**

**KOH LIANG HWE**

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*“Every person consulting a vision care professional should be **informed of the impact of digital devices and blue light**, as well as the importance of **good visual hygiene** and the availability of **optical solutions**. A wide range of high-quality solutions are available; it is regrettable, however, that current prices limit their use primarily to adults rather than children.”*

Helen Summers

*“A new specialty, ergo-optometry, could be created. The ergo-optometrist would **counsel patients on how to take better care of their visual health**, explain what products to use to treat dry eye and provide **personalized information with regard to lenses and frames**, even for patients without refractive error. Overweight people can contact Weight Watchers. People with ophthalmic problems should be able to contact Eyes Watchers.”*

Joachim Köhler

*“We are not usually aware of our posture; our organism chooses the most appropriate position for a given situation, without worrying about potential physiological repercussions. **It is essential to adopt good posture**. For reading, I recommend the Harmon distance at a minimum; this is the distance from the tip of the elbow to the middle of the index finger.”*

José de Jesús Espinosa Galaviz

*“**Good visual hygiene** also includes: **an ergonomic work space; good posture**, a straight head and back; **good lighting**, with lower lighting for screens and adequate room lighting; **breaks every 20 minutes; alternating between near and far screen distances, and suitable ophthalmic lenses.**”*

Helen Summers

## 2. PROFESSIONAL PRACTICES

How are digital devices influencing the everyday lives of vision care professionals? New consultation protocols, near vision refraction and control methods appropriate to digital displays, personalized counseling and more frequent continuing education are the main developments cited by experts. Many professionals are incorporating digital tools into their practices to better assess users' needs. In the context of overexposure to digital devices, experts are also beginning to take more interest in children and emmetropic people (without refractive error).

### Protocols and refraction

*“Just a few years ago, protocols were established on the basis of the symptoms one should look for rather than on patients' needs depending on their environment. This approach is now changing. **Currently, in addition to patients' histories, we are also interested in their concerns, expectations, environment and so on, and we are adapting protocols accordingly.**”*

Luis Ángel Merino Rojo

*“For people who rely heavily on their near vision, I apply a protocol based on behavioral optometry. This approach is important when prescribing the best lenses for a particular type of activity.”*

José de Jesús Espinosa Galaviz

*“My approach? First I exclude ocular pathology and perform a refraction. Then I evaluate the patient's visual faculties (accommodation, convergence, ocular mobility and sensory aspects such as stereoscopic vision, etc.). **Once all these criteria have been evaluated, the treatment strategy can be defined.**”*

Elizabeth Casillas

*“Far vision refraction is often performed using cyclopegic eye drops with a refractometer. Near vision is examined with trial frames equipped with interchangeable lenses to better **evaluate posture, head position and reading distance in relation to a support, computer or digital device**. Instruments such as ‘Capture I’ or ‘Visiooffice®’ are used to measure frame parameters and such individual parameters as pupillary distance and the eye's center of rotation.”*

Helen Summers

*“My staff has slightly modified their refraction methods to adapt to digital technologies. We placed a smartphone and tablet in the consulting room and, after the examination, we ask patients to read what is written on the screen. If they are unable to do so, we orient them towards specific lenses. Otherwise, all is well! **By using digital devices to test near vision, we fit in more closely with our patients' digital lifestyles.**”*

Joachim Köhler

### Prescriptions and counseling

*“**There are several complementary approaches.** The first involves optical correction, with high-tech lenses offering optimal vision quality and protection. The second approach involves training, consisting of various exercises designed to improve visual capabilities. The third approach involves education in visual hygiene (posture, breaks, a good work environment, etc.). **The final prescription depends on the age and issues of each patient.**”*

Elizabeth Casillas

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## “WE HAVE A REAL ROLE TO PLAY IN THE TREATMENT OF DISORDERS RELATED TO DIGITAL DISPLAYS”

ELIZABETH CASILLAS

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*“The patient’s age affects the proposed treatment. People with presbyopia will be advised to wear progressive lenses, with a coating (i.e. a filter) suited to the specific issues posed by digital devices. **For younger children, with or without a correction, lenses must primarily meet the objective of protecting their vision against the harmful effects of screens.**”*

Aravind Srinivasan

*“People working on computers are advised to have regular exams, in order to identify any symptoms of ophthalmic stress. **The prevention aspect is particularly stressed for children, especially for children under 10.**”*

Helen Summers

*“We must be attentive to each of our prescriptions, always follow the same consultation protocol, **compare feedback from each patient and keep a record of all results.**”*

Berenice Velázquez

*“Information provided by researchers, universities, specialized societies, suppliers and the like, helps us stay on top of new developments and **provide increasingly personalized solutions.** We must make an effort to step out of the ‘comfort zone’ of standardized options and **adapt them to individual needs.**”*

Sebastian Marx

*“We have a real role to play in the treatment of disorders related to digital displays and must devote more time to informing and educating ourselves and to testing new solutions. In this regard, it could be useful to reinforce the sharing of experiences and dissemination of information through forums and professional networks.”*

Elizabeth Casillas





*“There is a paradox. On the one hand, we have more and more technological tools available to us (auto-refractometers, digital phoropters, photo and video sharing capability to improve diagnosis, etc.), but on the other hand, we have a new generation of professionals who no longer know how to perform an exam without these devices. The right balance must be found between the assimilation of new technologies and basic knowledge.”*

José de Jesús Espinosa Galaviz

### 3. PROJECTIONS AND EXPECTATIONS

How do we anticipate future issues and respond to the realities of a multi-screen world? Between increased research efforts and the development of technological innovations that will facilitate customized products and services, the various ideas outlined offer a glimpse of the future of the ophthalmic optics sector, which is in a position to turn the digital challenge into a real growth engine.

#### Clinical studies and R&D

*“Technological progress is making rapid headway, but the ophthalmic optics industry should be further ahead than it is if it is to adequately meet the health challenges associated with digital displays. **It is important to invest more in health research in general and vision health in particular.**”*

José de Jesús Espinosa Galaviz

#### The place of emmetropes

*“My colleagues and I feel that **emmetropes** (i.e. people without refractive error) **have been completely forgotten by our profession. During screen use, they are exposed to the same risks as glasses wearers.** So it is important to educate them about the existence of simple solutions and practices to fight against asthenopia and other disorders related to digital devices.”*

Luis Ángel Merino Rojo

*“It would be useful to mount a major information campaign on the risks of overexposure to digital displays. And explain that **vision care professionals have solutions to respond to these issues, even for emmetropes.**”*

Berenice Velázquez

#### Digital devices and professional practice

*“For vision care professionals, digital technologies make it possible to share cases and experience, to the benefit of patients.”*

Jaime Bernal Escalante

*“**Digital tools and certain applications can be used to take a number of different measurements: asthenopia, the quantity of blue light emitted by screens, etc.** They can also be used to disseminate recommendations aimed at optimizing visual comfort and participate in the therapeutic education of users.”*

Berenice Velázquez

*“**New studies on the relationship between blue light and macular degeneration and the connection between the development of myopia and digital displays** could provide clinical responses to current hypotheses based solely on interpretation.”*

Sebastian Marx

*“**We must continue research efforts on myopia and its development, solutions to amblyopia, eye reactions during screen use, night vision, light radiation, etc.**”*

Luis Ángel Merino Rojo

**“EMMETROPES HAVE BEEN COMPLETELY FORGOTTEN BY OUR PROFESSION. DURING SCREEN USE, THEY ARE EXPOSED TO THE SAME RISKS AS GLASSES WEARERS.”**

**LUIS ÁNGEL MERINO ROJO**

**“ALL STUDIES FOCUSING ON THE EXACT RELATIONSHIP BETWEEN CONNECTED LIFE AND OPHTHALMIC DISORDERS SHOULD PROVE USEFUL.”**

**JAIME BERNAL ESCALANTE**

*“All studies focusing on the exact relationship between connected life and ophthalmic disorders should prove useful. And in my opinion, the development of shared databases would be a real “plus” for all vision health players.”*

Jaime Bernal Escalante

**Expected innovations**

*“More precise measuring equipment. The fact of having 20/20 (10/10) vision reveals nothing about the way patients’ use their eyes while watching a screen.”*

Elizabeth Casillas

*“Tools to measure the impact of luminous digital displays on the eye.”*

Aravind Srinivasan

*“New products, particularly ophthalmic lenses capable of protecting the eyes against technological ‘radiation’.”*

Jaime Bernal Escalante

*“The ideal lens: a product capable of integrating all treatments and filters on demand, based on the individual needs of each patient.”*

Koh Liang Hwee

*“A completely innovative approach, with ‘flexible’ smart lenses capable of adapting their optical properties to specific situations. A high level of modularity that could involve the use of electronic components.”*

Sebastian Marx

**Vision health in the future**

*“The multi-screen environment is part of daily life. This environment can potentially pose certain risks, particularly for the eyes, and it is up to us as vision care professionals to concern ourselves with these risks and provide some answers, either directly or via the Internet.”*



*Indeed, technological and societal developments are opening up new fields of practice that offer our industry an opportunity to evolve! Personally, however, I prefer direct contact with patients, to show them that I am indispensable as a specialist.”*

Joachim Köhler

*“New visual needs concern a large number of everyday activities; therefore growth opportunities for the vision health sector can only increase. The solutions developed must provide added value: filters to prevent eye strain or blue light-related risks, lenses capable of stimulating peripheral areas of the retina to fight against myopia or stimulate amblyopic eyes and improve their performance. There are still many little exploited or untapped areas that will undoubtedly drive development in the future. The response to digital issues is part of this.”*

Luis Ángel Merino Rojo





## Conclusion

The new digital era is witnessing new societal, sensorial and behavioral transformations. This brief survey of the situation worldwide highlights the increased overall level of awareness of the ophthalmic optics sector confronted with the rapid, wide-scale changes driven by the emergence of digital technology and, more particularly, its impact on users' vision and posture. From stronger prevention efforts to personalized treatment options, without forgetting projections for the future, the vision health sector is joining forces to adapt to developments, anticipate upcoming challenges and provide better performing solutions for ametropic and emmetropic patients of all ages.

Insights collected by Oliver Vachey,  
science journalist.



## KEY TAKEAWAYS

- The human eye is not designed for near vision over a long period. Spending too much time in front of screens results in asthenopia, dry eyes, red or irritated eyes and other ophthalmic symptoms.
- The medium-term impact on users' general physical condition and behavior is correlated with overexposure to blue light and screen flicker.
- Preventive solutions exist for each situation, but public awareness needs to be improved.
- Professional practices are evolving and adapting with the goal of providing increasingly personalized treatment options designed specifically for users of multiple screens.
- Efforts are still needed in the area of clinical studies, R&D and innovation, to enhance the already substantial offer, provide new solutions and anticipate upcoming issues.
- The satisfactory integration of digital vision issues is a major factor affecting the growth and development of the ophthalmic optics sector.

# THE WORLD OF MULTIPLE SCREENS: A REALITY THAT IS AFFECTING USERS' VISION AND POSTURE

Just a few years after their market introduction, digital devices are abundantly present in people's everyday lives. We now live in a multiple-screen environment and may use up to ten different devices with screens in a single day (laptop, desktop, tablet, console, digital TV, GPS, e-book reader, digital code device, smartphone or smartwatch). Users today want to be connected at all times. However, these new media are affecting their vision and posture. To measure this impact, the Ipsos institute conducted a broad survey on four continents with four thousand people. The results show the growing challenges posed by this new digital reality to public health.



 **Sophie D'Erceville**  
Research director at Ipsos, Paris, France

After earning a degree in marketing and communication (Masters 2) from CELSA, Sophie worked for seven years in the quantitative research sector. She joined Ipsos in 2011, where she is responsible for numerous studies on marketing issues and trends for various sectors, including the optical sector. She has been assisting Essilor for a number of years with the implementation of international surveys aimed at better understanding and anticipating trends in the area of visual health and optics.



## KEYWORDS

digital screens, posture, ergonomics, e-reading, digital devices, connected life, Internet, new technologies, computer, smartphone, tablet, e-book, e-reader, TV, console, connected lifestyles, blue light, visual fatigue, computer vision syndrome.

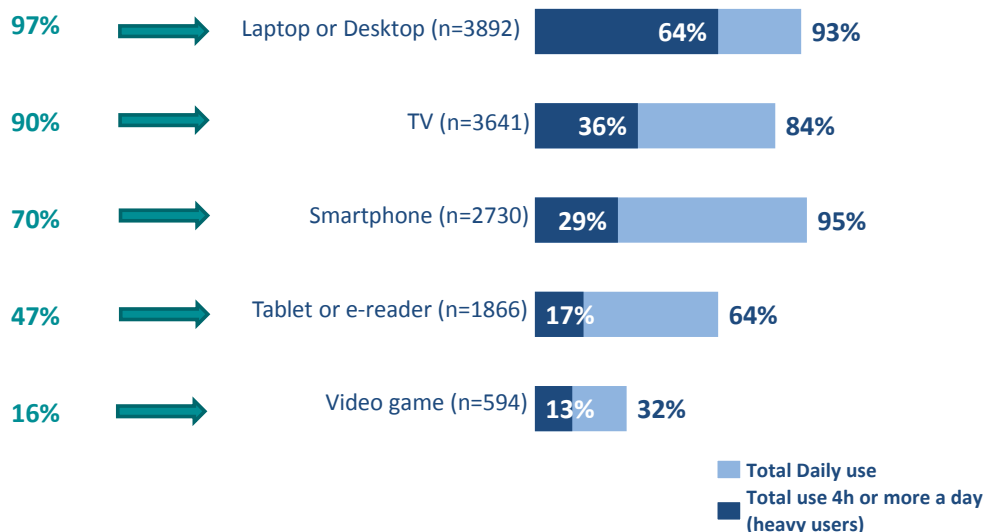
## Cross-generational use of digital devices is accelerating

Today, digital devices have become an accepted part of everyday life, irrespective of age, social class or geographical area. After years of undisputed reign, the supremacy of television and computers has now been challenged by a massive influx of small screens – smartphones, tablets, e-book readers and game consoles – that have truly revolutionized digital practices. In less than ten years – the launch of the iPhone barely dates back to late 2007, and the tablet to 2010 –, these new media devices have emerged as essential everyday tools, generating new habits and new needs.

## SURVEY

To measure the impact of the use of these new devices on users' vision and posture, Ipsos conducted a broad survey on an international scale in four countries (Brazil, China, France and the United States), with four thousand people aged 18 to 65.

Among those who use the device:



Base: Digital device users  
 Question a: On average, how often do you use these digital devices?  
 Question b: How often do you use digital devices per day ?

FIG.1| Usage of digital screens

The use of digital screens is now a daily reality for a very large majority of the population. Young and old alike use them several hours a day, and 29% of smartphone owners have their eyes riveted on their phone screens for more than four hours a day. Opportunities for use are varied and include reading, writing, watching videos, taking photos or videos and much more. Fig. 1.

**Multiple-screen use is intensifying**

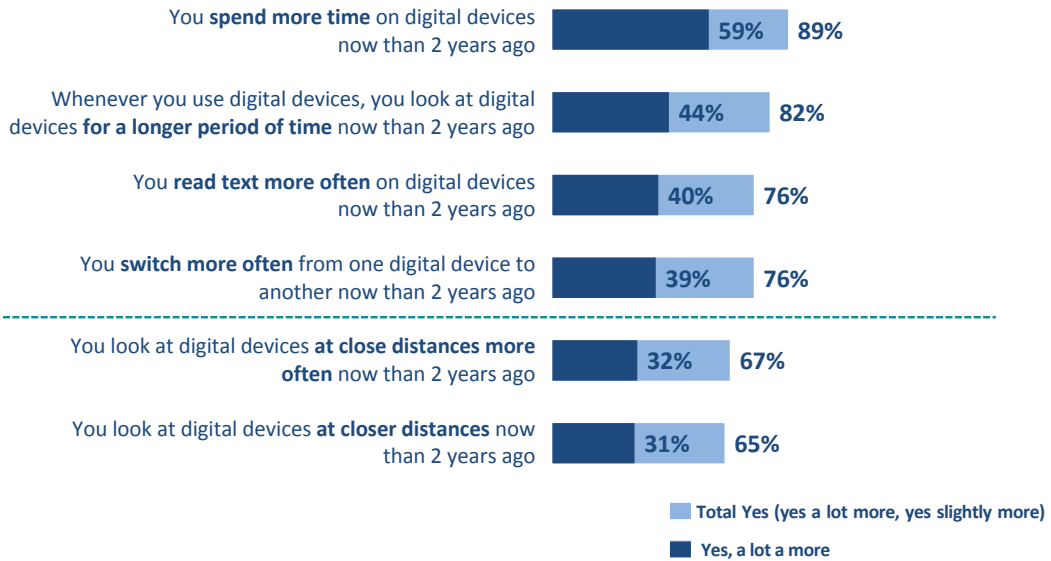
Devices are no longer used just sequentially; they are increasingly used simultaneously. Combined, they exact a heavy toll on the eyes at any distance, whether viewed from afar or close-up: for example, 72% of people surveyed have watched television while using a smaller screen, such as a smartphone, tablet, e-book reader or game console, forcing them to constantly look back and forth from one screen to the other. 69% have used a computer while alternating with a smaller screen(s). This intensified use is reported by users themselves: 89% of them confirm that they seem to spend more time using screens, and 82% say they are watching screens for longer periods than two years ago. Fig. 2.

**New digital uses are causing visual and physical discomfort**

The increasingly intensive daily use of digital devices, particularly small screens – the smartphone is the most frequently used device on a daily basis –, involves a certain amount of discomfort, and users are well aware of this: 89% have felt discomfort or pain in their eyes, which they associate, at least in part, with their use of screens. But most of the time, their symptoms seem to be temporary and fairly harmless: they complain of eyestrain (74%), itchy eyes (50%), dry eyes (46%), rather than report that their eyes sting (34%) or hurt (35%). Their eye symptoms, especially eyestrain (which 51% describe as moderately or highly bothersome) are considered just as uncomfortable as the bodily pain affecting the neck and shoulders (54%) or back (51%) Fig. 3. In addition to these visual and physical symptoms, 46% of respondents report they have difficulty sleeping, including 35% for whom this is a real problem.

Even though these symptoms cause little or no concern on the part of users of digital devices, several factors should nonetheless alert healthcare professionals, leading them to monitor their development over time:

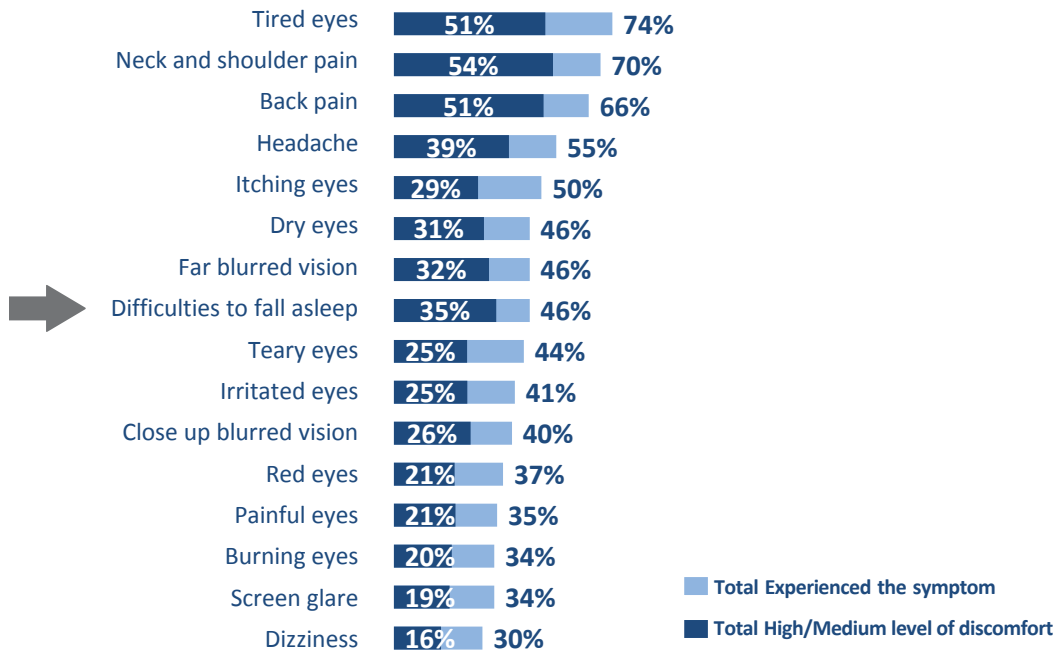
### Differences in habits with digital screens between now and 2 years ago



Base: All Respondents (n=4034)  
 Question a: If you had to compare the way you used digital devices 2 years ago to your actual habits, would you say that...

FIG.2| Intensification of multi-screen use

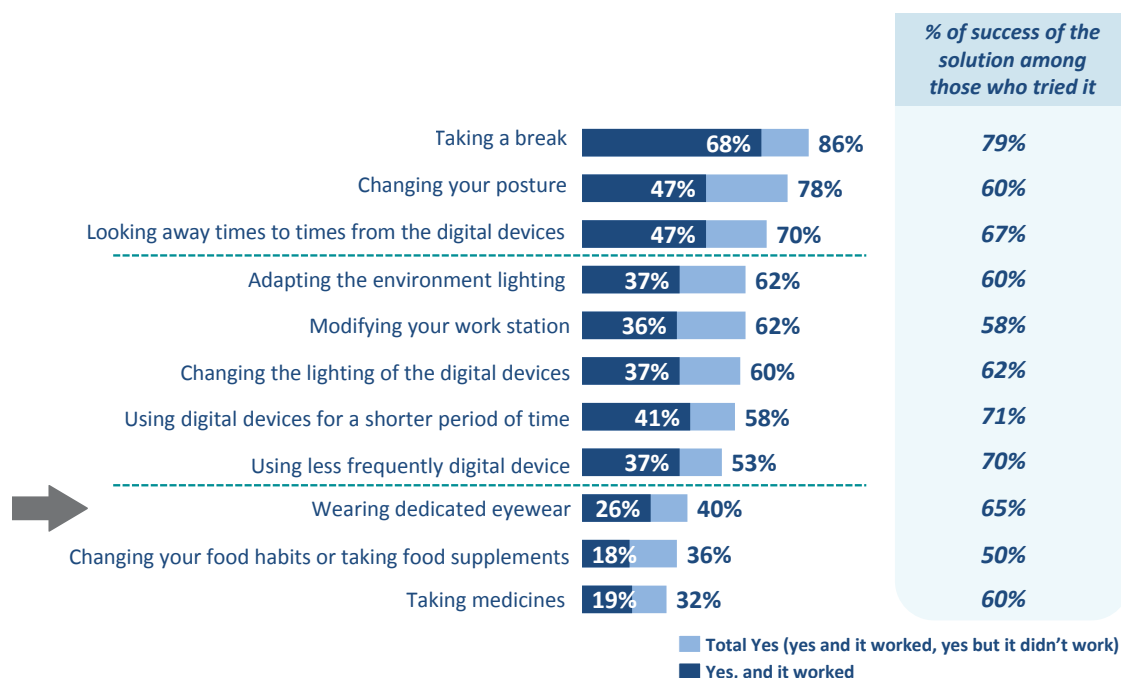
### Level of discomfort experienced for each symptoms



Base: All Respondents  
 Question a: Have you ever experienced these symptoms, even rarely?  
 Question b: How would you evaluate the level of discomfort when you experience these symptoms?

FIG.3| Body and visual discomfort linked to multiscreen uses (including difficulty falling asleep)

### Solution tried to relieve symptoms



Base: Think the symptoms are caused by the usage of digital devices (n=3463)  
 Question: Have you tried the following solutions to relieve your symptoms linked to the usage of digital devices?

FIG.4| Solution tried to relieve symptoms

- There already seems to be a very strong link between intensity of screen use and the symptoms felt. In other terms, the longer and more frequently one uses digital devices, the more one is affected by ocular or physical symptoms. Small screens, especially those found on smartphones, tablets, or game consoles, seem to cause more problems for the eyes, due in particular to difficulty reading small type: people using these devices heavily (i.e. more than four hours a day) seem to feel that they have dry eyes more often than others (62% had already experienced this symptom, versus 46% for all users) or experience sore eyes more often (46% versus 35%). And as the use of digital devices continues to expand, it is likely that more and more people will face these symptoms in coming years.

- Moreover, more than half of those reporting one of these symptoms feel that their symptom(s) are worsening over time, and becoming increasingly troublesome.

- Users of digital devices also encounter the problem of blurred vision, when viewing them close-up (40%) or from

afar (46%), which may be perceived as getting worse over time (31% for distance vision, and 29% for near vision).  
 - Despite these specific signs, few envisage spending less time viewing screens: over 40% of those surveyed state that they have simply not considered reducing the length of time or frequency they use their digital devices to relieve their symptoms, illustrating by this attitude their increasingly strong dependence on these everyday objects. Most of the time, users opt for quick, simple solutions, such as taking a break, changing position or looking away from the screen from time to time. It is also noteworthy that 60% have already tried to change the brightness of their screen, and that 40% wear dedicated eyewear during screen use. Fig. 4.

#### Everyone is concerned, particularly young people

Since they use these devices for longer periods and more intensively than those over fifty, young people are the primary victims of damage related to digital device use, even before they become presbyopes, they now seem to suffer from a greater number of ocular and physical symptoms than their elders. Tired or sore eyes, headaches and blurred distance vision are felt far more frequently by those under forty year of age. These symptoms are also

**“The longer and more frequently  
one uses digital devices, the more  
one is affected by ocular  
or physical symptoms”**

accompanied by a greater awareness by those under forty of the link that may exist between the use of screens and visual discomfort.

Everyone is concerned by eye problems, including wearers of corrective lenses, and particularly contact lens wearers. A significant proportion of non-wearers are also affected: 61% of them have the impression that they must make more of an effort to see well when using digital devices (versus 66% of corrective lens wearers).

Finally, countries like Brazil and China, which are experiencing an unprecedented boom in the use of these new digital media, are also particularly exposed to this situation, due to their usage practices: in China, 45% of smartphone users say they use their phone over four hours a day (versus 29% for all countries), and for activities that are often more time-consuming than average (i.e. watching a film or a video, reading for long periods, etc.).

**What are the potential risks of digital screen use and what solution(s) are available to prevent them?**

Even though they are aware of being “addicted” to screen use, people still seem to be insensitive to the risks inherent in prolonged use of digital devices. For example, the danger to the brain of increased exposure to electromagnetic waves, supported by numerous scientific studies,

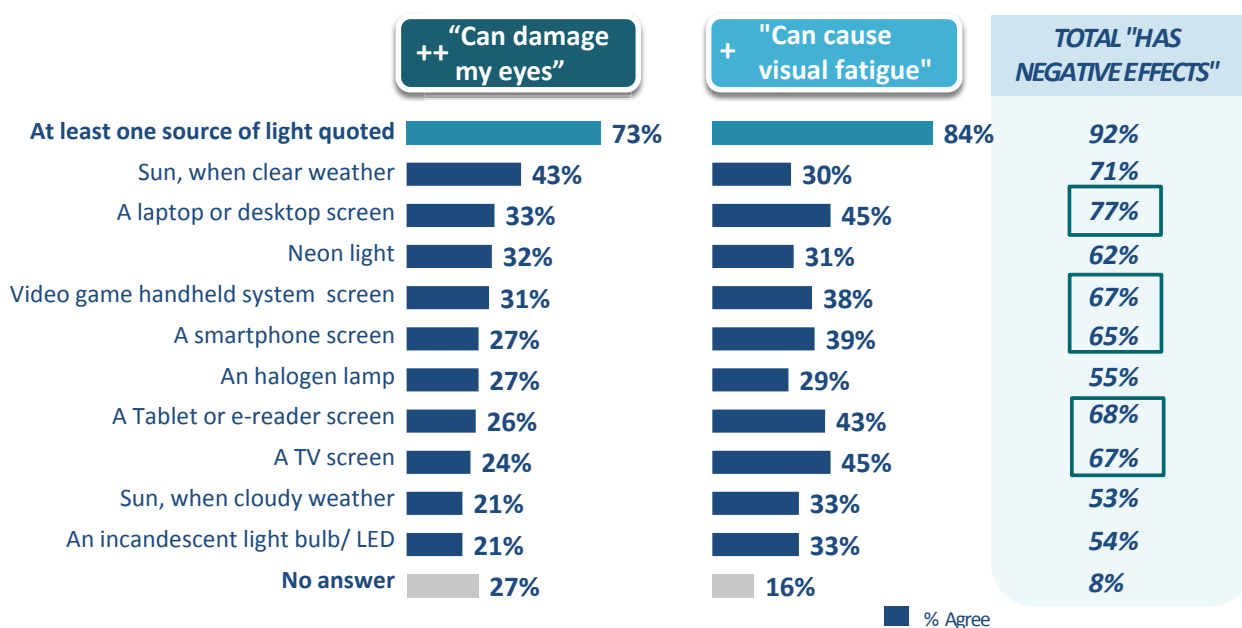
is a topic that comes up regularly in the news without provoking much of a reaction from the public (in France, ANSES published reports in 2009 and 2013, that were widely reported in the press; and a law governing public exposure to electromagnetic waves was adopted on 29 January 2015).

Similarly, users of digital devices do not yet clearly perceive (or do not wish to perceive) the possible link between increased exposure to screens and a potential decline in their eye health. Regardless of the digital device used, those surveyed see the screen more as a source of eyestrain than as a potential danger for their eyes. For example, smartphones are considered by 27% as a device that could damage the eyes, while 39% consider instead that it is simply responsible for visual fatigue. Fig. 5.

Currently, sunlight and exposure to UV radiation are still considered the main risk for the eyes. As for blue light and its potential dangers, this remains an elusive concept for most people: only 47% consider spontaneously that they are familiar with the principle of blue light but, in fact, when it is explained to them, over half realize that they are not familiar with this phenomenon.

Awareness of the potential dangers of the intensive use of screens and the cumulative effect over time is more

## Negative effects linked to screens and other light sources



Base: All Respondents (n=4034)

Question: There can be many sources of light, which can have various effects on ocular health. For each source of light, please indicate if you think it can be harmful to your eyes or if you think it has little negative effect to your eyes.

FIG.5| Negative effects linked to screens and other light sources

important than ever, particularly among young people, who are by far the most intensive users of digital displays. Healthcare professionals have an important support role to play in their education.

Faced with these new uses for digital devices, a dedicated eyewear range, designed to relieve the eyes and protect them would appear to be quite relevant: 77% of those surveyed state that they would consider purchasing this type of eyewear, particularly the most intensive users of small digital displays. And those who do not wear corrective lenses should not be ignored, since 65% of them also state that they are interested.

Despite this positive reception in principle, the challenge

in marketing this new type of eyewear will be to convince people of its effectiveness and, more importantly, to create a desire for it, particularly when we understand that the populations most concerned are those most averse to wearing glasses on a daily basis (i.e. people under forty and contact lens wearers, in particular).

For this reason, an appropriate educational effort must be made to really convince the different target groups of the tangible benefits of this type of eyewear. In view of the visual and physical discomfort reported by those surveyed, an improvement in visual comfort and a decrease in fatigue and headaches are the benefits expected by digital device users.

**“Young people are the primary victims of damage related to digital device use, they now seem to suffer from a greater number of ocular and physical symptoms than their elders”**

**“Awareness of the potential dangers of the intensive use of screens and the cumulative effect over time is more important than ever”**

### Conclusion

With rapidly changing digital use practices, everyone is or will be concerned by the potential dangers represented by these screens. But increased awareness of the inherent risks is slow to develop; certainly, physical and ocular discomfort are increasingly felt by digital device users in their daily lives, but the long-term effects remain poorly understood. Healthcare professionals therefore have an important role to play in heightening people’s awareness and helping them protect themselves, in the face of this growing public health challenge. •



### KEY TAKEAWAYS

- The increasing use of digital devices is a transgenerational, global reality.
- 72% of respondents report that they use a combination of several different screen-based devices.
- The use of digital devices causes visual and physical discomfort (including difficulty falling asleep).
- Half of respondents consider their visual and physical symptoms bothersome.
- Half of respondents are bothered by strong screen brightness.
- Two out three people feel that they must make an additional visual effort when using screens.
- Three out of four people suffer from visual fatigue
- Everyone is affected by this discomfort, particularly young people.
- 77% of users report that they are interested in purchasing dedicated eyewear to relieve this discomfort.
- Healthcare professionals have an important role to play in raising awareness and providing treatment.



### **III. POPULATIONS MOST AT RISK**

## Ocular phototoxicity in the mountains *Fototoxicidad ocular en la montaña*



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"The eye is born from light and for light" JW von Goethe

Although light is necessary for ocular physiology, notably for phototransduction, acute and chronic exposure can cause lesions to the eyeball.

The harmful effect of light has been suspected from antiquity; Socrates reported eye discomfort after watching eclipses.

The consequences of light exposure on the retinal function were demonstrated experimentally in rats over 40 years ago, including at low intensity and over a long period of exposure. More recently, in vivo and in vitro models have demonstrated more specifically the role of blue light (BL) (380-480 nm) in the apoptosis of photoreceptors and of the cells of the retinal pigment epithelium<sup>[1]</sup>. Light thus leads to photochemical reactions within ocular tissues. These require a chromophore, exposure time and a sufficient dose, releasing the free radicals involved in oxidative stress and the processes of eye ageing.

Ultraviolet rays and blue light which are of particular interest to us, belong to the vast range of electromagnetic waves.

These are made up of photons, which are classified according to their wavelength with its own energy (inversely proportionate to their wavelength). We are familiar with UV rays particularly due to their action on the skin and the cornea (snow blindness) in our particular speciality. The ozone layer filters UV rays up to 290 nm, and the eye is therefore exposed to the remaining UVs, from 290 to 400 nm (UVB and UVA) and to the spectrum of visible light (which starts with blue light) in the absence of efficient protection. Intraocular transmission of the rays depends on their wavelength, but in fact UVs are mainly absorbed by the cornea and the crystalline. It is estimated that less than 2% of the initial UV dose reaches the retina in adult eyes, compared with 2 to 8% in children under the age of 10<sup>[7,21]</sup>.

«El ojo nació por la luz y para la luz» JW von Goethe

*Aunque la luz es necesaria para la fisiología ocular, especialmente para la fototransducción, una exposición aguda y crónica puede generar lesiones en la globo ocular.*

*Ya desde la Antigüedad se había sospechado el papel nocivo de la luz, Sócrates había mencionado una molestia ocular secundaria a raíz de la contemplación de los eclipses.*

*Hace ya más de 40 años, en experimentos en ratones, se han demostrado las consecuencias de la exposición a la luz sobre la función retiniana, incluso a un bajo nivel de intensidad incrementando la duración de la exposición. Más recientemente, los modelos in vivo e in vitro han puesto de relieve, más particularmente, el papel de la luz azul (LB) (380-480 nm) en la apoptosis de los fotorreceptores y de las células del epitelio pigmentario de la retina<sup>[1]</sup>. La luz induce así reacciones fotoquímicas en los tejidos oculares. Estas necesitan un cromóforo, una cierta duración de la exposición así como una dosis suficiente para liberar radicales libres implicados en el estrés oxidativo y los procesos de envejecimiento ocular.*

*Los rayos ultravioleta y la luz azul, que nos interesa más particularmente, pertenecen al gran conjunto de las ondas electromagnéticas.*

*Las ondas electromagnéticas están constituidas de fotones, clasificadas según su longitud de onda y contienen energía propia (inversamente proporcional a su longitud de onda). En nuestra especialidad, las radiaciones UV nos son familiares, particularmente por su acción en la piel y la córnea (oftalmía de la nieve). La capa de ozono filtra los UV hasta los 290nm, de esta manera, en ausencia de protección eficaz, el ojo queda expuesto al resto de los UV de los 290 a los 400 nm (UVB y UVA) y al espectro de la luz visible (que comienza con la luz azul). La transmisión intraocular de los rayos es función de*

Visible light (400 to 800 nm) provides us with the coloured sensation of our vision, whilst infrared light has mainly heat-related properties. The retina is exposed to the components of visible light due to their wavelengths, whence its potential danger. Sliney et al. estimate at 40% the fraction of blue light transmitted to the retina in adults aged 60 and still more in children, for whom 65% of blue light rays are transmitted.

Back in 1908, Hess discovered that the dose of cosmic rays increased with altitude during balloon travel. **Thus, the dose of UVs received by the eye increases by 10% in levels of 1000m of altitude**, by 20% on water, by 10% on sand and **by 80% on snow**. Mountain professionals are therefore a population who are overexposed to light (particularly UV and blue light) due to the combination of these elements.

Several large scale studies have been carried out amongst populations living in sunny plains (POLA, Sète, France<sup>3,4</sup>, Beaver Dam Eye study Wisconsin USA[10], Chesapeake Bay study, Australia<sup>9</sup>); these showed an increase in the prevalence of cataracts, notably cortical and, more controversially, of maculopathies <sup>[3,4,10,9]</sup>.

To our knowledge, no study has been published on a population living at altitude and thus over-exposed. In our department we have carried out an original study on high mountain guides compared with a population living in the plains of the Lyon region (Etude enregistrée Eudract 2010-A00647-32, Promoter Essilor International, principal investigator Prof. Corinne Dot). This study highlights mainly the effects of the sun's rays at altitude as well as under the more secondary conditions of the combined effects of the wind and low temperatures.

Study undertaken amongst high mountain guides in Chamonix<sup>6</sup>

Ninety-six high mountain guides (GHM) from the Chamonix valley aged over 50 and 90 control patients from the refraction department at the Desgenettes Hospital in Lyon, of comparable age, took part in this study.

A questionnaire was used to evaluate exposure at altitude (number and altitude of trips) and the means of protection used. Each of the patients was examined under dilatation by means of a clinical examination of the anterior segment (classification LOCS, III, Lens Opacities Classification System III,) together with analysis using a sheimpflug camera (Oculus®, Alcon), and then of the posterior segment with retinal photography of the posterior pole. Statistical analyses used Student's T test for the comparison of the 2 groups and a logistic regression to evaluate the risk factors.

The results were as follows:

- **Regarding surface pathologies**, the mountain guides (GHM) presented statistically more dermatochalasis (28.1% compared with 4%,  $p < 0.001$ ), chronic blepharitis (52.1% compared with 10.2%,  $p < 0.001$ ) and abnormalities of the lachrymal points (33.3% compared with 4%,  $p < 0.001$ ). Their Break Up Time (BUT) is also statistically lower (4.55s compared with 7s,  $p < 0.001$ ). We also observed more pterygium (8.9% compared with 0%,  $p < 0.001$ ), pinguecula

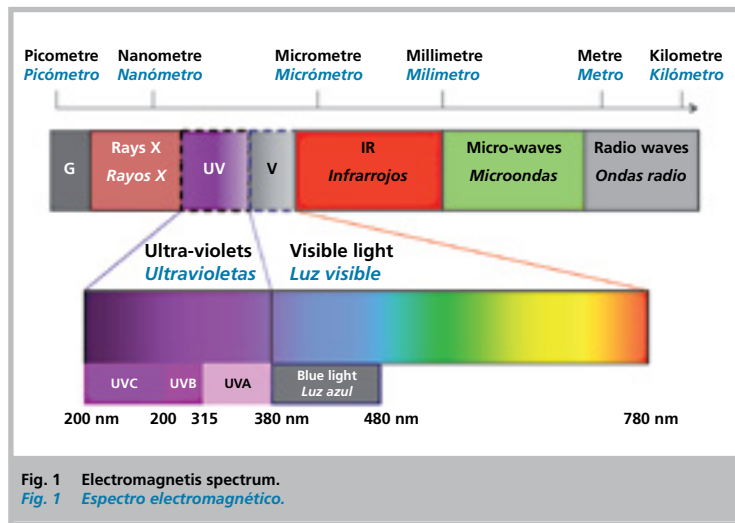


Fig. 1 Electromagnetic spectrum.  
Fig. 1 Espectro electromagnético.

su longitud de onda; sin embargo, de hecho, los rayos UV quedan esencialmente absorbidos por la córnea y el cristalino. Efectivamente, se estima que menos del 2% la dosis de los UV iniciales alcanzan la retina en un ojo adulto, en contraste con el nivel del 2 al 8% en niños menores de 10 años.<sup>[7,2]</sup>

La luz visible (400 a 800nm) nos aporta la sensación de colores de nuestra visión mientras que los rayos infrarrojos poseen esencialmente propiedades calóricas. Por su parte, la retina está expuesta

a los componentes de la luz visible debido a sus longitudes de onda, de ahí su peligro potencial. Sliney et al. estiman en un 40% la fracción de la luz azul que se transmite hacia la retina en los adultos de 60 años y ésta es aún mayor en los niños en los que más del 65% de los rayos de la luz azul se transmitiría.

En 1908, Hess descubrió, en el transcurso de vuelos en globo, que la dosis de radiaciones cósmicas aumenta con la altitud. **De esta manera, la dosis de UV que recibe el ojo aumenta en un 10% por tramos de 1000m de altura**, un 20% en el agua, un 10% en la arena y **un 80% en la nieve**. De esta manera, mediante la combinación de estos elementos, los profesionales de la montaña son un grupo de personas sobreexpuestas a la luz (especialmente a los UV y a la luz azul).

Se han realizado algunos estudios con grupos significativos entre los habitantes de planicies soleadas (POLA, Sète, France<sup>3,4</sup> Beaver Dam Eye study Wisconsin USA[10] ; Chesapeake Bay study, Australia<sup>9</sup>). Los hallazgos de dichos estudios han puesto de relieve un aumento de la prevalencia de las cataratas corticales, en particular, y se discute si también favorece el desarrollo de las maculopatías<sup>[3,4,10,9]</sup>.

En nuestro conocimiento, no se ha publicado ningún estudio sobre algún grupo de personas habitantes en gran altitud y sobreexpuestas. En nuestro departamento llevamos a cabo un estudio original sobre los guías de alta montaña comparándolos con una población que vive en una planicie de la región de Lyon (Estudio registrado en Eudract 2010-A00647-32, Promotor Essilor international, Investigador principal: Dr. Corinne Dot). Este estudio resalta principalmente los efectos de los rayos solares en altitud así como algunos aspectos más secundarios de los efectos combinados del viento y bajas temperaturas.

Estudio realizado sobre los guías de alta montaña de Chamonix<sup>6</sup>

Participaron en este estudio noventa y seis guías de alta montaña del valle de Chamonix mayores de 50 años de edad, así como 90 controles de edad comparable que acudieron a la consulta de refracción del Hospital Desgenettes en Lyon.

El cuestionario diseñado tenía como objetivo evaluar la exposición a la altitud (número y altitud de las excursiones) así como los medios de protección utilizados. Se examinó a cada uno de los pacientes bajo dilatación con un examen clínico del segmento anterior (clasificación LOCS, III, Lens Opacities Classification System III,) completado por un análisis por cámara de sheimpflug (Oculus®, Alcon) y del segmento posterior asociado a una retinofotografía del polo posterior.

(58.3% compared with 21.7%,  $p < 0.001$ ) and arcus senilis (27.6% compared with 11.7%,  $p < 0.001$ )

- **Regarding the crystalline:** the mountain guides had more abnormalities of the crystalline (42.4% compared with 16.2%,  $p < 0.0001$ ). They had mainly cortical opacities (30.8% compared with 10%,  $p < 0.0001$ ). The difference is also significant for cataract surgery (5.4% compared with 0%,  $p = 0.02$ ). The maximum average crystalline density measured by Oculyzer® was also greater in the mountain guides (22.5% compared with 20.2%,  $p = 0.016$ ). We also observed in the peripheral cortex of the guides round punctiform cortical micro-opacities in a significantly higher proportion ( $p = 0.004$ ) mostly located towards the nose.

- **Regarding the macula,** 30.2% of the mountain guides presented an abnormality of the macula area (including all abnormalities) compared with 18.9% in the control group ( $p < 0.001$ ). These abnormalities are mainly represented by drusen (28.7%) of a variety of sizes and numbers, and mainly seed-like.

- **Significant risk factors** identified are the high altitude (3000m to 5000m) and work in a snowy environment, a separate factor due to the scale of the reflection it generates.

Protections used were photochromic lenses ( $OR = 0.53$  for crystalline opacities), the wearing of a visor ( $OR = 0.37$  for the crystalline,  $OR = 0.4$  for the macula) and the wearing of a ski mask ( $OR = 0.44$  for blepharitis,  $OR = 0.5$  for the crystalline,  $OR = 0.6$  for arcus senilis).

## Discussion

The mountain guides group presents more superficial pathologies, which are not described in literature as being linked to UV exposure, with the exception of pterygium. It is probable that this increase is due to a number of factors, combining UV action with weather conditions (cold and wind).

With regard to the crystalline, our results agree with the French POLA<sup>(4)</sup> study and with those of the Chesapeake Bay study<sup>(9)</sup> carried out amongst Australian fishermen and concerning the increased prevalence of crystalline cortical opacities. The crystalline would appear to behave like a **real intraocular dosimeter of the UV rays received.**

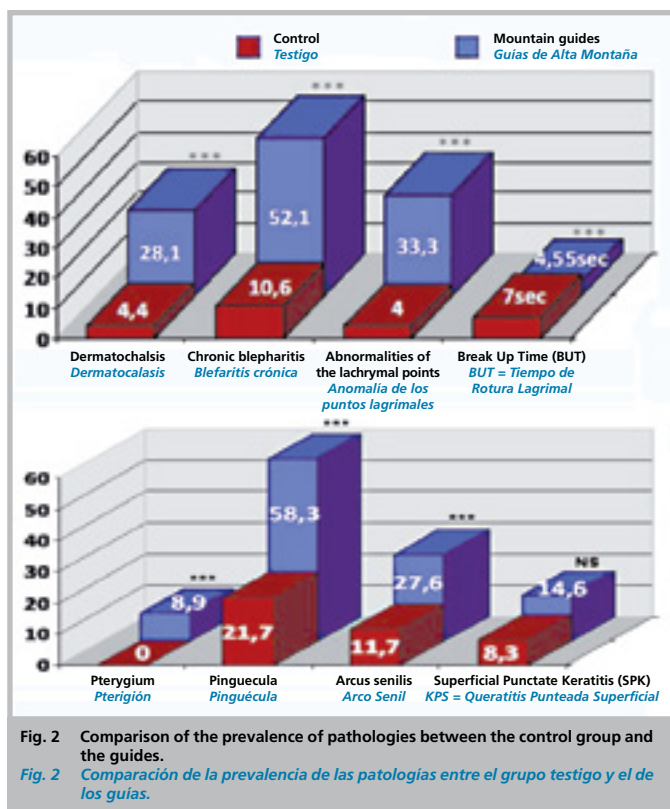


Fig. 2 Comparison of the prevalence of pathologies between the control group and the guides.  
Fig. 2 Comparación de la prevalencia de las patologías entre el grupo testigo y el de los guías.

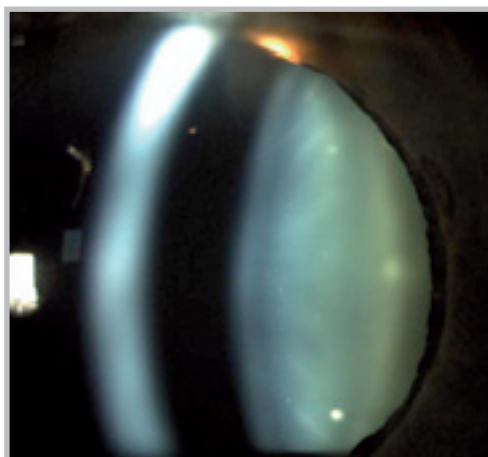


Fig. 3 Section showing anterior cortical micro-opacities using a Slit Lamp.  
Fig. 3 Micro-opacidades corticales anteriores en corte LAF (Lámpara de hendidura A).

Los análisis estadísticos utilizaron el test T de student para la comparación de los dos grupos y una regresión logística para evaluar los factores de riesgo.

Los resultados fueron los siguientes:

- **En cuanto a las patologías de superficie,** los GHM presentaron estadísticamente un mayor número de dermatocalasis (28,1% versus 4%,  $p < 0,001$ ), de blefaritis crónica (52,1% versus 10,2%,  $p < 0,001$ ) y anomalías de los puntos lacrimales (33,3% versus 4%,  $p < 0,001$ ). Su tiempo de rotura lagrimal (Break Up Time, BUT) también está estadísticamente disminuido (4,55s versus 7s,  $p < 0,001$ ). Hemos observado también un mayor número de casos de pterigión (8,9% versus 0%,  $p < 0,001$ ), de pingüecula (58,3% versus 21,7%,  $p < 0,001$ ) y de arco senil (27,6% versus 11,7%,  $p < 0,001$ ).

- **En cuanto al cristalino:** los guías de alta montaña presentaron un mayor número de anomalías del cristalino (42.4% vs. 16.2%,  $p < 0.0001$ ) y presentaron esencialmente opacidades corticales (30.8% vs. 10%,  $p < 0.0001$ ). La diferencia también es significativa cuando se comparan las cirugías de cataratas (5.4% vs. 0%,  $p = 0.02$ ). La densidad máxima media del cristalino medida en Oculyzer® también es más elevada en el grupo de los guías de alta montaña (22.5% vs. 20.2%,  $p = 0.016$ ). Por lo demás, hemos observado en el córtex periférico de los guías de alta montaña algunas micro-opacidades corticales anteriores redondas puntiformes en una proporción significativamente más elevada ( $p = 0.004$ ) y con una localización preferentemente nasal.

- **En cuanto a la mácula,** el 30.2% de los guías de alta montaña presentaban una anomalía del área macular (incluyendo a todas las anomalías) contra el 18.9% del grupo testigo ( $p < 0.001$ ). Estas anomalías estaban representadas esencialmente por drusas (28.7%) en número y tamaño variables y, en la mayoría de los casos, drusas miliares.

- **Los factores de riesgo** significativos encontrados son la gran altitud (3000m a 5000m) así como las actividades en un ambiente nevado, factor independiente por la magnitud del reflejo que genera.

Los factores de protección son el porte de gafas fotocromáticas ( $OR = 0,53$  para las opacidades del cristalino), el porte de una visera le ( $OR = 0,37$  para el cristalino,  $OR = 0,4$  para la mácula) así como el porte de una máscara de esquí ( $OR = 0,44$  para las blefaritis,  $OR = 0,5$  para el cristalino,  $OR = 0,6$  para el arco senil).

In terms of macular impact, results in literature are controversial. The POLA study does not find any difference in the population living in Sète. On the other hand the relative risk of showing signs of age-related maculopathy is 2.2 in the American Beaver Dam Eye study. The risk of developing AMD is also increased amongst Australian professional fishermen in Chesapeake Bay. In our study we also noted an increase in the prevalence of mainly seed-like drusen, which are a sign of macular ageing.

The low numbers in our population, along with the long-standing use by mountain guides of preventive equipment in the form of the wearing of sunglasses, certainly explains why we did not find more AMD, and underlines the relative efficiency of the means of protection used. However, the results of the questionnaire show that vigilance in terms of protection at medium mountain altitudes is lower, particularly when hiking and climbing. Yet exposure to UV rays is identical, whatever the weather, since UVs are not filtered by the clouds, whence insidious and chronic exposure, even at medium mountain altitudes.

**Optimal ocular protection** therefore involves the **wearing of a visor with protective glasses**: either sunglasses or photochromic lenses. This important data for professionals exposed to these rays (mountain and sea), should also be taken into consideration for children whose clear crystalline allows more rays to pass and for keen mountaineers and fishermen.

This data also underlines the importance of the latest technological progress made in terms of materials. Polycarbonate stops 100% of UVs (cut off at 385nm). For the visible spectrum, class 3 lenses halt 85% of visible rays and therefore allow 15% of rays through, to enable colour vision.

An interesting technological advance is the arrival of melamine-coated, class 3 brown sun lenses, which offer the "plus" of cutting out 100% of the start of blue light (cut out up to 425nm, preventing the absorption peak of ganglion cells at 480nm).

Our study underlines the protection offered by photochromic lenses. Photochromic lenses also exist mounted on curved frames, transiting from class 2 to class 4 shade, depending on outdoor conditions; these are also a good means of protection in the mountains.

## Conclusion

Recent data confirms the harmful action of chronic sun exposure without protection. The increase in ocular surface pathologies, impact on the crystalline and impact on the macular, means that extraocular protection optimised by means of the new materials available should be advised, right from the youngest age.

This study on ocular phototoxicity in the mountains was the subject of a thesis for a Medical Doctorate, presented by H. El Chehab on 18th October 2011 in Lyon.

Conflicts of interest: Essilor International (promoter of the study)

## Discusión

*El grupo de guías desarrolla un mayor número de patologías de superficie que no han sido descritas como ligadas a una exposición a los rayos UV, con la excepción del pterigión. Es posible que este aumento sea multifactorial, a través de la combinación de la acción de los rayos UV y las condiciones climáticas (el frío el viento).*

*En cuanto al cristalino, nuestros resultados están en concordancia con el estudio francés POLA<sup>(4)</sup> así como con los obtenidos en el estudio Chesapeake Bay<sup>(9)</sup> en pescadores australianos sobre el aumento de la prevalencia de las opacidades corticales del cristalino. El cristalino parece comportarse como un verdadero dosímetro intraocular de los UV recibidos.*

*En cuanto a las afecciones maculares, los resultados en la literatura muestran una cierta controversia. En el estudio POLA no se encuentra ninguna diferencia con la población que vive en Sète. En cambio, en el estudio estadounidense Beaver Dam Eye Study, el riesgo relativo de presentar signos de maculopatía asociada a la edad es del 2,2. El riesgo de desarrollar una DMAE también aumenta entre los pescadores profesionales australianos de Chesapeake Bay. En nuestro estudio, también hemos observado un aumento de la prevalencia de drusas, principalmente miliares y que constituyen signos de envejecimiento macular.*

*La cantidad reducida de personas que constituyen nuestro grupo de estudio, así como la ya antigua tradición de prevención de los guías de alta montaña con el porte*

*de protección solar seguramente explica por qué no se ha encontrado un mayor número de casos de DMAE y también pone de relieve una relativa eficacia de los medios de protección utilizados. No obstante, los resultados del cuestionario muestran que la vigilancia de la protección en media montaña es inferior, particularmente en la práctica de la escalada o senderismo. No obstante, la exposición a los rayos UV es idéntica cualquiera que sean las condiciones climáticas puesto que los rayos UV no son filtrados por las nubes, de ahí una exposición insidiosa y crónica incluso en media montaña.*

*La protección ocular óptima requiere el porte de una visera además de gafas protectoras: solares o fotocromáticas. Estos datos importantes sobre los profesionales expuestos (montaña o mar) también hay que tomarlos en consideración en el caso de los niños cuyo cristalino claro transmite más los rayos, así como los aficionados de montaña y pesca.*

*Estos datos subrayan también el interés de estos últimos avances tecnológicos sobre los materiales. El polycarbonato bloquea el 100% de los UV (bloqueo a 385nm). En el espectro visible, las lentes de clase 3 bloquean el 85% de los rayos visibles y dejan pasar el 15% de los rayos para permitir una visión en colores.*

*Un avance tecnológico interesante es la llegada de las lentes melaminadas, gafas solares de categoría 3, con tinte marrón, que*

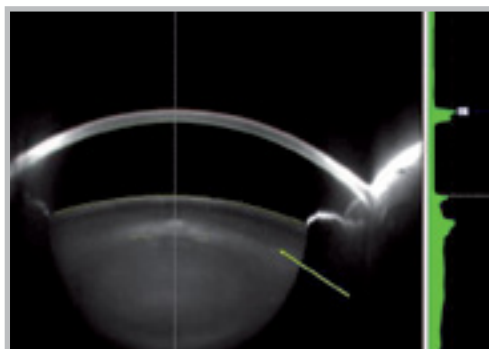


Fig. 4 Highlighting crystalline micro-opacities by Oculyser® analysis.

Fig. 4 Puesta en evidencia de las micro-opacidades en análisis Oculyser®.

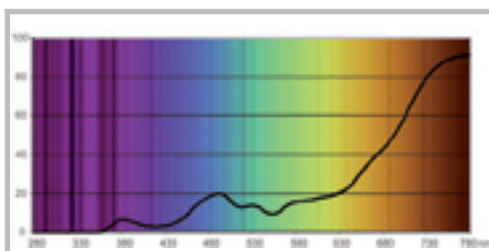


Fig. 5 Effect of a class 3 sun lens on the sun's rays. Under the graph: rays transmitted to the eye despite the wearing of a class 3 lens, i.e. around 15% of blue light.

Fig. 5 Efecto de una lente solar de categoría 3 en las radiaciones solares. Por debajo de la curva: radiaciones transmitidas al ojo a pesar del porte de una lente de categoría 3, es decir, aproximadamente el 15% de la luz azul.

### Acknowledgements

Marc Alexandre (Essilor International) for his work on ensuring that this original study was possible and could be undertaken in 2010, seventeen years after an initial study in 1993 covering a more limited number of guides.

Laboratoire Alcon, for the loan of the Oculyzer® equipment, which permitted an original objective analysis of the crystalline. □

*tienen el mayor poder de bloqueo del 100% del inicio de la luz azul (bloquean a los 425nm, evitando el pico de absorción de las células ganglionarias a 480nm)*

*Nuestro estudio subraya la protección aportada por las lentes fotocromáticas. También existen lentes fotocromáticas tintadas montadas en monturas torneadas, pasando del tinte categoría 2 a 4 según las condiciones exteriores; también constituyen una buena protección en montaña.*

### Conclusión

*Los datos recientes confirman el papel nocivo de la exposición solar crónica sin protección. El aumento de las patologías de superficie ocular, de la afección del cristalino y de la afección de la mácula, aboga por una protección extraocular optimizada acorde a los materiales que ahora están disponibles y desde la más temprana edad.*

*Este estudio de fototoxicidad ocular en la montaña ha sido objeto de una tesis Doctoral en Medicina, sostenida por H. El Chehab el 18 de octubre de 2011 en Lyon.*

*Conflicto de interés: Essilor international (promotor del estudio)*

### Agradecimientos

*A Marc Alexandre (Essilor international) por la energía dedicada para que este estudio original fuera posible y realizable en el 2010, diecisiete años después de un estudio preliminar en 1993 en un número más limitado de guías.*

*Al laboratorio Alcon por el préstamo de material Oculyzer® que ha permitido un análisis objetivo del cristalino inédito. □*

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# Ultraviolet damage to the cornea in the Tropics

## *Daños córneales por rayos ultravioleta en zonas tropicales*

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#### Summary

Ultraviolet radiation has been shown to cause harmful effects on the cornea, particularly in the tropics. This is further exacerbated by the depletion of the ozone layer. As UV-C is filtered by the ozone, acute photokeratitis is typically seen in eyes exposed to manmade implements such as during welding. Chronic exposure to UV-B can present with a plethora of corneal conditions, such as pterygium and pinguecula, climatic droplet keratopathy and ocular surface squamous neoplasia. Exposure of the cornea to UV-B during photorefractive keratectomy may predispose to the formation of subepithelial haze. It is therefore prudent to use personal protective devices to shield the eye from excessive UV radiation.

Ultraviolet (UV) radiation spectrum is classified by its wavelength: UV-A (315-380 nm), UV-B (280-315 nm), and UV-C (100-280 nm). While the ozone layer completely filters UV-C and 90% of UV-B from reaching the Earth's surface, the remaining UV radiation is sufficient to cause damage to the eye, particularly so in the tropics where there is year-long exposure to strong sunlight. And this is further exacerbated by the losses of the stratospheric ozone of about 6% in the southern mid-latitudes and 4% in the northern mid latitudes<sup>[1]</sup>. A 1% reduction in the ozone layer leads to an increase in radiation of 0.2% to 2% reaching the Earth's surface.

The cornea absorbs most of the UV-B and all of the UV-C that reaches the eye. While the corneal epithelium and Bowman layer have significantly higher absorption coefficients than that of the stroma, the whole thickness of the corneal stroma absorbs 70-75% of the UV spectra shorter than 310 nm<sup>[2]</sup>.

The threshold for acute UV photokeratitis is found at a peak sensitivity of 270nm, which is only possible with manmade implements since the ozone layer blocks off UV-C. But it is possible to develop acute UV keratitis under natural sources such as solar eclipse burns<sup>[3]</sup> and during skiing (commonly referred as "snow blindness"). Welders with acute photokeratitis may present with tearing, pain, photophobia, and is usually not apparent till several hours after exposure. It is akin to sunburn of the cornea and conjunctiva, though it is shown to be phototoxic rather than thermal injury to the corneal epithelium. Signs include superficial punctate keratopathy, conjunctival injection and chemosis.

#### Resumen

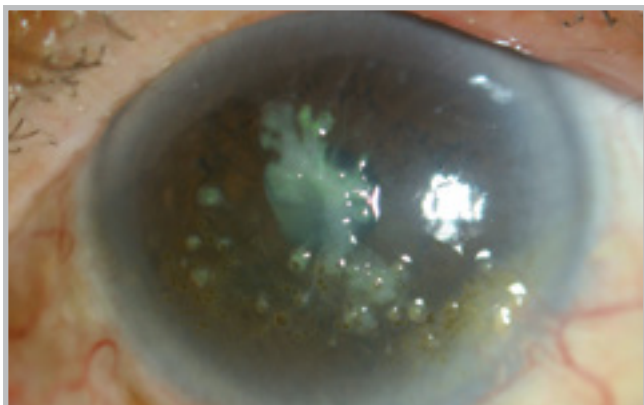
*Se ha demostrado que la radiación ultravioleta tiene efectos nocivos en la córnea, especialmente en las zonas tropicales. Este fenómeno se ha acentuado con la desaparición de la capa de ozono. Dado que el ozono bloquea los rayos UV-C, la fotoqueratitis se observa más frecuentemente en ojos expuestos a herramientas fabricadas por el hombre como los aparatos de soldadura. En cambio, la exposición crónica a los rayos UV-B puede ocasionar un amplio abanico de trastornos de la córnea, como pterigión y pingüecula, queratopatía climática en gotas y neoplasia escamosa de superficie ocular (OSSN en inglés). La exposición de la córnea a los UV-B durante la queratectomía fotorrefractiva puede predisponer a la formación de opacidades subepiteliales (haze en inglés). Por lo tanto, es prudente utilizar dispositivos de protección personal para proteger al ojo de la radiación excesiva de los UV.*

*El espectro de radiación ultravioleta (UV) tiene diferentes clasificaciones según su longitud de onda: UV-A (315-380 nm), UV-B (280-315 nm), y UV-C (100-280 nm). Aunque la capa de ozono filtra completamente los UV-C y el 90% de los UV-B para que no alcancen la superficie de la tierra, la radiación de los UV restantes es suficiente para causar daños al ojo, especialmente en los trópicos donde la exposición a la luz solar es muy fuerte a lo largo del año. Esta exposición se acentúa con la desaparición del ozono estratosférico: 6% en las medias latitudes del sur y 4% en las medias latitudes del norte<sup>[1]</sup>. Una reducción del 1% en la capa de ozono conduce a un aumento de la radiación que llega a la superficie de la tierra de unos 0.2% a 2%.*

*La córnea absorbe la mayoría de los UV-B y todos los UV-C que llegan al ojo. Aunque el epitelio corneal y la capa de Bowman tienen coeficientes de absorción significativamente más elevados que el estroma, el espesor total del estroma corneal absorbe el 70-75% del espectro de UV inferiores a 310 nm<sup>[2]</sup>.*

*El umbral de fotoqueratitis aguda por UV encuentra su sensibilidad máxima en 270nm, lo cual sólo puede alcanzarse con herramientas fabricadas por el hombre puesto que la capa de ozono bloquea los UV-C. No obstante, es posible desarrollar queratitis por radiación UV aguda*

Chronic solar exposure has been linked to multiple ocular surface disorders, such as pterygium, pinguecula, climatic droplet keratopathy and ocular surface squamous neoplasia (OSSN). Pterygium commonly occurs in the tropics, and multiple studies have shown an association with increased levels of UV-A and UV-B<sup>[4-5]</sup>. However, the mechanism by which UV radiation induces pterygium remains to be investigated.



**Fig. 1** Climatic droplet keratopathy. Golden-yellowish subepithelial spherules are seen on the inferior half of the cornea, associated with secondary amyloidosis of the central cornea.

**Fig. 1** Queratopatía climática en gotas. Se pueden ver esférulas amarillas o doradas subepiteliales en la mitad inferior de la córnea, asociadas con amiloidosis secundaria de la córnea central.

Climatic droplet keratopathy, also known as Labrador keratopathy, chronic actinic keratopathy, proteinaceous degeneration and keratinoid degeneration, is a spheroidal degeneration of the superficial cornea, found in areas of high UV exposure. A study of Chesapeake Bay watermen found a high odds ratio of 6.36 for average annual UV-B exposure in the upper quartile<sup>[5]</sup>. Histologically, the hyaline-like deposits are found in the Bowman's layer and superficial stroma. The source of the deposits remains controversial. Fraunfelder<sup>[6]</sup> believed that it is secreted by corneal and conjunctival fibroblasts, while others postulated that it is of plasma origin. Clinical findings are characterized by yellow, oily-appearing spherules in the subepithelium, within Bowman's layer, or in the superficial corneal stroma (Fig.1). These spherules measure 0.1 to 0.4 mm, appearing at the limbus in the interpalpebral region in the early stages.

While there is strong association between UV-B exposure and squamous cell carcinoma of the eyelid<sup>[7]</sup>, the etiology and pathogenesis of ocular surface squamous neoplasia is multifactorial, including UV-B exposure, cigarette smoking, Human Papilloma Virus infection, exposure to petroleum derivatives and host susceptibility<sup>[8]</sup>. OSSN invariably involves the cornea at the sun-exposed interpalpebral region. Whether it is due to a greater propensity for malignant change in this zone, or environmental exposure remains unclear.

Excimer laser of different wavelengths can be produced with a combination of a noble gas and a halogen gas. The 193 nm excimer laser in the range of UV-C is utilized in laser refractive surgery such as photorefractive keratectomy (PRK) and laser in-situ keratomileusis (LASIK) for its precise etching abilities<sup>[9]</sup>. In vitro tests have shown a risk of carcinogenesis with the excimer laser, but its cell-damaging effects are less for lasers at 193 nm compared to the longer wavelengths. Furthermore, the short exposure of the cornea to the excimer laser mitigates this risk. The exposure of the stromal bed to

*mediante exposición a los elementos naturales como las quemaduras causadas por los eclipses solares<sup>[3]</sup> y mediante la práctica del esquí (comúnmente denominada "ceguera del esquiador"). Los soldados con fotoqueratitis aguda pueden presentar signos como lagrimeo, dolor o fotofobia y habitualmente no se presentan hasta 4 horas después de la exposición. Es parecido a las quemaduras de la córnea y de la conjuntiva aunque parece ser fototóxico en vez de ser una herida térmica del epitelio corneal. Los signos incluyen queratopatía punctata superficial, inyección conjuntival y quemosis.*

*Se ha asociado la exposición solar crónica a múltiples trastornos de la superficie ocular como el pterigión, la pingüecula, queratopatía climática en gotas y la neoplasia escamosa de la superficie ocular (OSSN). Se ha observado que el pterigión ocurre comúnmente en los trópicos y toda una serie de estudios han demostrado su asociación con niveles elevados de UV-A y UV-B<sup>[4-5]</sup>. Sin embargo, el mecanismo mediante el cual la radiación por UV induce pterigión todavía queda por ser investigado.*

*La queratopatía climática en gotas, también conocida como queratopatía del Labrador, la queratopatía actínica, la degeneración proteinácea y la degeneración queratinoide es una degeneración esferoidal de la córnea superficial que se observa en zonas de alta exposición a los UV. En un estudio realizado en marinos de la Bahía de Chesapeake, se encontró un coeficiente de alta probabilidad (odds ratio) de 6.36 de la media anual de exposición a los UV-B en el cuartil superior<sup>[5]</sup>.*

*Histológicamente, se encuentran depósitos hialinos en la capa de Bowman y el estroma superficial. La fuente de dichos depósitos sigue siendo objeto de controversia.*

*Fraunfelder<sup>[6]</sup> pensaba que se trataba de una secreción de los fibroblastos corneales y conjuntivales mientras que otros postulaban que era más bien de origen plasmático. Los hallazgos clínicos han mostrado que éstos se caracterizan por esférulas amarillentas, de apariencia grasa subepiteliales, en la capa de Bowman o en el estroma corneal superficial (Fig.1). Dichas esférulas miden de 0.1 a 0.4 mm, apareciendo en la zona límbica de la región interpalpebral en las fases precoces.*

*Si bien existe una fuerte asociación entre la exposición a los UV-B y el carcinoma celular escamoso del párpado<sup>[7]</sup>, la etiología y patogénesis de la neoplasia escamosa de la superficie ocular es multifactorial, incluyendo la exposición a los UV-B, tabaquismo, infección por Virus de Papiloma Humano, exposición a derivados del petróleo y susceptibilidad del anfitrión<sup>[8]</sup>. La neoplasia escamosa de la superficie ocular (OSSN) invariablemente incluye a la córnea en la zona interpalpebral expuesta al sol. Todavía no está claramente definido si se trata de una mayor proclividad de esta área a cambios malignos o si es una cuestión de exposición al entorno.*

*Se pueden utilizar láseres excímer de diferentes longitudes de onda con una combinación de un gas noble y un halógeno. El láser excímer de 193 nm en el rango de los UV-C se utiliza en la cirugía refractiva por láser como en la queratectomía fotorrefractiva (PRK) y la queratomileusis in-situ por láser (LASIK) por sus capacidades precisas de grabado<sup>[9]</sup>. Las pruebas in vitro han mostrado un riesgo de carcinogénesis con el láser excímer pero los efectos nocivos en las células son menores en los láseres a 193 nm en comparación con las longitudes de onda más largas. Además, la breve exposición de la*



UV-B during PRK may cause prolonged stromal healing and subepithelial haze formation<sup>[10]</sup>. It has been suggested that the lower incidence of haze seen in laser-assisted subepithelial keratectomy (LASEK) may be due to less UV radiation causing cellular damage to the corneal stroma with the near intact epithelium<sup>[2]</sup>.

UV radiation has been implicated in the pathogenesis of multiple corneal disorders. Although further studies need to be done to ascertain the casual effect on these conditions, there is sufficient data to suggest such an association. With the depleting ozone layer, there is an increasing exposure of UV radiation, especially in the tropics. And personal protective devices such as hats and sunglasses, and life style changes can help to minimize exposure of UV radiation to the eye. □

*cornea al láser, mitiga este riesgo. La exposición del lecho estromal a los UV-B durante la PRK puede causar una prolongada fase de curación y formación de opacidades subepiteliales<sup>[10]</sup>. Se ha sugerido que la menor incidencia de opacidad observada en la queratectomía subepitelial asistida por láser (LASEK) puede deberse a un nivel menor de radiación de UV que ocasionan daño celular al estroma corneal con el epitelio casi intacto<sup>[2]</sup>.*

*La radiación de los UV está involucrada en la patogénesis de múltiples trastornos corneales. Aunque es necesario realizar más estudios para establecer el efecto causal de estos trastornos, existen datos suficientes para sugerir que existe dicha asociación. Con la desaparición de la capa de ozono, existe una mayor exposición a la radiación UV, especialmente en los trópicos. Los dispositivos de protección personal como sombreros y gafas de sol, así como cambios en el estilo de vida pueden contribuir a minimizar la exposición del ojo a la radiación UV. □*

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# THE INFANT'S VISION AND LIGHT – THE ROLE OF PREVENTION IN PRESERVING VISUAL CAPACITY

The eyes of infants are permeable to both ultraviolet radiation and blue light, and extremely sensitive to glare. Although light is essential for the proper development of visual function in children, surveillance and protection are particularly important in the first months of life. Moreover, medical surveillance and early screening help prevent risks associated with possible anomalies of the visual system.



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#### KEYWORDS

UV, blue light, prevention, protection, screening, surveillance, diagnosis, infant, baby, child

The newborn child can see from the moment of birth, and even before. When we laterally illuminate a pregnant woman's womb around the sixth month of pregnancy, we can see under ultrasound that the foetus turns its head away from the light source. This is also the case after birth. If newborns quite often keep their eyes closed, it may be because they are asleep. But if they are awakened in a low-light environment, they will look at us. This enables us to measure their acuity, which is about 1/20. Depending on their complexion (very light or more pigmented), they are dazzled by light up to the age of about six months. For their comfort, strong light should be avoided. At the age of six months, their acuity reaches 2/10, and then 4/10 at one year and 10/10 at about five years of age, remembering that in preverbal children we measure detection acuity with acuity cards and then the more demanding morphoscopic acuity. The field of vision is complete at one year but the child needs to learn to use it, a process that will continue more or less successfully throughout life, depending on motivation. This is evidenced by the large proportion of motorists who do not use the rear-view mirror.

Colour and contrast vision is good at three months, but will continue to improve until adolescence. Stereoscopic vision appears at four months and rapidly becomes excellent.

Focusing becomes precise at about eight months with the development of the fovea in which the cones are gradually concentrated, enabling a reliable orthoptic examination. Ocular motor control, including saccades and pursuit, is precise at one year, although latency or reaction time is characterized by a certain slowness up to the age of about ten. This relative slowness facilitates examination.

#### The role of light

Light plays a fundamental role in this visual performance. Numerous visual deprivation experiments conducted in baby monkeys and kittens show attrition of visual pathways due to vision deprivation, making it possible to define a "deprivation-sensitive period". The existence of this sensitive period in humans is now widely recognized. A baby presenting early lens opacity should be operated on during the first months of life to prevent severe amblyopia. Fitting aphakic infants with contact lenses allows them to acquire normal vision. Similarly,

wandering attention and obesity due to lack of exercise and meals on the run.<sup>5,6</sup>

The two studies agree on recommending limited use. One may only wonder why no impact on the visual system was identified (or it was possibly ignored) in either report.

#### Lighting levels

The introduction of fluorescent lighting, driven by cost concerns and possibly comfort concerns, has significantly impacted luminous power in indoor environments. School children must receive 400 lux on their desks. But one wonders if is this for the teacher's comfort or the children's.

Sensitivity to light develops rapidly in children, reaching its adult level in adolescence. It then gradually decreases with age. What teenager has not been reprimanded for reading in semi-darkness? But we forget that by age 35, we have already lost half of our sensitivity. "You'll ruin your eyes... I know dad, speak for yourself." With the introduction of fluorescent tubes in the 60s along with improvements in lighting and its use for longer periods, concern has spread about possible adverse effects that have not proven justified. So we use lighting generously. Night lights in children's rooms calm their parents' anxiety. Studies in this field are fraught with methodological problems. How do we isolate the factors responsible for the increase in the incidence of myopia or other pathologies in a rapidly changing world? Should we blame it on the increase in close work? That remains to be proven. Nutritional changes? Perhaps. On the other hand, the effect of relative confinement on

FIG. 1 | Evolution of sun protective eyewear for children. Sunglasses with side shields for adults and design not really optimized for babies.



the development of myopia has been clearly demonstrated in urban areas in Asia, among people living in confined, rather than open spaces. Lighting quality and quantity become important for comfort with age, and particularly with advanced age.

#### The precautionary principle

This term drawn from the fields of theology and law has been increasingly used in the medical field in recent times. It consists in establishing a practice on the basis of a body of knowledge, or even presumptions. It must be weighed against the constraints imposed by the practice, by estimating the benefit-cost ratio. A concern for optimizing living conditions, coupled with longer life expectancies – one in two baby girls born today will live to be 100 – accounts for the widespread implementation of medical and health measures to reduce risk exposure. In the field we are dealing with, what constitutes a reasonable attitude?

#### Sun protection

One finds spectacles with flat coloured lenses as early as the 18th century, known as "conserves", which were meant to shield the eyes from glare and protect vision (see the 1759 Richelet and 1902 Larousse dictionaries), but wide-brimmed hats and more recently caps have also come into wide use. Climbers have long worn protective sun goggles. In both cases, the aim was to shield the wearer's eyes from glare and improve comfort. Sunglasses for babies are a recent development. They have a wide bridge, often featuring a non-slip design and wide temples that provide side protection. But most importantly, they have a wraparound design that covers the eyebrows.

In the 1980s, I saw an albino child at the Bébé Vision clinic whose parents lived at a high elevation in the Alps. The optician prescribed the glasses shown in Figure 1. The side shields for adults were supplied by a manufacturer's representative. A model for babies

FIG. 2 | Evolution of sun protective eyewear for children. Wraparound design with wide bridge and wide temples that provide side protection.



FIG. 3 | Evolution of sun protective eyewear for children. Wraparound design that covers the eyebrows.



was not yet available. But times have long since changed. Opticians have developed a wide range of wraparound performance products, including side protection. Today, babies are well protected, if only for comfort reasons (Fig. 2, Fig. 3).

But I was told by certain ophthalmologists that sun protection should only be resorted to in extreme situations in order to allow children's retinas to develop defence mechanisms to prevent them from becoming dependent on glasses!

### New parental attitudes

Parental behaviour has evolved considerably, and in a positive direction as regards protective gear for children. The increased average age of parents at the birth of their first child – 30 for women and even older for men – as well as the choice of family planning are factors conducive to a higher level of concern in the care of children. Just consider how often parents run to the doctor at the slightest

concern. As for protective gear, parents are proud to show off their babies with sunglasses, helmets and knee pads on their toy scooters. This is quite commendable. Such prudent behaviour has given rise to investments by the protective equipment sectors, including the optical sector, in response to the emerging needs of children and echoing current information provided to paediatricians, general practitioners and, of course, ophthalmologists and opticians.

### Screening, surveillance and diagnosis

The founding of the first Bébé Vision clinic in 1982 contributed to raising awareness in professional circles. The publicity given this initiative, devoted to the search for visual anomalies of all kinds, has raised

awareness of the visual capabilities of the preverbal child. Infants see better than previously thought, and their vision deserves to be protected. The concept of a “sensitive period” led to recommending a first routine exam at the age of nine months. At this age, the examination is easy, and the child is cooperative and follows the treatment. Opposition begins to appear at approximately 12 months. Once an indication has been identified, whether it is due to heredity, prematurity or an apparent eye disorder – often an epicanthic fold – the medical profession recommends a check-up with a specialist (ophthalmologist or orthoptist). This practice has significantly reduced the number of surgical procedures for strabismus, since most of them can be avoided by early correction of refractive errors. The discovery of amblyopia during the health check performed at the entrance to the first year of primary school (at age 5) has become much less frequent. Consequently, treatment for the most serious ophthalmologic pathologies is provided earlier and remarkable progress has been made in therapeutic regimens.

### Determining best practice: screening, surveillance or protection?

Routine screening of all children would be costly and unproductive, since it would inevitably be cursory. Nevertheless, in the absence of accurate statistics, it is estimated that nearly 15% of infants require follow-up, and more than half of these have a significant refractive error or a more serious disorder. Surveillance consists in referral to a specialist as soon as an indication or risk factor

**“Although certain therapeutic ratios still need to be measured, all evidence indicates that protecting the eyes against cumulative sun exposure is the responsible attitude.”**

has been identified. This the current practice in France and it is paying off. It is during these visits, but also during visits to the paediatrician or general practitioner, that parents raise the issue of sun protection.

Opticians have also contributed to raising parents' awareness. The eyes should be protected from the sun for reasons of visual health and comfort from a very early age, and this practice must become routine. There are no contraindications. Although certain therapeutic ratios still need to be measured, all evidence indicates that protecting the eyes against cumulative sun exposure is the responsible attitude.

### Conclusion

It is somewhat delicate to propose a hierarchy of factors that have contributed to the increasing acceptance of eye sun protection for infants and children. Much remains to be done, however, to encourage widespread acceptance of the need for children to wear protective eyewear. The dissemination of information on the dangers

of exposure to high-energy visible light – particularly blue light and UV radiation – is gaining momentum, spurred on by the introduction of new lighting solutions. But better knowledge about vision in children, coupled with low birth rates, is focusing parents' attention on their limited number of offspring, leading to a more protective attitude in their regard. Increased life expectancies are also making everyone more aware of the difficulties faced by the elderly as their sight begins to fail, irrespective of the origin of the pathology. Eyewear manufacturers have made a particular effort to provide appropriate solutions at a reasonable cost. Such products are even found in sporting goods stores.

Finally, the medical and paramedical professions have become aware of the need to protect the vision of infants and provide more comfort for this little toddler who is not yet able to express his or her discomfort.

Protective eyewear for infants and children undoubtedly has a bright future. •



### KEY TAKEAWAYS

- The visual system is an integral part of the brain and begins to form 18 days after conception. During the sixth or seventh month of pregnancy, the foetus begins to see and react to light.
- Light plays a crucial role in the development of such visual functions as acuity, and colour and contrast vision, from the first days after birth.
- At birth, the newborn's visual acuity is still very low (1/30); objects can only be detected from a short distance (30 cm), and only in black and white and with little contrast.
- The eyes of infants are highly sensitive to glare and their ocular media are permeable to both ultraviolet light and blue light, due to the fact that their pigmentation is not yet complete.
- The visual system matures gradually: babies develop stereoscopic vision at the age of six months and are able to distinguish all colours at one year, but their visual acuity only begins to function optimally (10/10) when they reach the age of six.
- The paediatrician and ophthalmologist play essential roles in monitoring and detecting anomalies throughout the process of visual development.
- It is recommended that children be fitted with sun protective eyewear as early as possible for their comfort and visual health.

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## **IV. HOW TO PREVENT**

# **1. EXPERTS AND ECP INITIATIVES**



# Ultraviolet Radiation and the Eye: Complete Protection Requires Blocking Both Transmission and Backside Reflection

New research shows that effective protection from the serious hazards of ultraviolet radiation (UVR) requires that clear, photochromic, and tinted/polarized lenses protect wearers from both transmitted and reflected UVR.

Chronic exposure to the ultraviolet radiation in sunlight has been implicated in a number of serious ocular diseases, including pterygium, cataract, and climatic droplet keratopathy; and recent research has uncovered new, unexpected risks to the eyes. Unfortunately, the public remains dangerously under-informed about the nature and degree of this risk as well as the circumstances in which eye protection is most necessary.

## Unexpected Risks

Recent research has shown that the time of maximum risk for UVR damage to the eyes is very different from the time of maximum risk to the skin. Risk to the skin is greatest when the sun is highest in the sky—ie, at solar noon and on the summer solstice (June 21st).

But because the eyes are deep set in the orbit, they are partially protected when the sun is high in the sky; so direct ocular UVR exposure is greatest when the sun is somewhat lower in the sky. For spring, summer, and fall, maximum ocular UVR exposure occurs between 8:00AM and 10:00AM, and between 2:00PM and 4:00PM.<sup>1</sup> These, however, are not the times that people are most likely to wear sunglasses.<sup>1</sup>

## Side and Back Exposure

Even when the sun is high in the sky, the eye is exposed to a significant amount of UVR that is scattered by clouds or reflected by surrounding surfaces (Figure 1). This in-

direct radiation is responsible for nearly half of the UVR we receive.<sup>2</sup>

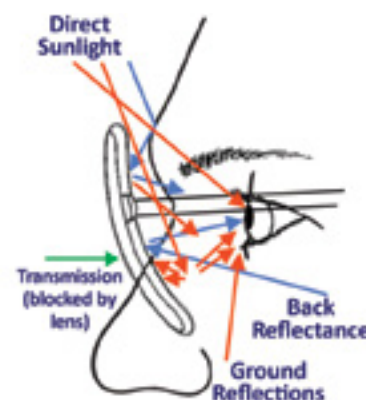
Most higher-quality sun, photochromic, and clear spectacle lenses effectively block the transmission of UVR, so UVR coming from in front is not usually an issue for people wearing glasses. But eyes still need to be protected from the significant amount of UVR that is reflected off the backside of clear, photochromic, and tinted/polarized lenses (Figure 1).

## Measuring Protection

Existing regulatory norms for UVR blocking are designed for sunglasses and are based solely on how much perpendicularly incident UVR passes through the lens; they do not take into account the substantial amount of UVR that comes from the side and is reflected off the backside of the lens. Nor are they applied to clear lenses, where UVR protection is equally, if not more, important.

Research by Karl Citek, OD, PhD, has found that while lenses treated to be anti-reflective transmit almost all of the visible light spectrum, they actually reflect over 25% of the incident UVR.<sup>3</sup> So even lenses that block its transmission can reflect UVR into the eyes when the source is not directly in front of the wearer.<sup>3,4</sup>

With this important information in mind, a new index, the Eye-Sun Protection Factor (E-SPF), was created. Like the refer-



**FIGURE 1** Note that UVR blocking can effectively eliminate transmission through the lens, but UVR can still enter the eye from the side by reflection from the backside of the lens. Up to now, all antireflective treatments have increased backside reflection of UVR (although they markedly reduced reflection of visible light).


ence index for skin care products, it measures the degree of protection provided by a lens. Unlike transmission data alone, however, the E-SPF measures total protection by integrating reflected UVR data with transmission data (see box).

## What Patients Need

Knowing what we now do about sources of UVR exposure, it becomes apparent that for everyday protection, clear lenses and sun lenses must offer UVR blocking of both transmission and reflection. To address this need, a new generation of Crizal® antireflective lenses (launching in 2012) has been engineered to virtually eliminate UVR reflection from the backside, for a lens that truly maximizes UVR protection.

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### The Eye-Sun Protection Factor (E-SPF)

The reference index utilized in the skin care industry tells consumers how well a sunscreen protects skin from UVR; but although UVR protection is as important for the eyes as it is for the skin, we have no similar system to compare the total UVR protection of different lenses. Aiming to develop an index for eyewear similar to the system for sunscreens, Essilor scientists, in conjunction with an independent third party expert, have created the Eye-Sun Protection Factor (E-SPF).

By incorporating measurement of both UVR transmission and backside reflection, the E-SPF provides a simple but effective way to grade the total protection offered by a lens: higher values of E-SPF indicate greater levels of protection against damaging UVR.

\*E-SPF is a new global index developed by Essilor, endorsed by independent third parties, measuring the lens' UV protection excluding direct eye exposure from around the lens. © Essilor International - January 2012 - RCS Creteil B 712 049 618. E-SPF and Crizal are trademarks of Essilor International.

# LIGHT AND OCULAR PATHOLOGIES: RISK PREVENTION IN OPHTHALMOLOGY

Ultraviolet radiation, among other aetiological factors, is implicated in several ocular pathologies. Dr. Sylvie Berthemy describes the most common clinical cases and identifies the most vulnerable population groups for *Points de Vue*. She also stresses the importance of including prevention in her clinical and medical practice.

**DR. SYLVIE BERTHEMY**  
Ophthalmologist

## **Points de Vue: Which eye diseases and conditions are related to the chronic effects of light exposure?**

**Dr. Sylvie Berthemy:** It all depends on the segment of the eye you are talking about.

Let's start with the **adnexa**. Almost everyone has had eyelid erythema (sunburn) which can lead to the formation of an actinic keratosis. We could also mention UV radiation's role as an aggravating risk factor in basal or squamous cell carcinoma or melanoma.

People exposed short-term to high-intensity solar radiation without protection may get what is known as "snow blindness". This condition, clinically known as acute photokeratitis and common in ski areas, is accompanied by pain, photophobia and tearing. In the work environment, among welders, it is commonly called "arc eye" or "welder's flash". It heals in three to four days with local vitamin treatment.

In the long term, patients exposed to severe weather and dust more readily develop pinguecula or pterygium, which are conjunctival conditions usually located in the area of

the medial palpebral fissure where the tissue is least protected by the eyelids. And we may encounter corneal degeneration or actinic or climatic droplet keratopathy, also called Bietti dystrophy, Labrador keratopathy (which affects 14% of the Inuit), elastic dystrophy, proteinaceous corneal degeneration or spheroidal corneal degeneration. When examined with a slit lamp, it resembles band shaped keratitis although, histologically, it is not the same. Despite the fact that ultraviolet radiation exposure appears to be the major aetiological factor, evidence of genetic origin has been demonstrated.

Take the **iris** next. Melanoma is increasing in frequency (approximately 6.5/10 million). Three-quarters of cases develop on the bottom part of light-coloured irises, and UV exposure may be a contributing factor. However, the link has not been definitely established.

As for the **crystalline lens**, the POLA study (evaluating age-related ocular pathologies) conducted on 2,600 inhabitants of Sète, France, showed that cataracts are three times more frequent and appear five to ten years earlier in people exposed to solar radiation (e.g. fishermen, guides, construction workers, etc.).

And as far as the **retina** is concerned, virtually all practitioners have been consulted by patients suffering from photic retinal injury caused by staring at an eclipse. UV exposure could also be a risk factor in the aetiology of AMD (Age-Related Macular Degeneration).

### KEYWORDS

eyelid erythema, actinic keratosis, carcinoma, melanoma, acute photokeratitis, pinguecula, pterygium, keratopathy, UV, ultraviolet radiation, cataract, AMD, lipofuscin, melanin, prevention, Crizal® Preveniria®



### In practice, what are the most frequent clinical cases of these diseases?

Pinguecula-type conjunctival lesions, UV keratitis and cataracts.

### What groups of patients are particularly at risk?

Children, because their pupils are larger and their crystalline lenses more transparent; patients with a family history of retinal degeneration: too many patients still go outdoors without the protection of specific filtering lenses; patients with fair complexions and those who tend to be photophobic (with hypo-pigmented irises and choroids); people who work outside: gardeners, construction workers, farmers, fishermen, pilots, tour guides, etc.; those in contact with a source of radiation and heat: welders, glassmakers, users of UV therapy and researchers who work in contact with LEDs (Light Emitting Diodes) – not to mention the length of time people spend in front of computer screens or other devices; those who have had cataract surgery, although implants increasingly have UV protective filters; people with hypermetropia, whose convex lens acts as a

**“Risk prevention is an integral part of our mission as medical doctors.”**

magnifying glass, concentrating rays on the retina; and the elderly, who have developed lipofuscin, a pigment found in the RPE (Retinal Pigment Epithelium), which is made up of molecular residue. Lipofuscin increases with age and is responsible for the photoreactivity of RPE, resulting in the production of free radicals that promote AMD.

### In the area of phototoxicity, are there any similarities between the eye and the skin?

Yes, they are subject to the same aging factors, both through the Joule effect – more prosaically known as heat – which can burn cells (causing erythema and keratinization) and harm the retinal pigment epithelium, for example, and through the photochemical effect, which is responsible for producing free radicals by breaking down cellular membranes, denaturing proteins or even attacking the nucleus. We know, for example that melanin (a pigment found in skin, hair and eyes) absorbs the  $\epsilon$  (epsilon) of wavelengths ranging from 300-700 nm (nanometres) and curbs harmful photochemical reactions by trapping unstable particles generated by these reactions which would otherwise cause the accumulation of retinal cellular debris, thus slowing down premature aging of the retina. But our stock of melanin decreases with age.

### In your opinion, at what age should we start talking about prevention?

As early as possible! **We need to educate parents of young children about the risks involved and their greater vulnerability.** Asking patients about their professional and leisure-time activities – a practice that is all too often neglected – is a natural lead-in to prevention counselling. We also need to take into account pathologies that weaken the eyes, such as diabetes (which affects the retina), glaucoma (daily eye drops: the conjunctiva and cornea) and so on.

### What precautionary principles, recommendations and/or solutions should we prescribe to patients?

We need to advise them to protect their eyes by wearing headgear with a visor; to wear filtering glasses, or specific protective eyewear designed for the workplace; and to consult their ophthalmologist on a regular basis if they are exposed to radiation on a regular basis.

In families with a history of retinopathy in the broadest sense, we can recommend and prescribe transparent filtering lenses (Crizal® Previncia®), and/or they should take advantage of a corrective lens prescription to add a filter. Depending on one's own convictions and the patient's sensitivity, we can extend this protection to everyone.

Risk prevention is an integral part our mission as health-care providers. Our counselling should also include diet

and lifestyle recommendations for placing limits on tobacco and alcohol use, thus reducing oxidative stress and cell apoptosis.

Lastly, by working with opticians, we can adjust our recommendations to fit the specific needs of various types of patients.

### In the coming years, what impact might preventive clinical practice (and the role of the ophthalmologist) have on the frequency of eye problems?

One hopes that preventive clinical practice – which, I repeat, is an integral part of our role as medical doctors – will impact eye problems by decreasing their frequency! •

Interviewed by Annie Rodriguez

#### BIO

**Dr. Sylvie Berthemy**  
Ophthalmologist



Ophthalmologist, court expert, hospital practitioner.

Postgraduate degree in Ophthalmological Genetics.

President of the Société de Contactologie des Alpes.

Head of the department of genetic diseases of the retina and optic nerve at Grenoble University Hospital.

CEA consultant, Institut Laue Langevin, ESRF, MBL, in school and sports medicine.

Lecturer at Joseph Fourier University in ophthalmological risk prevention for safety engineers and occupational physicians.

Numerous publications in ophthalmic journals dealing with preventive and occupational ophthalmic medicine (white rooms, LEDs, etc.).

Numerous articles on ophthalmology in mainstream magazines.

Participation in a number of reports: 2009 SFO and 2001 and 2005 SFOALC, coordinator of the 2013 report on myopia and contact lenses.

Author of five films: one on the tear film, three related to the use of lenses in children and one on myopia.

Speaker at many national and international conferences.



#### KEY TAKEAWAYS

Those most vulnerable to the chronic effects of light exposure are:

- Children
- The elderly
- People with a family history of eye disease
- People with photophobia
- People who have had cataract surgery
- People with hypermetropia
- People who work outdoors
- People exposed to sources of radiation and heat
- People in prolonged contact with LEDs
- People with fair complexions

# PREVENTION OF OCULAR PATHOLOGIES IN OPHTHALMOLOGY

In ophthalmology, the prevention of ocular diseases is gaining increasing prominence.

Educational programmes, screening campaigns, early medical detection along with protective eyewear can all together reduce the incidence of ocular alterations and limit their social and financial implications. Eye phototoxicity (due to UV and blue-violet light) is one of modifiable risk factors and, as such, can be reduced by a photo-protective eyewear.



**Dr. Marcus Safady**

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Marcus Safady graduated in medicine in 1980 from Universidade Federal do Rio de Janeiro. Ophthalmologist with the Associação Médica Brasileira in 1984.

Teacher of the ophthalmology specialization course of Sociedade Brasileira de Oftalmologia. Head of the glaucoma department of Hospital Federal de Bonsucesso, Rio de Janeiro. Currently chairman of the Sociedade Brasileira de Oftalmologia (S.B.O.).

## KEYWORDS

prevention, refractive error amblyopia, diabetic retinopathy, glaucoma, glaucomatous optic neuropathy, age-related macular degeneration, AMD, pterygium, cataract, actinic keratitis, phototoxicity, protective eyewear, UV, blue light

There is a saying in Portuguese that goes: *melhor prevenir que remediar*, which means “prevention is better than cure”. Originating from the Latin *praevenire* (*prae* = “before”, *venire* = “to come”), “prevention” literally means “to anticipate, to perceive in advance”. In medicine, the great challenge of the public health programmes is precisely to prevent diseases or to diagnose them as early as possible. With the ageing of the world population, it is vital to create programmes for the prevention of Chronic Non-communicable Diseases (NCDs), responsible for 63% of deaths in 2008. The majority of deaths from NCDs are attributed to diseases of the circulatory system, cancer, diabetes and chronic respiratory diseases. The principal causes of those diseases include modifiable risk factors such as smoking, harmful alcohol consumption, lack of physical activity and inadequate diet. Therefore, programmes for the prevention of these diseases must focus their actions on these aspects. In addition to the scientific aspects, prevention and early diagnosis promote better economic-financial indicators in health budgets, with less expenditure and better use of resources.

## Ophthalmology and prevention programmes

In ophthalmology, the prevention of some diseases is gaining increasing prominence. An ophthalmological test carried out in pre-school children, in adults at around the age of 40 and in older people aged over 60, is capable of preventing changes such as refractive error amblyopia, diabetic retinopathy, glaucomatous optic neuropathy and age-related macular degeneration, amongst others<sup>1</sup>.

We know that **the cost of treating glaucoma is much higher than investments to prevent it**. The increase in cases of blindness, with its social and financial implications, shows that the right

**“In ophthalmology, the prevention of some diseases is gaining increasing prominence.”**

thing to do is to adopt major screening campaigns for early detection of suspected cases.<sup>2,3</sup> Educational programmes in terms of control of cardio-circulatory diseases would

greatly reduce cases of retinal vascular occlusion, a major cause of diminished visual acuity in adults.

Several authors have already demonstrated the advantages of diabetic retinopathy control in telemedicine, with a reduction in the incidence of reduced visual acuity from diabetes.<sup>4</sup> The World Health Organisation re-

FIG.1 | Clinical aspect of cataract

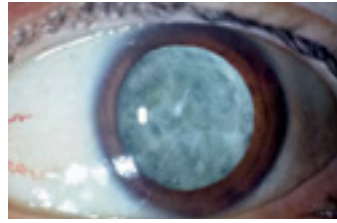
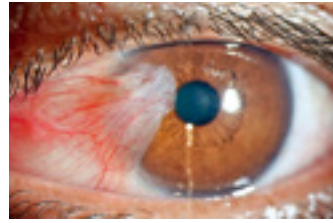


FIG.2 | Clinical aspect of pterygium



cently launched an Ocular Health and Prevention of Blindness programme, one of the most important chapters of which is cataract surgery.<sup>5</sup>

### Ocular phototoxicity

The biggest cause of avoidable blindness throughout the world, cataract is perhaps one of the major examples of ocular alterations due to phototoxicity. (Fig. 1) It is already a well-known fact that the earliest appearance of presbyopia occurs in geographic regions with the highest incidence of UV rays. In Brazil, the age at which it appears in the north of the country may be up to 5 years lower, with patients presenting symptoms at age 38, whereas in the south this occurs at around 43 years. By clinical analogy, if UV rays are able to alter the flexibility of the lens and modify its accommodation capacity, continuity of that action would lead to the degeneration of its fibres and the onset of cataract. Continuing its intra-ocular pathway, part of the solar radiation reaches the retina and may be deleterious to the retinal tissue, causing age-related macular degeneration (AMD).

The incidence of pterygium is also known to be higher in populations with greater daily exposure to sunlight.<sup>6,7,8</sup> (Fig. 2) Another example of ocular phototoxicity is actinic kerati-

tis in addition to peri-ocular cutaneous lesions.

### Importance of ocular protection

All this clinical evidence has created awareness of the need for ocular protection against UV rays. Taking into account the fact that a clear eye lens lets more radiation through than a lens that is beginning to form a cataract, **protection against UV rays is advisable from childhood.** Long-term longitudinal population studies would be necessary to enable us to judge the reduction in ocular diseases caused by solar radiation in a population that used protective glasses from childhood, compared to a population without protection.

But it is not only UV rays that are dangerous for the eyes. Recent studies have shown that blue light also has harmful effects on the retina. Known for its importance in relation to chronobiology, the blue light of the visible spectrum has a part of wavelength range that is harmful for the cells of the retina; the other part is beneficial to cognitive and chronobiology functions. This shows us that the concept of “selective” ocular protection against solar radiation is a reality that needs to be observed. The use of ophthalmic lenses with selective photo-protective features is a major advance in ophthalmology. •



### KEY TAKEAWAYS

- The phototoxicity of solar radiation may be deleterious to the ocular tissues.
- The higher daily exposure to sunlight, the higher incidence of photo-induced ocular damage (pterygium, actinic keratitis, cataract, age-related macular degeneration, etc.)
- UV rays are able to alter the flexibility of the lens and modify its accommodation capacity; continuity of that action would lead to the degeneration of its fibres and the onset of cataract.
- A part of blue light (blue-violet portion) also has harmful effects on the retina.
- Clinical evidence has created awareness of the need for ocular protection against UV rays and blue-violet light.


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# PUTTING THE MEDICINE IN THE LENSES: THE IMPORTANCE OF BLOCKING ULTRAVIOLET RADIATION AND BLUE LIGHT

Advancements in spectacle lens technology have given eyecare providers the ability to blend medical and refractive eyecare in our dispensaries. Lenses can do more than just provide amazing vision, they can be used to prevent or delay the onset of certain ocular disease states. Proper use of Crizal® UV, Crizal® Previncia® and Xperio® UV will allow us to exceed our patient's expectations by not only providing superior vision now, but by simply wearing lenses, protect their visual system for years to come.



 **Dr. Ryan L. Parker, OD,**  
Ardmore, Oklahoma. USA.

Dr. Ryan L. Parker, OD, is in private optometry practice in Ardmore, OK, USA. He is a 2004 graduate of the Oklahoma College of Optometry and is author of several publications and lectures delivered to many schools and colleges of optometry throughout the country on his experiences and successes in private optometry practice.

**KEYWORDS**

Ocular disease prevention, UV radiation, age related macular degeneration, AMD, ARMD, cataract, dry eye, blue light, Crizal® UV, Crizal® Previncia®, Xperio® UV

**My passion for medical optometry**

When I think back on my fond memories of optometry school I can still remember the anticipation and excitement that came when it was time to grab that patient chart and get to work. The level of excitement was even more pronounced if the patient happened to be a medical case instead of just a boring refractive patient. So was born the great divide in my mind with my chosen profession, medical optometry vs. refractive optometry. As I now enter my tenth year of private practice I know my days will be filled with both medical and refractive cases and that is one of the many things that I believe makes the optometric profession a great one. Now that I have the chance to go lecture to many schools and colleges of optometry I stress to future optometrists that the medical aspect is exciting and challenging but not to forget about that all-important refractive part. The bulk of my day in private practice is filled with patients wanting to see as well as possible, which usually ends up with a refractive solution.

**Prevention now is part of the discussion with patients**

The technology wave in optometry seems to be ever-changing and it continues to improve the care that I can deliver to my patients. Thanks to companies like Essilor that understand the importance of re-investing in research and development, I now have optical products that intertwine medical and refractive optometry. Daily I am having conversations with my patients' that discuss glasses and ocular disease in the same breath. These cutting-edge technological lens advancements are one reason why I have chosen to utilize Essilor products in my practice. These products are very exciting to me as an optometric physician because now instead of using products to simply just solve problems, I can use these products to actually prevent and delay the onset of certain conditions. As many other medical professions are having conversations with patients about prevention, I feel it is imperative that we have those same conversations. Due to medical advancements, patients are living longer and as we age, our natural

anti-oxidant defense mechanisms naturally decrease. Most diets are not what they should be, with an increase in processed fatty foods and a decrease in nutrient-rich natural foods. This creates the perfect storm: our patients are living longer and they are not getting the proper nutrients, which is why the number of cataract and macular degeneration cases is expected to double over the next twenty years. Thus prevention is critical.

**Light is both beneficial and harmful**

How then as eyecare providers do we have the ability to prevent damage to the visual system? To understand that, it is important to remember what gives us sight: light, which is part of the electromagnetic spectrum (see Figure 1). While most of the electromagnetic spectrum is beneficial, parts of it are not, mainly UV radiation and high-energy blue light. We all know UV radiation is bad for the skin, but we often forget that it also damages the visual system as well. Only 2% of UV radiation reaches the retina, thanks to the cornea and crystalline lens. Since those structures absorb so much UV radiation, that is where the damage will occur, mainly in the form of cataract formation, pterygium formation, and some studies suggest dry eye issues<sup>3</sup>. While these issues are many times not sight-threatening and fairly fixable, patients do not want to go through surgery or start dry eye therapy early in life. By educating patients that products exist that not only provide superior vision but limit UV exposure and may prevent ocular disease onset, we are addressing the medical need for proper eyewear.

The eye treats visible light differently than UV radiation. The visual system is adapted to focus visible light onto the retina, which gives us the ability to see. But not all visible light is good for the visual system. High-energy blue light, which sits next to UV radiation in the electromagnetic spectrum, causes damage to the eye, specifically the cone photoreceptors. To understand how this occurs, we

**“ While most of the electromagnetic spectrum is beneficial, parts of it are not, mainly UV radiation and high-energy blue light. ”**

need to remember the chemical reactions that occur during the visual pathway (see Figure 2). We can see that in both the photoreceptor outer segment and RPE, blue light can cause oxidative stress. As we age, and based on our genetics, our anti-oxidant defense mechanisms decrease. We can't change our genetics, we can take vitamins to help those defense mechanisms, but what about reducing our exposure to damaging blue light?

**Dramatic increase in blue light exposure**

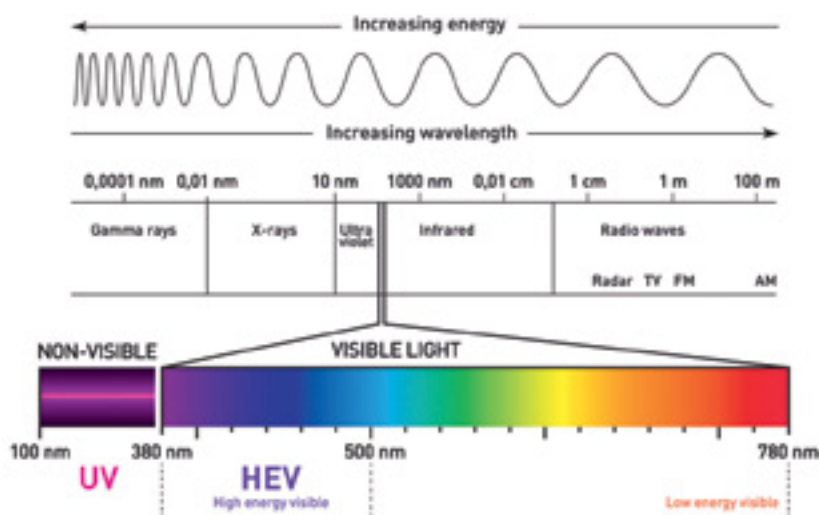
I believe that since blue light exposure is cumulative, just like UV radiation, if we can limit exposure, we can prevent disease progression. To limit exposure we must know the sources of blue light. First is the sun. The blue light portion of daylight varies between 25% and 30%<sup>2</sup>. Remember the sun also exposes us to UV radiation in addition to visible

light. Blue light also comes from artificial light sources, which have been on a dramatic increase over the past few years. Compact fluorescent bulbs contain 25% harmful blue light<sup>2</sup>. LEDs contain 35% harmful blue light; the cooler white the LED is, the higher the blue light proportion<sup>2</sup>. Many of us have made the switch to these new energy-saving bulbs in our homes and offices, which will cause an increase in blue light exposure. If you still think you and your patients do not have increased blue light exposure, think again: smartphones, tablets and laptops are all sources of blue light exposure as well.

**Blue-violet light, the most damaging band**

We must then begin to understand blue light better. Thankfully, the Paris Vision Institute has done some groundbreaking research on that topic. In 2008 they began an eye health research project to better

FIG. 1 | Electromagnetic spectrum and zoom on visible light.



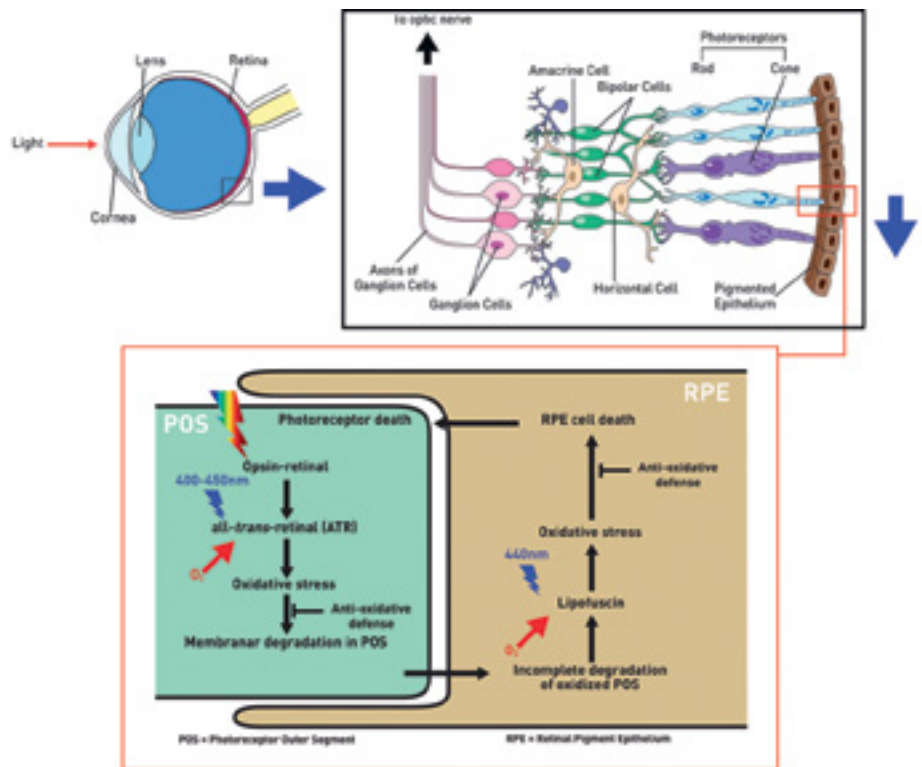


understand blue light. This was the first *in vitro* test in the ophthalmic industry to split the visible light spectrum into 10nm bands and see which bands of light caused the most damage on swine retinal cells. The results showed maximum cell damage occurs from 415-455nm, with a peak at 435nm +/- 20nm<sup>2,4</sup>. This damaging band of light was termed blue-violet light. Cumulative exposure to blue-violet light will lead to retinal cell death and is one of the risk factors for macular degeneration. Compact fluorescent bulbs, LED sources and sunlight all emit these damaging wavelengths of light. Another important finding was that not all blue light is damaging. Blue-turquoise light ranges from 465-495nm and is essential for sleep/wake cycles, memory, mood, cognitive performance and pupillary constriction<sup>2</sup>. Blue-turquoise light is also needed for visual acuity and color perception. Just because it's blue does not mean it's bad.

**Limiting UV exposure with Crizal® UV and Xperio® UV**

What can we do as eyecare providers to provide our patients with the clearest sharpest vision possible, while limiting exposure to the damaging part of the electromagnetic spectrum? This is where we can put the medicine or preventive medicine in the lenses. By utilizing the right products in our dispensaries, not only can we provide great vision, we can potentially delay and/or prevent onset of ocular disease. Let's deal with UV radiation first. Typically when we talk about UV, we think of sunglasses. Sunglasses are important, but our patients receive up to 40% of their UV exposure when they are not in direct sunlight. The UV conversation is important on both the sun pair and everyday pair. When I talk with my patients about UV prevention on their everyday pair, I talk about Crizal® UV non-glare lenses. Crizal® UV delivers amazing

FIG. 2 | Scientific assumption: phototoxicity mechanisms in the outer retina



vision by fighting the five enemies of vision: glare, scratches, smudges, dust and water. In addition to these great features, Crizal® UV greatly reduces the amount of UV radiation that enters the visual system. When thinking about UV radiation, we have to think about both sides of the lens. UV entering the front side of the lens can either pass through the lens or be reflected/absorbed. By selecting the proper index of materials, polycarbonate and above, no UV radiation will pass through the lens. But that is only part of the equation; what about UV radiation reflecting off the backside of the lens? Studies suggest that up to 50% of UV exposure can come from reflections off of the back surface of the lens<sup>1</sup>. Crizal® UV lenses reduce the backside UV reflections to 4%, giving it an industry-best eye-sun protection factor (E-SPF®) of 25 for clear lenses. In other words, wearing Crizal® UV lenses means you are 25 times more protected from UV radiation than not

wearing any lenses at all. This built-in UV protection separates Crizal® UV from other non-glare lenses on the market and allows me to have medical-focused conversations about preventing ocular damage by wearing glasses. What happens when the patients goes outside and is in direct intense sunlight? UV protection is of the utmost importance in this environment. My product of choice for sunwear is Xperio® UV. Similarly to Crizal® UV, Xperio® UV deals with UV radiation on both sides of the lens. The same rules still apply to UV coming through the front of the lens, so proper lens material selection is extremely important. The backside reflections are still present on sunwear and Xperio® UV reduces them to 1.5%, giving the highest E-SPF® available today of 50+. Not only does Xperio® UV limit UV exposure but it is also polarized, which means my patients get the maximum UV protection and best vision possible in their sunglasses. By

utilizing these products on my patients' everyday pair and sun pair, I am protecting their visual system by preventing damage caused by UV radiation.

**Limiting blue light exposure with Crizal® Previncia®**

What about reducing blue light? I have the blue light conversation with my patients that have a strong family history of macular degeneration, have signs of macular degeneration or have a high exposure to blue light. In my practice Crizal® Previncia® is my lens of choice when it comes to reducing blue light exposure. This product is superior to the competition because it blocks more of the damaging blue-violet light and UV radiation than anything on the market today. It has patented LightScan™ technology that selectively filters out harmful blue-violet light and UV radiation, including backside reflections. It also allows beneficial blue-turquoise light to pass through the lens while maintaining excellent lens transparency. Crizal® Previncia® No-Glare lenses

**“ With Crizal® UV, Crizal® Previncia® and Xperio® UV, we now have the power to blend the medical and refractive sides of optometry. ”**

are able to deflect 20% of the harmful blue-violet light that our patients are exposed to on a daily basis<sup>2</sup>. The Paris Vision Institute showed that this amount of deflection reduced retinal cell death by 25%<sup>2</sup>. On the surface, those numbers may not sound amazing, but it is greater than any other product on the market, and that 25% protection is very similar to what we expect when we discuss AREDS vitamin formulations with our patients<sup>2</sup>. With Crizal® Previncia® you can ex-

pect it to perform like the other Crizal® UV products. It has an E-SPF® of 25 and virtually eliminates backside UV reflections and features complete protection from the enemies of clear vision: glare, scratches, smudges, dust and water.

**Conclusion**

Our goal in the eyecare profession is simple, to provide our patients with the best vision possible. We strive to accomplish this goal daily by providing patients with the best medical eyecare they can get and/or by providing them with the best means of correcting their refractive error. This type of care has become standard and patients expect this when they visit their eyecare providers.

How then can we exceed our patient's expectations? I believe by using the technological advancements that are available in today's spectacle lenses we can do more than we have ever been able to do before. We now have the power to blend the medical and refractive sides of optometry. We can do more

than just deliver the best vision possible; we can now put the medicine in the lenses and have conversations with our patients about prevention of future ocular diseases by simply wearing the right lenses in the correct environment.

Essilor has given my dispensary the tools to do just that. I talk about Crizal® UV to all my patients on their everyday pair, Xperio® UV on their sun pair, and for those patients that have risk of macular degeneration or high exposure to damaging blue light, Crizal® Previncia® is the answer. I encourage you to explore the benefits of these practice-changing products and begin having these same conversations with your patients and exceed their expectations. •



**KEY TAKEAWAYS**

- Patients receive up to 40% of their UV exposure when they are not in direct sunlight.
- UV conversation is important on both the sun pair and everyday pair.
- Crizal® UV lenses (everyday pair) with E-SPF® of 25 protect 25 times more from UV radiation than not wearing any lenses at all.
- Xperio® UV polarized lenses (sun pair) deal with UV radiation on both sides of the lens, giving the highest E-SPF® available today of 50+.
- Blue light conversation is important with all patients and particularly with patients who have a strong family history of macular degeneration, already have signs of it or have a high exposure to blue light.
- Crizal® Previncia® lenses (everyday pair) selectively filter out harmful blue-violet light and UV radiation, while allowing beneficial blue-turquoise light to pass through.

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## CANCER COUNCIL AUSTRALIA'S INITIATIVES

Australia has the world's highest rate of skin cancer. When it comes to preventing the threat of UV, the Cancer Council of Australia is probably the most experienced organisation in the world. Prof. Ian Olver, CEO of the Cancer Council of Australia, highlights the main initiatives implemented in the marketplace for *Points de Vue*, and gives his perspective on the future.

**PROFESSOR IAN OLVER**  
CEO of Cancer Council Australia

***Points de Vue:*** Professor Olver, please could you provide our readers with your perspective on the current scope of the activities of Cancer Council Australia and give them a little background on its origins and vision?

**Prof. Ian Olver:** Cancer Council Australia is the national body in a federated structure of state and territory Cancer Councils. We are funded by our member organisations to undertake national activity, such as advocacy for cancer policy to the Federal Government and national media. We help drive national prevention campaigns and activities, and working with our national committees, we produce the National Cancer Prevention Policy, which is

updated by our committees according to the latest evidence available. We also produce clinical practice guidelines on a custom designed wiki to allow continual updating and wide dissemination.

Our Supportive Care Committee co-ordinates patient information and we communicate to the public through social media and interactive sites such as *iheard.com*, which allows people to ask questions about cancer claims that they have seen on the web.

We promote cancer prevention lifestyle messages such as tobacco control, diet and exercise and sun protection, as well as early detection by encouraging participation in national cancer screening programs. On the fundraising side, Cancer Council Australia is responsible for national corporate partnerships and national promotion of major fundraising events such as Daffodil Day, Pink Ribbon and Australia's Biggest Morning Tea. Cancer Council Australia's vision is to minimise the threat of cancer to Australians, through prevention, best treatment and optimal support for patients with cancer and their families.

#### KEYWORDS

UV, skin cancer, ocular cancers, peri-ocular cancers, prevention, Crizal® UV



**“Children can be very sensitive to sun damage.”**

**Overwhelmingly Australians have been made aware of the risk of skin cancer via the “Slip Slop Slap” campaigns of the Council. How important is this awareness of the dangers of UV exposure both locally and internationally? What is the impact of this on public health?**

Protection against excessive UV exposure is a modifiable risk factor for skin cancer. In Australia skin cancers are a great economic burden. There are over 1 million GP consultations each year for non-melanoma skin cancer. Over 430,000 non-melanoma skin cancers are diagnosed each year and around 12,000 melanomas. We have over 2,000 deaths from skin cancer each year. The “Slip Slop Slap” campaigns have raised awareness of the importance of covering up the skin, as well as using sunscreen on exposed areas to reduce skin damage, and subsequent skin cancers, when the UV level is three or above. We know from measures like our National Sun Survey, younger Australians are starting to get the message. For example,

in our 2004 survey, 60 per cent of adolescents said they would like to get a suntan, which had fallen to 45 per cent by 2011.

**What have been the most significant developments in the scientific or clinical research in relation to UV exposure and cancer since you started with Cancer Council?**

From the public health perspective the introduction of the UV index and its reporting in the press gives people an accurate picture of what times during the day in their geographic location the UV index will be 3 and above, which signals the need for sun protection. With regard to skin cancers, the most lethal, melanoma, has been curable if caught early and surgically removed, but fatal after it spreads. For the first time we have seen new targeted therapies developed that increase the survival time of widespread disease, because they target altered genes that are responsible for the growth of the cancer or target

proteins that are preventing the body's immune system from attacking the cancer. These drugs alone and in combination offer promise of vastly improved outcomes with less side effects than previous therapies.

**In recent years Cancer Council has added “Seek and Slide” as required actions against UV exposure. What were the drivers behind this change, in particular with relation to ocular health?**

Cancer Council added “Seek and Slide” to “Slip Slop Slap” to reinforce the message that seeking shade when the sun is most intense also helps to reduce the risk of skin damage. Sliding on sunglasses recognised the damage that UV exposure can do to the eyes, ranging from cataracts to retinal cancers and cancers on the skin surrounding the eyes. We have encouraged both children and adults to get used to protecting their eyes along with protecting the rest of the skin.

**Sunglasses have had mandated standards and classification for UV protection for some time, but now Cancer Council is embarking on the endorsement of the “clear” prescription spectacle coating Crizal® UV. What role do you believe this will play in the further prevention of ocular and peri-ocular cancers?**

Many who wear prescription spectacles have had difficulty adequately protecting their eyes. Devices such as clip on sun lenses are often bulky and address the UV that comes through the lens, but not that which comes in from the sides and reflects off the back surface of the lens into the eye. The Crizal® UV prescription lenses reduce both the UV coming to the eye through the lens and that being reflected onto the eye from the back of the lens, which will increase the protection of the eyes and skin around them. Reducing the UV exposure translates into reduced risk of skin cancer and eye cancer.

**What other initiatives do you believe are required to improve the level of public safety and awareness to help reduce avoidable cancers, particularly in relation to the eyes?**

There are target groups such as outdoor workers who are constantly exposed to UV as part of their regular job. They should be aware of the risks of sun damage to their skin and eyes and provided with protection or even have working hours changed to avoid the times of day when the UV index is high. Protection should include adequate eye protection.

**Children are often thought of but also often overlooked when it comes to protecting their eyes. With their clear ocular media allowing greater UV transmission, what level of protection do they actually require?**

Children can be very sensitive to sun damage. Avoiding sun exposure when the UV level is three or above is a good strategy for young infants. As a part of encouraging sun protection behaviour, children should wear hats, suitable clothing and have their eyes protected. Behaviours commenced in primary school are important. In addition schools should provide adequate shade cloth protected areas to allow shelter when the UV level is 3 or above.

**In your opinion, what is the key role that ophthalmic clinicians (ophthalmologists, optometrists and optical dispensers) should be playing in prevention and protection against cancer?**

The key role of ophthalmic clinicians in cancer prevention is in examining the eyes to ensure that they monitor pigmented lesions on the retina and detect early cancers in the skin around the eyes. Early detection of both is important to their outcomes. In terms of prevention, they should counsel patients to protect the eyes as well as wearing hats, appropriate clothing and using sunscreen when the UV exposure warrants it (a UV index of 3 or above).

**“Reducing the UV exposure translates into reduced risk of skin cancer and eye cancer.”**

## interview

**Where to next? What are the key areas in the next decade for this important health issue?**

Increasing public awareness of the need for sun protection, including the eyes, remains the major challenge to reduce the incidence of skin cancer. The UV coating of prescription lenses and the wearing of sunglasses each has a place in modifying this risk.

The advances in personalised medicine with more targeted therapies for melanoma will result in increasing survival rates for those with widespread disease. •

Interviewed by Tim Thurn

**BIO****Professor Ian Olver**

Chief Executive, Cancer Australia



Professor Ian Olver, a highly respected medical oncologist and researcher both in Australia and overseas, is a member of the Advisory Council for Cancer Australia (the Australian Federal Government's cancer control agency) and sits on the Council of the National Health and Medical Research Council. As head of the nation's peak non-government cancer control organisation, he is a leading independent voice on evidence-based cancer control policy.

While Clinical Director at Royal Adelaide Hospital Cancer Centre, Professor Olver established the first oncology clinic in Alice Springs and pioneered a telemedicine link for multidisciplinary cancer care between Adelaide and Darwin. He is a leading campaigner for improved care of Indigenous Australians with cancer, following his groundbreaking work as a remote oncologist in Central Australia.

His books include *Conquering Cancer: Your Guide to Treatment and Research* and *Is Death Ever Preferable to Life?* He has also written 22 book chapters and over 240 research articles in journals.

Professor Olver's perspective is informed by his unique mix of clinical/scientific experience and his work in the prevention and public health fields. He is also a well known researcher, whose current research focus is on psycho-social aspects of cancer.

Clinical Professor in the Department of Medicine at the University of Sydney, Ian Olver was awarded the Cancer Achievement Award by the Medical Oncology Group of Australia in 2008 and in 2011 became a Member of the Order of Australia.

**KEY TAKEAWAYS**

- Cancer Council Australia encourages both children and adults to get used to protecting their eyes along with protecting the rest of the skin.
- Among several initiatives, Cancer Council Australia endorses products such as sunscreen, sunglasses and UV protective clothing.
- 2014 is the first time that Cancer Council has endorsed a product related to prescription (clear) lenses: Crizal® UV.
- Cancer Council Australia only endorses one product in a category. Crizal® UV is that product in the area of anti-reflection coatings.
- Crizal® UV lenses reduce UV by both transmission and reflection.



# WHAT ROLE DO YOU THINK SCIENCE AND/OR CLINICAL PRACTICE SHOULD PLAY IN THE PREVENTION OF OCULAR PROBLEMS GENERATED BY UV AND BLUE VIOLET LIGHT?


The scientific and medical communities throughout the world actively contribute towards preventing ocular diseases. Reflecting on this important responsibility, *Points de Vue* recently interviewed several experts for their opinion on the role science and clinical practice should play in preventing eye diseases caused by exposure to UV and blue-violet light.

**Bret Andre MS, AB0c**   
Principal Consultant, EyeReg Consulting Inc., USA

**Rowena Beckanham OD**   
Beckenham Optometrist, Australia

**B. Ralph Chou MSc, OD, FAOD**   
Editor-in-Chief, Canadian Journal of Optometry and Professor Emeritus, University of Waterloo, Canada

**Walter Gutstein MSc, PhD**   
Adjunct Faculty PCO at Salus University and Clinical Director, SOLCIOE Opening Eye Special Olympics, Austria

**David Slaney Ms, PhD**   
Consulting Medical Physicist, USA

**Randall Thomas OD, MPH, FAOD**   
Optometrist, Cabarrus Eye Center, USA

**Kazuo Tsubota MD**   
Chairman and Professor of Ophthalmology, Keio University School of Medicine, Japan

“Recently, the relationship between light and health has gained interest,” points out Dr. Kazuo Tsubota. In this context, several scientists, clinical researchers and practitioners are paying growing attention to the harmful effects of chronic light exposure, primarily to UV and blue-violet light. All experts are looking at further research to elucidate individual risk factors and bring clinical evidence through quality solutions. The common view, shared by Dr. Rowena Beckanham, is that “prevention is critical to ocular health management” and it will remain critical in the future.

**KEYWORDS**

UV, blue-violet light, prevention, cataract, pterygium, circadian rhythm

## THE ROLE OF SCIENCE: the way ahead for research

The adverse affects of specific wavelengths of light, particularly UV, has been extensively covered in published research in the past decades. As Dr. David Sliney confirms, "there exists strong scientific evidence connecting the risks of cortical cataract and pterygium with UV (principally UV-B) radiation." Although today, a significant body of work exists on both UV and blue light, there is further scope of scientific research in the days to come, especially on blue light. Encouraging researchers on this topic, Dr. Ralph Chou comments: "There is a lack of both basic and clinical scientific research into the ocular effects of optical radiation between 385 and 420 nm, and very little to follow up on the work published before 2005 on threshold exposures across the entire optical spectrum. We need a new generation of researchers in this field of study."

At the same time, Dr. David Sliney emphasizes the need for more epidemiological studies on the subject. "Although most laboratory studies demonstrate the retinal phototoxicity of blue light, many epidemiological studies do not confirm an increased risk of age-related eye retinal pathologies," he says. "Further research is needed to clarify why this contradiction exists."

In academia, the association of certain wavelengths of blue light with circadian system has also come under discussion. It is an area of great interest that needs extensive scientific investigation. Dr. Kazuo Tsubota sheds some light on this: "We know that light governs the circadian rhythm, but have more recently learned that it is blue light, specifically, which controls this task. Intrinsically photosensitive retinal ganglion cells (ipRGCs), a third class of photoreceptors found in the retina of the mammalian eye in 2002, primarily recognise blue light and send signals to the brain. In other words, the eye not only sees, but also functions as a clock. We believe that disruption of the natural circadian rhythm through protracted night time usage of computers and smart phones disrupts sleep and can lead to depression among other health problems, and scientists also consider that blue light may aggravate eyestrain and dry eye. I am more convinced than ever that further research is necessary in this area."

**“PREVENTION  
IS CRITICAL  
TO OCULAR  
HEALTH  
MANAGEMENT.”**

## THE ROLE OF CLINICAL PRACTICE: patient education and prescription

Prioritizing the patient's health and best interests, even with the progressing nature of scientific and clinical evidence, practitioners recommend educating patients on possible risks of UV and blue light and prescribing products that protect against these. Dr. Randall Thomas observes: "It is difficult to know with scientific certainty, but there is a growing body of science that indicates a health benefit to diminishing human tissue exposure to certain, specific wavelengths of visible blue, and ultraviolet light. It is likely prudent that we as clinicians do all that is practical and reasonable to protect the eyes of our patients by recommending eyeglasses that limit the amount of these wavelengths. Most certainly, the aggressiveness of such interventions will continue to be shaped with on-going research."

Dr. Sliney encourages patient education as well. He adds: "The reduction of excessive short-wavelength, blue-violet light is prudent as extra 'insurance' against potential delayed effects upon the retina. Clinical practice should serve an educational role in promoting UV protection for their patients, including peripheral (temporal) protection by frame design. Reducing short-wavelength light exposure may also be



beneficial – particularly in bright daylight and in some domestic light sources.”

Dr. Walter Gutstein feels protection against UV and high-frequency violet light is going to become a standard in the future, “As far as the retina is concerned, we know that the blue receptor is always affected first. Unfortunately, if this receptor is damaged it would further lead to significant impairment. Not only this receptor displays blue and yellow but it is also majorly responsible for contrast regulation. Damage to this receptor is much more noticeable than to all other photoreceptors even though it varies from one person to another depending on several conditions. Evidently, protection from both UV and high frequency blue-violet light should become a standard in coming years.”

When educating patients, attention should also be given to life style choices and occupation. “Eye care practitioners have a fair amount of knowledge on the adverse effects of UV radiation and blue-violet light on the eye,” explains Dr. Ralph Chou. “They should educate their patients on how occupational and lifestyle exposure to optical radiation can be reduced or modified to prevent future ocular health problems, and prescribe appropriate eyewear as well.”

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**“PROTECTION FROM BOTH UV AND BLUE-VIOLET LIGHT SHOULD BECOME A STANDARD IN COMING YEARS”**

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## NEXT STEPS: clinical evidence for preventive eyewear

Clinical evidence of eyewear performance helps convince patients greatly of their benefits. As a practitioner herself, Dr. Rowena Beckanham strongly urges the need for this. She argues: “As practitioners we need a strong evidence base to show consumers the benefits of new coatings and lenses to enable performance in a fast changing digital world. We need clinical trials published in reputed journals that stand up to the rigor of the scientific community to show the risks of increasing blue light exposure:

- a. risks to macular health;
- b. the use of digital technology and visual fatigue;
- c. interference with sleep patterns in sleep deprived teenagers with overuse of digital technology.”

In practice, there is still very little known on the eyewear options and the role of the lens coating in filtering out UV and blue-violet visible light. “Although it is generally understood that sunglasses provide ocular protection from potentially harmful ultraviolet (UV) radiation, what is less known is the importance of the lens coating quality, filtration properties and fitting geometry. When treating patients, eye care professionals should explain the potential consequences of short- and long-term exposure to UV, as well as offer well-fitting treatment options that adequately filter UV and other potentially harmful short-wavelength visible light,” says Bret Andre. From his perspective, “further research isolating visible light wavelengths that cause ocular damage will assist lens designers to optimize protective lenses without sacrifice to visual function.”

Survey conducted by Anwesha Ghosh




### KEY TAKEAWAYS

- UV radiation and blue-violet light can have adverse effects on the eye.
- The eye not only sees, but also functions as a clock.
- Protracted night time usage of computers and smart phones disrupts sleep and can lead to depression, among other health problems.

# U.S. OPTOMETRISTS BEGIN GLOBAL INITIATIVE OF EYE DISEASE PREVENTION

Macular degeneration (AMD) and cataracts play a major role in the United States health care system and global effort directed to the prevention of these conditions now is part of optometry initiatives. To benefit society both from a financial and a productivity perspective, optometrists focus on four areas in clinical practice: protective lenses, nutraceuticals, genetic testing and periodic examinations.



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#### KEYWORDS

AMD, UV, HEV, prevention, protective blue-blocking lenses, nutraceuticals, genetic testing, clinical protocol in AMD, Crizal® Previncia®, LED, Transition®, Essilor S Series™

#### Introduction to disease prevention

In February 2014, approximately 24 optometrists gathered at the University of Houston for the first ever Ocular Surface Disease Wellness Conference. The subject of "wellness" and disease "prevention" were addressed in this historic two-day meeting. Prior to this meeting, most specialized gatherings by optometrists addressed disease diagnosis and treatment, rather than prevention. The concept of disease prevention is unique in the vision care arena. One possible exception is in the area of myopia where efforts to retard progression have been tried using bifocal eyeglasses, contact lenses (orthokeratology) and pharmacological agents (atropine).<sup>1</sup> A follow-up meeting has been scheduled for December, 2014 in Dallas, Texas.

Two conditions that lend themselves to prevention discussions by optometrists in the United States include ocular surface disease (OSD) and ocular damage from high-energy visible light (HEV) as well as damage from ultraviolet light (UV). Macular degeneration (AMD) and cataracts play a major role in the United States health care system and any effort directed

to the prevention of these conditions will benefit society both from a financial as well as a productivity perspective. Cataract surgery is the most commonly performed surgical procedure in the United States today. The average cost of cataract surgery today is \$3,230 per eye<sup>2</sup>, and it is rising because of the use of new technology (laser cataract surgery and multifocal IOLs). Estimates of the global cost of visual impairment due to age-related macular degeneration is \$343 billion.<sup>3</sup>

Specific to AMD prevention, U.S. optometrists now focus on four areas of preventative steps. Those areas include nutritional supplements, genetic testing, specialty lens coatings to block selective wavelengths of blue light, and periodic dilated fundus examinations with OCT studies. While there are several OCT models available, we have personally been pleased with our newer Cirrus™ HD-OCT instrument. Genetic risk assessment for age-related macular degeneration is becoming commonly employed in the United States for those patients with risk factors. Steve Arshinoff<sup>4</sup> writes: "Previously we considered the phenotypic appearance of

Demonstrating Crizal® Preveniria® to a patient



the eye, macular pigment levels and patient-related non-genetic factors to determine AMD risk.”<sup>4</sup> Genotyping with commercially available genetic testing (Macula Risk™, RetnaGene™) now allows us to predict with 90 percent accuracy an individual’s 2-, 5- and 10-year risk for progression to advanced AMD. Following the reporting of the Age-Related Eye Disease Study 2 (AREDS2) (NEI) results, we now have definitive information on AMD prevention and progression using particular nutritional supplements, although further research is necessary.

#### Pathophysiology and economics

The number of people living with macular degeneration is similar to that of those who have been diagnosed with all types of invasive cancers.<sup>5</sup> As many as 11 million people in the United States have some form of age-related macular degeneration. The number is expected to double to nearly 22 million by 2050. Most researchers believe that blue light exposure has a role in the pathogenesis of AMD. According to Margrain *et al.*<sup>6</sup>: “Laboratory evidence has demonstrated that photochemical reactions in the oxygen-rich environment of the outer retina lead to the liberation of cytotoxic reactive oxygen

species (ROS). These ROS cause oxidative stress, which is known to contribute to the development of AMD. The precise chromophore that may be involved in the pathogenesis of AMD is unclear but the age pigment lipofuscin is a likely candidate.” They continue: “Studies in human macular pigment density and the risk of AMD progression following cataract surgery lend further weight to the hypothesis that blue light exposure has a role in the pathogenesis of AMD but the epidemiological evidence is equivocal. Blue-violet light has a twofold effect on lipofuscin. It causes an increase in production and also activates its phototoxic components (free radicals), causing the death of RPE cells. On balance the evidence suggests but does not yet confirm that blue light is a risk factor in AMD.”<sup>7</sup> Research by the Schepens Eye Institute (Harvard University) suggests that a low density of macular pigment may also represent a risk factor for AMD by permitting greater blue light damage.

**“AMD is on the rise.  
Prevention is a must.”**

#### Science

Existing artificial light sources are basically of two types: incandescent (includes halogen) and luminescent (fluorescent and LED). Incandescent lights are becoming difficult to find in the typical home repair stores in the United States as the newer LED light sources begin replacing them. These newer light sources are much more energy efficient, have a longer lifetime and the government has decreed that this exchange takes place. It is thought that by 2020, 90% of all

light sources worldwide will be based on solid state lighting products and LEDs. These newer light sources give

off a greater proportion of blue light than the older incandescent bulbs. We know that the sun is the standard light source. The blue light proportion of our daylight in the entire visible spectrum varies between 25% and 30%. We know that blue light is vital to a number of physiological processes<sup>8</sup> and interfering with it may have adverse effects. A recent study by Gray and colleagues in the *Journal of Cataract and Refractive Surgery* found that patients with blue-light filtering IOLs performed significantly

better under driving conditions with glare compared with similar patients who had clear IOLs. Dr. Henderson and her colleagues see no harm posed by blue filters, at least in visual parameters: they “feel that the potential protection against AMD is worth it.”<sup>9</sup>

### Clinical practice

Several groups around the world have studied the potential health risks of products using LEDs. Basically three high-risk populations have been identified: (1) children and aphakes who receive a higher blue light proportion on the retina, (2) those individuals suffering from ocular photosensitive pathologies or using photosensitive drugs (light-sensitive agents used in photodynamic therapy such as Verteporfin used to ablate blood vessels in the eye when treating wet macular degeneration), and (3) those individuals who are daily exposed to LEDs while using short viewing distances.

### 1. AMD AND PROTECTIVE LENSES

As a practical matter, optometrists and ophthalmologists in the United States have begun the process of utilizing electronic medical records (ObamaCare). During the early part of the patients' examination they are asked several questions by the technician and those individuals who fall into one of the above three groups are then counseled on the particular risks they face and are prescribed spectacle lens treatments which will help protect them from the increased threats offered by increased blue light presence. Because optometrists are the guardian of good vision, it is important for us to counsel patients about modifiable risk factors. Two of those risk factors include smoking and cumulative light exposure, especially UV and HEV blue light.

We have found at the Clayton Eye Center in Morrow, Georgia that the

best results are achieved when the doctor himself/herself initiates the conversation about blue light protection in the examination room and then the dispensing optician reinforces the message. We specifically prescribe the new Crizal® Previncia® lens treatment in order to selectively filter out only the dangerous wavelengths while allowing the good wavelengths to pass through. We know that blue wavelengths are the most potent portion of the visible electromagnetic spectrum for circadian regulation. Because the timing and quantity of light and darkness both affect sleep, evening use of amber lenses to block blue light might affect sleep quality. We have found over the past several months that our patients appreciate the fact that we are protecting their eyes with these discussions and we feel that to not educate our patients would be a great disservice. We reference data from the Beaver Dam and Blue Mountain studies, which implicate blue light as a factor for age-related macular degeneration, particularly following cataract surgery. Our clinic performs more than 3,000 cataract surgeries a year and each post-op visit emphasizes the potential risk of blue light. Our IOLs are blue blocking for added protection. Our practice

recently became involved with an accelerated program emphasizing doctor-directed dispensing. Each of our nine optometrists now prescribes various lens products and coatings to each patient when indicated and outlines the specific products on a specially designed form and reviews these products with the patient. The patient is then escorted to the optical department from the clinical area by a technician or the doctor and the form is presented to the dispensing optician. Products such as AR, Transitions®, digitally surfaced progressive designs (such as the Essilor S Series™) and Crizal® Previncia® coatings have increased substantially as a result of this new process. Several lens manufacturers have become involved with blue blocking technology; however, so far only Essilor has designed a coating that blocks specific wavelengths. VSP's Unity BlueTech lens, Hoya's Recharge™, PFO's iBlucoat™ and Signet Armorlite's BlueTech (Indoor and Outdoor) all block HEV (high energy visible light) and offer improved contrast sensitivity. However, they also block the blue-turquoise range, which has been demonstrated to be “good” light and necessary for other functions, including increased contrast sensitivity and mood regulation.

**“The concept of disease prevention is unique in the vision care arena.”**

## 2. AMD AND NUTRACEUTICALS

The Age-Related Eye Disease Study 2 (AREDS2) was a multi-center, randomized trial designed to assess the effects of oral supplementation of macular xanthophylls (lutein and zeaxanthin) and/or long-chain omega-3 fatty acids (docosahexaenoic acid [DHA] and eicosapentaenoic acid [EPA]) on the progression to advanced age-related macular degeneration (AMD). While the results of the study left several questions unanswered, it also led the way to changes with respect to the prescribing of nutritional supplements for those patients with early macular degeneration and those at risk. Optometrists in the United States now routinely encourage their patients to take these nutraceutical supplements as a matter of procedure and this author suspects that this practice will become standard of care in only a matter of time. There are several commercial products on the market to choose from: Bausch and Lomb's Preservision Eye Vitamin AREDS 2 Formula Soft Gels are probably the most commonly used. This particular product is beta-carotene free, which is a positive for current/former smokers. Another product that I have frequently used is Science Based Health's Macula Protect Complete, which is also beta-carotene free. The study demonstrated that there was a 25% overall risk reduction of progression to exudative AMD. The role of macular pigment (MP) is also acknowledged and many optometrists now measure macular pigment and dose supplements accordingly. The U.S. diet is known to be low in lutein and zeaxanthin.<sup>10</sup> The third carotenoid, Meso-Zeaxanthin, is a key carotenoid in the macula and even lower in the U.S. diet. We know that smokers are at high risk for AMD.<sup>11</sup> In smokers and former smok-

ers, beta-carotene has been associated with an increased risk of lung cancer.<sup>12, 13, 14</sup>

## 3. AMD AND GENETIC TESTING

Genetic testing has progressed in several areas of medicine over the past ten years. One area that has enjoyed the benefits of continuing research is AMD. We can now make a prognosis to within 90% accuracy of how a patient's eye disease will progress.<sup>15</sup> Several research projects have demonstrated that those patients subjected to testing have better outcomes than those without. At the 2013 American Society of Retina Specialists Annual Meeting, Dr. Peter Sonkin, a retina specialist from Tennessee Retina, presented the results from an analysis of the impact of genetic testing in their practice over a five-year period. The data revealed that patients who had Macula Risk testing and were subjected to a stratified surveillance schedule as well as a patient edu-

**“The number of people living with macular degeneration is similar to that of those who have been diagnosed with all types of invasive cancers”**

cation program had better visual acuities on presentation compared to those patients without genetic testing. The November 2013 Issue of Ophthalmology highlighted an article titled “Prediction of Age-Related Macular Degeneration in the General Population – The Three Continent AMD Consortium”, which is a study evaluating AMD prognostics using three prospective population-based studies: the Rotterdam Study, the Beaver Dam Eye Study, and the Blue Mountain Eye Study. The non-genetic model which included age + sex + BMI + smoking + AMD status has a 78% predictive accuracy, while the genetic model, which included genetics with the above criteria, had an 82% predictive accuracy. Using all available information I have now come up with a formula for what the primary care optometrist should now do to prevent vision loss. This protocol is used by our doctors and many others and is a compendium of existing good practices.

#### 4. THE CLAYTON EYE CENTER VISION LOSS MODEL IN AMD

- Diagnose AMD
- Perform genetic testing on each AMD patient
- Increase monitoring frequency including OCT testing
- Prescribe the appropriate nutraceuticals
- Prescribe selective blue-blocking spectacle lenses
- Counsel patients on diet, smoking, exercise and weight (BMI).

Optometrists in the U.S. have embraced genetic testing for AMD much in the same way other physicians have embraced genetic testing for cancer and several other diseases. There are over 2,000 tests available. Screening embryos for disease is becoming more frequent.

#### Conclusion

In summary, AMD is on the rise. As individuals continue to live longer, the optometrist is going to diagnose increasingly larger numbers of cases. Prevention is a must. We now have several tools that will allow us to aid in our preventative efforts. Government-mandated lighting changes will expose us to larger doses of potentially harmful HEV blue light. Com-

puter usage continues to be on the rise and these tools as well as electronic tablets, smart phones and other games used at closer near point distances will also increase our exposure. By prescribing spectacle lenses that can aid in filtering out the noxious wave lengths, we may be able to prevent many individuals from acquiring this dreadful disease down the road. By adding genetic testing and nutraceutical supplements to our armamentarium, we may be doing the world a tremendous favor. Our job is vision preservation, and this is one way to accomplish that task. To not implement the above protocol but rather take a "wait and see" approach may be doing your patients more harm than good. The Optometric Oath promoted by the American Optometric Association includes the following charges:

"I WILL advise my patients fully and honestly of all which may serve to restore, maintain or enhance their vision and general health.

I WILL strive continuously to broaden my knowledge and skills so that my patients may benefit from all new and efficacious means to enhance the care of human vision."

The above approach fulfills my responsibility. •



#### KEY TAKEAWAYS

- By 2020 90% of all light sources worldwide will be based on solid state lighting products and LEDs
- The blue light proportion of our daylight in the entire visible spectrum varies between 25% and 30%.
- The Clayton eye center vision loss model in AMD – a compendium of existing good practices – recommends the following steps :
  1. Diagnose AMD
  2. Perform genetic testing on each AMD patient
  3. Increase monitoring frequency including OCT testing
  4. Prescribe the appropriate nutraceuticals
  5. Prescribe selective blue-blocking spectacle lenses
  6. Counsel patients on diet, smoking, exercise and weight (BMI).


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# AMD: CLINICAL PROTOCOL, PREVENTION AND OUTLOOK

AMD is the leading cause of legal blindness in industrialized countries. It has two forms, atrophic and exudative, and a multifactorial pathogenesis. To cope with the ever-increasing incidence of AMD, retinal specialists resort to three strategies: primary prevention, patient management in clinical practice and prospective medical research aimed at finding new therapies.



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## KEYWORDS

AMD, macula, maculopathy, retinal pigment epithelium, lipofuscin, photoreceptors, A2E, oxidative stress, phototoxicity, blue light, in vitro, photoreceptors, anti-VEGF, drusen, prevention, antioxidants, photo-protection, Crizal® Prevenzia®

**A**ge-related Macular Degeneration (AMD) is a chronic degenerative disease of the retina. It selectively affects the central portion of the retina called the macula and causes the degeneration of retinal visual cells.

AMD is the leading cause of legal blindness in industrialized countries. The pathology affects people over 50, and leads to the progressive loss of central vision, which is essential for seeing the details required to perform such everyday tasks as reading, recognizing faces and driving.

## Pathophysiological mechanisms

The exact pathophysiological mechanisms of AMD are still poorly elucidated, but the implication of intoxication processes leading to the death of retinal pigment epithelial cells has been established in recent years. During aging, these cells may present functional impairment related to the accumulation of proteo-lipid complexes, known as lipofuscin granules, in lysosomes.

These granules are formed gradually by the accumulation of undegraded protein and lipids from the external photoreceptor fragments phagocy-

tosed by the pigment epithelium.<sup>1</sup> Lipofuscin also contains cytotoxic derivatives derived from the visual cycle such as A2E. Under the effect of blue light, A2E oxidizes and induces protein, lipid and DNA oxidation, causing significant oxidative stress in the cells of the retinal pigment epithelium during aging and resulting in the death of the latter.<sup>2</sup>

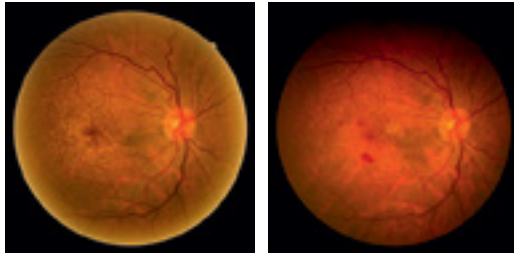
## Pathogenesis

Age-related degeneration of the macula has a multifactorial pathogenesis. The primary factor is, of course, **age**, since the disease appears after age 50 and its prevalence increases rapidly after age 75.

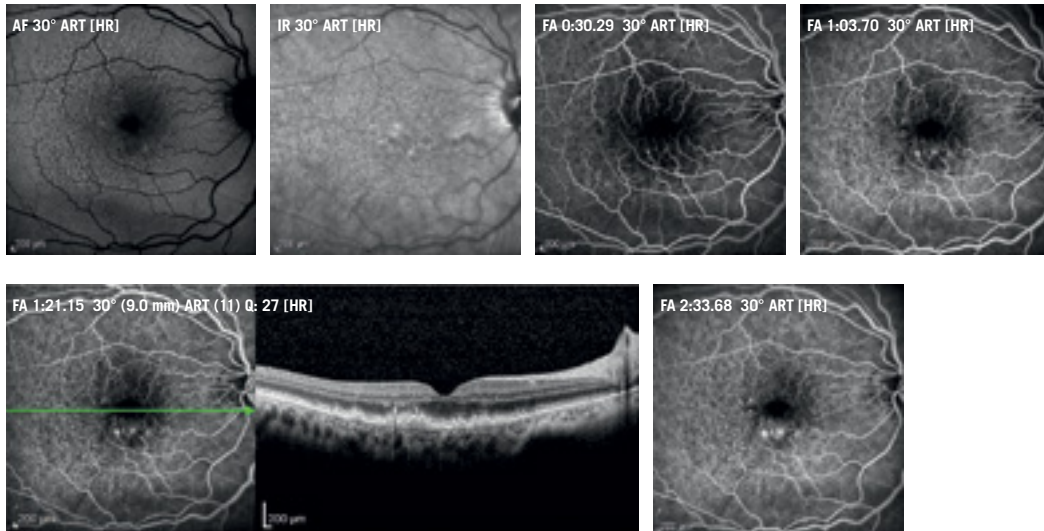
There is also a **genetic** predisposition to the disease: the risk of developing AMD is four times greater if a parent or sibling has it. Several genetic polymorphisms associated with the disease have been identified. Among them, variants of the gene coding for complement factor H or the gene encoding HTRA1 (a protease) are implicated. Since 2005, a total of 19 loci have been identified as being related to AMD<sup>3</sup>. They involve a variety of biological functions, including the regulation of the innate immune

FIG. 1 | Example of the progression of a patient with serious drusen to exudative AMD with chorioretinal anastomosis type neovascularization

1.a - colour fundus photographs



1.b - fluorescein retinal angiograph



system, maintenance of cellular structure, growth and permeability of blood vessels, lipid metabolism and atherosclerosis. The simultaneous presence of three variants (factor H, HTRA1 and CC2-FB) in the same individual can increase the risk of developing AMD by a factor of up to 250.

**Smoking** is strongly associated with AMD: it increases the risk of developing the disease by a factor of three.<sup>4</sup> Numerous research studies have shown that a **diet** low in vitamins, trace elements and antioxidants can predispose to the disease.<sup>5</sup>

Retinal **phototoxicity related to blue light** is also implicated in the pathogenesis of AMD. The wavelengths responsible for this toxicity in the presence of lipofuscin were recently elucidated *in vitro* revealing a spectrum of blue-violet light ranging from 415nm to 455nm with a highly toxic peak at 435nm.<sup>6</sup> This toxicity in-

creases in proportion to the amount of lipofuscin in the retina, but a slight toxicity remains, even in the absence of lipofuscin. These wavelengths are, of course, present in the solar spectrum, but can also be found in the radiation of certain light-emitting diodes.

**Obesity** also doubles the risk of AMD. **Hypertension**, cardiovascular diseases and cholesterol have been implicated as well, but their role remains uncertain.

#### The forms of AMD

AMD has two different forms, atrophic and exudative. The atrophic or “dry” form is related to atrophy of the macula, characterized by the progressive degeneration of the retinal pigment epithelium and the neurosensory retina. There is no known cure for this form of the disease, which progresses slowly. The exudative or “wet” form is character-

ized by the abnormal development of blood vessels below the macula. This ocular neovascularization is also known as choroidal or subretinal neovascularization, thus providing another name for this form: neovascular AMD. These malformed new blood vessels are fragile and porous, and are there-

**“Age-related degeneration of the macula has a multifactorial pathogenesis.”**

fore subject to vascular hyperpermeability. They also destroy the normal architecture of the retina and its functioning.

The neovascular form has various subtypes depending on the type and location of neovasculature relative to the pigment epithelium. The photoreceptors suffer and ultimately scar tissue develops, permanently destroy-



ing the macula. This is the most aggressive form of the disease and may represent two-thirds of the forms of AMD.<sup>7</sup> Choroidal neovascularization is due to the phenomenon of angiogenesis, in which vascular endothelial growth factor (VEGF) plays a significant role. VEGF has therefore been the target of new therapeutic strategies developed in recent years, leading to the development of anti-VEGF treatments. These treatments are now the gold standard for treating the disease and are administered via intravitreal (i.e. intraocular) injections, which are repeated every other month on average.

The early stages of AMD are characterized by the presence of small yellowish white spots on the fundus in the macula region called drusen and/or alterations of the pigment epithelium. This feature defines age-related maculopathy or pre-AMD.

#### Exudative AMD: treatment protocol

The severity and speed of development of the exudative form, along with the efficacy and cost of the treatments developed to date, make it a real public health concern and a diagnostic and therapeutic emergency.

Ophthalmologists/retinologists who treat AMD patients must be able to see them on very short notice (within a week at the most) if they present with scotoma (dark spots in their central vision) or macular syndrome: a decrease in visual acuity or difficulty reading; metamorphopsia (distorted perception of images and straight lines). In the presence of these symptoms, eye exams must be conducted promptly, including visual acuity assessment via an EDTRS chart, a fundus examination via a binocular slit lamp, fluorescein and/or indocyanine green (ICG) retinal angiography

and optical coherence tomography (OCT).

If the diagnosis of subfoveal exudative AMD is confirmed by these examinations, it is recommended that anti-VEGF treatment be initiated as early as possible, irrespective of the initial level of visual acuity. Anti-VEGF treatments must be administered by intravitreal injection. Extra- and juxtafoveal choroidal neovascularization with subfoveal exudative manifestations should be considered a subfoveal location of AMD.

In the current state of science, the most commonly adopted treatment protocol is as follows: one anti-VEGF

injection per month during three consecutive months (the interval between the two injections must be at least four weeks), followed by a monitoring phase. During the monitoring phase, patients must be examined every four weeks as follows: a visual acuity assessment using an ETDRS chart; a fundus examination and/or retinogram; an optical coherence tomogram (OCT). Fluorescein angiography may be performed if necessary.

Another injection must be given after the first three injections, if persistent or recurring signs of continued activity of the neovascular lesion are clinically detected via a fundus examination and/or optical coherence

FIG. 2 | Fluorescein angiography of atrophic AMD

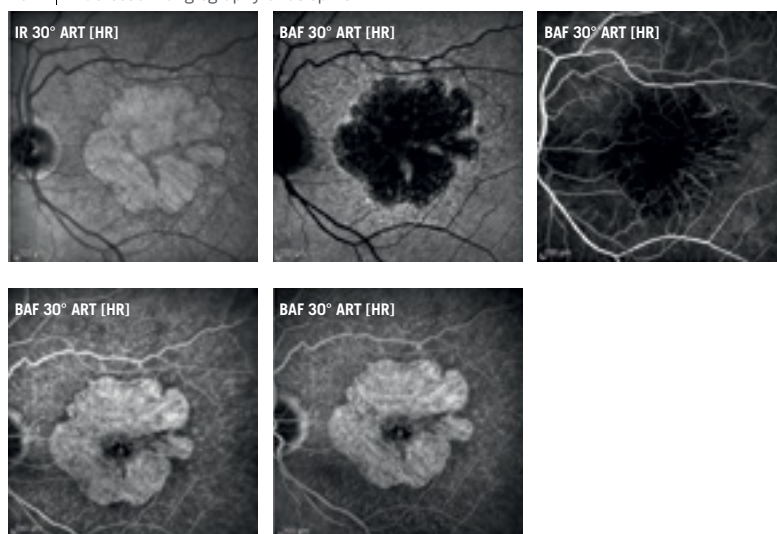
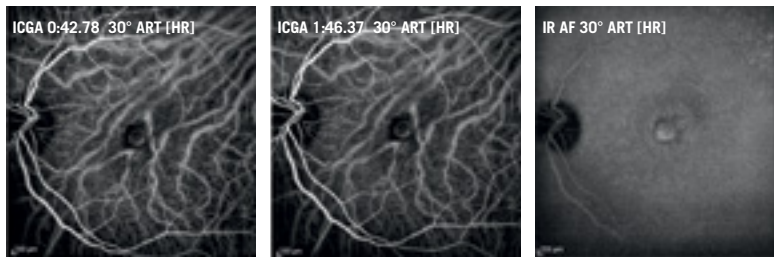
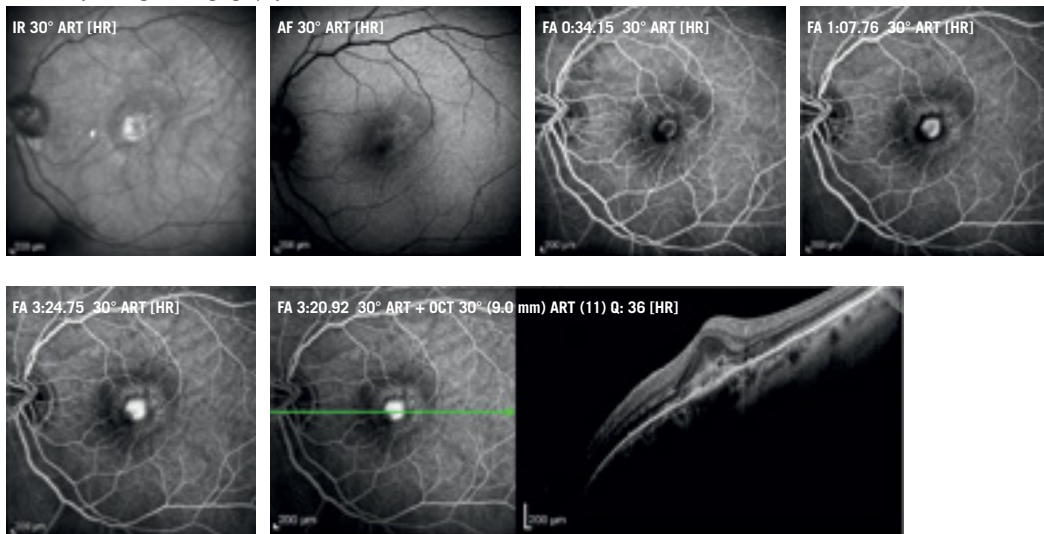


FIG. 3 | Exudative AMD with visible subfoveal neovascularature

## 3.a fluorescein



## 3.b indocyanine green angiography



tomography. On average, patients receive six or seven injections per year. AMD is a bilateral disease. After the first eye is affected, there is an increased risk of bilateralization (about 10% per year). In the presence of functional symptoms (i.e. visual impairment, metamorphopsia, scotoma, etc.) concerning the fellow eye during follow-up, the patient should be seen on an emergency basis. It is recommended that surveillance examinations for AMD be performed on both eyes to screen for an asymptomatic incipient lesion in the fellow eye.

**Atrophic AMD: patient management**

Unfortunately, the same therapeutic advances are not available for patients with atrophic AMD as for those with the exudative form.

Although it progresses more slowly, the long-term prognosis remains poor and possible complications involving neovascularization warrant regular

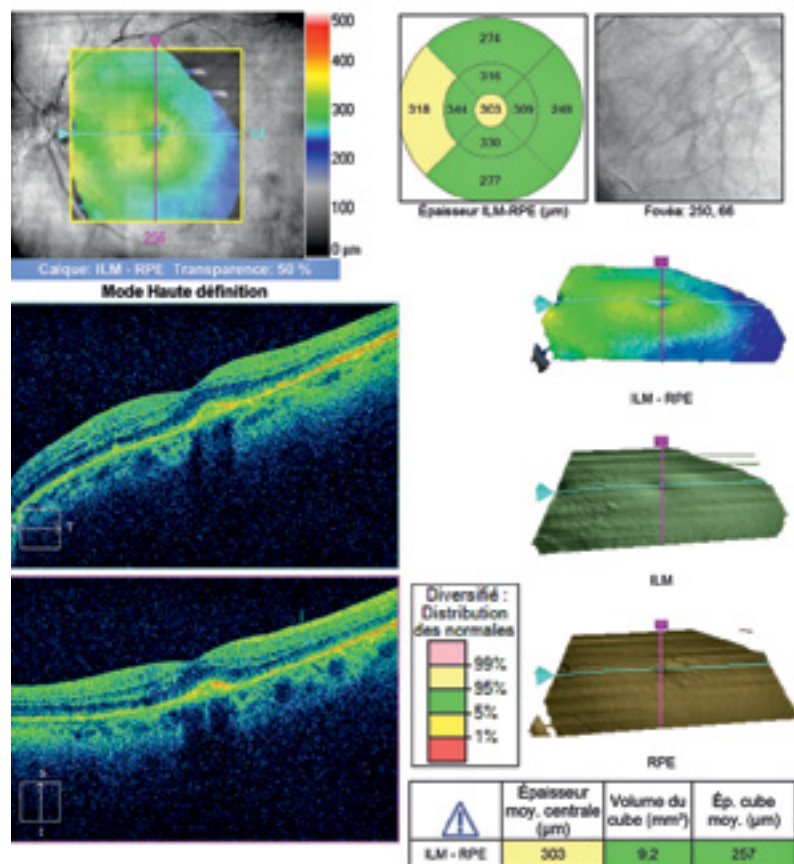
monitoring (i.e. self-monitoring using the Amsler grid, leading to a rapid consultation if there is any change in functional symptoms).

When the decrease in visual acuity becomes debilitating, management of patients with advanced AMD involves rehabilitation and the use of low-vision-support magnifying optical systems to mobilize unaffected areas of retina to improve vision.

Patients presenting with age-related maculopathy must be educated about self-monitoring methods, via the Amsler grid in particular. Patients at very high risk with large confluent drusen and RPE alterations must be examined frequently to detect the possible appearance of neovascularization amenable to treatment. It is essential that patients receive a clear diagnosis. Ensure that patients know

**“Protection from the sun via photo-protective lenses is still called for out-of-doors from an early age in view of the transparency of the crystalline lens in children.”**

3.c Control OCT after three anti-VEGF intravitreal injections.



the name of the disease that is the cause of their declining visual acuity and whether they are suffering from an early or advanced stage of the atrophic or exudative form of the disease.

Explain to patients that this is a chronic condition that can be treated but cannot be cured, and that it does not lead to total blindness (since peripheral vision is preserved). Regular follow-ups are essential.

Inform patients about their visual prognosis, the risk of involvement of the second eye and the risk of progression from the atrophic form to the exudative form.

### Primary prevention

The constantly increasing incidence of AMD fully justifies strong primary prevention efforts to combat this condition. Primary prevention is based on combating the risk factors for the disease. For example, simple lifestyle

and **dietary preventive measures** can be recommended to all, such as: combating tobacco use; combating obesity, lipid disorders and hypertension; practicing a physical activity on a regular basis; and adopting a diet rich in the macular pigments lutein and zeaxanthin (found in fruits and vegetables) and omega 3s (oily fish like salmon, tuna, etc.).

Based on the results of conclusive research on the toxicity of blue-violet light radiation, a partnership with a manufacturer of **eyeglass lenses** has led to the development of lenses (Crizal® Prevencia®) capable of reflecting a fraction of this toxic

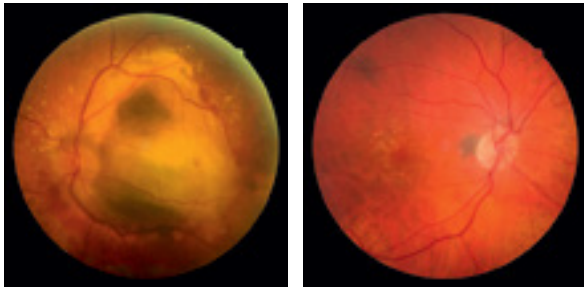
radiation and preventing it from penetrating the eye. It is therefore logical to recommend that as many people as possible wear this type of photo-selective protection, particularly those with genetic risk factors.

Protection from solar radiation via photo-protective lenses is still called for out-of-doors from an early age in view of the transparency of the crystalline lens in children.

The prevention of complications for patients with precursor lesions is also currently necessary. This is accomplished primarily through the prescription of **food supplements**, on the basis of evidence provided by the publication of a number of large epidemiological studies. Supplementation with **antioxidants** (zinc and vitamins C and E) decreases the risk of progression and worsening of AMD by 25% in at-risk patients.<sup>8</sup> Supplementation with 10mg of lutein and 2mg of zeaxanthin in addition to antioxidants would reduce the progression of advanced AMD by 18%.<sup>9</sup> The value of omega 3 is not as clear-cut, but studies have shown that taking large doses of DHA could reduce the risk of developing neovascular AMD in high-risk patients.<sup>10</sup>

The prescription of food supplements whose composition is consistent with data from these studies is therefore recommended for at-risk patients and patients known to have AMD.

FIG.4 | Example of a very-high-risk patient with untreated AMD in one eye and drusen and pigmentary alterations in the other eye.



“The constantly increasing incidence of AMD fully justifies strong primary prevention efforts to combat this condition.”

### New therapeutic avenues

A number of new therapeutic avenues for AMD are currently being explored. Some **new molecules** should soon be available in association with anti-VEGF treatments for exudative AMD, including anti-PDGF (Platelet derived growth factor) agents, also administered via intraocular injection. Numerous other molecules are also being tested, including complement factor inhibitors and anti-TNF (tumor necrosis factor) molecules. **Gene therapy** is also being studied in exudative AMD with the goal of producing an anti-VEGF agent directly in the retina by introducing a gene directly into retinal cells by a viral vector. This would free patients from risks related to repeated injections.

**Cell therapy** is a new avenue being explored for atrophic AMD. The idea is to implant stem cells or autologous RPE cells in the retina to renew the supply of functional cells and stop the degenerative process.

Lastly, for visually impaired patients at a very advanced stage, an **artificial retina** is also under development. An implant is placed in the retina that will receive images via an eye-glass-mounted camera. •



### KEY TAKEAWAYS

AMD has a multifactorial pathogenesis:

- Age
- Genetics
- Smoking
- Diet low in vitamins, trace elements and antioxidants
- Retinal phototoxicity (blue light)
- Obesity
- Hypertension

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## **2. INDUSTRY SOLUTIONS**

# SUNGLASS and Rx STANDARDS - UV protection

## Normas de gafas de sol con (Rx) y sin graduación - protección contra los UV



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There are standards in a number of countries for sunglasses, an ISO standard for Rx sunglasses, and a new ISO International Sunglass standard which will be published soon. These standards cover requirements and test methods for limiting UV transmittance.

### 1/ What is driving the standardisation of UV limits?

Eye care professionals, consumers and patients are becoming more and more aware of the risks to the health of their skin and eyes caused by the harmful effects of UV rays in sunlight.

For skin protection the use of protective clothing and sunscreen is improving dramatically with increasing education and awareness of the risk of serious sun damage.

But for protecting the eyes, the wearing of hats gives only partial protection, especially from UV radiation (UVR) reflected from the ground..

So sunglasses are the only effective way to significantly reduce eye exposure to safe levels along with achieving reduced glare levels.

The demonstrated risk and public awareness associated with UVR exposure is the main driver for standards to be created which can be trusted to be used for regulating the manufacture and use of sunglasses.

### 2/ The risks to the eye from UVR exposure

The large number of studies about the harmful effects to the eye of UVR exposure have created widespread acceptance that there are strong links between levels of eye exposure to UVR and the incidence and severity of a number of conditions including cataract, pterygium, snow blindness, macular degenerations, eyelid cancers and accelerated orbit skin aging.

And there are some unexpected risks. While the damage to the skin is greatest when the sun is highest in the sky, the eyes are deep set in the orbit, and partially protected when the sun is high in the sky. For most seasons, maximum solar UV exposure occurs between 8:00 and 10:00 am, and 2:00 to 4:00pm – which is not what would be expected.

*En un gran número de países existen normas para las gafas de sol, existe también una norma ISO para las gafas de sol graduadas y, próximamente, se publicará una norma ISO internacional de Gafas de Sol. Dichas normas tratan de los requisitos y métodos de prueba para limitar la transmitancia de los UV.*

### 1/ ¿Cual es el motivo que impulsa esta dinámica de normalización sobre los límites de los uv?

*Los profesionales de la atención ocular, los consumidores y los pacientes son cada vez más conscientes de los riesgos para la salud de la piel y los ojos de los rayos UV cuando uno se expone al sol.*

*En cuanto a la protección de la piel, se siguen observando mejoras significativas en la utilización de ropa protectora y pantalla solar así como una mayor concienciación e información sobre los riesgos de daños graves debido a la exposición solar.*

*No obstante llevar gorra o sombrero sólo brinda protección parcial a los ojos, especialmente si tomamos en consideración la radiación UV que se refleja desde el suelo (UVR).*

*Por lo tanto, las gafas de sol son la única manera efectiva para reducir significativamente la exposición de los ojos a los UV para llegar a niveles seguros además de reducir el deslumbramiento.*

*La demostración de los riesgos así como la concienciación del público a la exposición de los rayos UV desde el suelo (UVR) constituyen el motor principal de la elaboración de normas que pueden constituir pautas confiables para reglamentar la fabricación y el uso de las gafas de sol.*

### 2/ Los riesgos de la exposición a los rayos uvr para el ojo

*El gran número de estudios sobre los efectos nocivos de la exposición a los rayos UVR para los ojos han logrado que se acepte de manera generalizada que existe una relación significativa entre los niveles de exposición ocular a los rayos UVR y la incidencia y gravedad de toda una serie de trastornos incluyendo las cataratas, pterigión, ceguera del esquiador, degeneraciones maculares, tumores palpebrales así como el envejecimiento acelerado de la piel periocular.*

*También hay riesgos inesperados. Se conoce que los efectos nocivos para la piel son máximos cuando el sol está en su punto más elevado.*

And the exposure levels are not the same everywhere. People living in equitable climates, in latitudes closer to the equator, especially in the Southern Hemisphere, and in places with high number of sunny days per year receive up to 15% more exposure to UVR than the average.

The experts contributing to formulation of the eye protection standards interpret these risks, the science, and use data from recognised authoritative sources to formulate UV limits.

It is important that standards hold wide margins of safety to deliver the confidence in the sunglasses to protect well in all circumstances and location of wear.

### 3/ Consumer awareness and expectations

In a recent consumer survey of purchasing behaviour across all major markets, the following result was obtained.

These sunglasses :

*Los ojos, al estar ubicados dentro de sus órbitas, se encuentran parcialmente protegidos cuando el sol está en su punto más alto. En cambio, en la mayoría de las estaciones, la máxima exposición ocular a los UV solares ocurre entre las 8 y 10 de la mañana y entre las 2 y 4 de la tarde, lo cual no era perevisible.*

*Además, los niveles de exposición no son los mismos en todas partes. Las personas que viven en climas cálidos, en latitudes más cercanas al ecuador, especialmente en el hemisferio sur, y en lugares con un gran número de días soleados al año, reciben hasta el 15% más de exposición a los rayos UV que la media.*

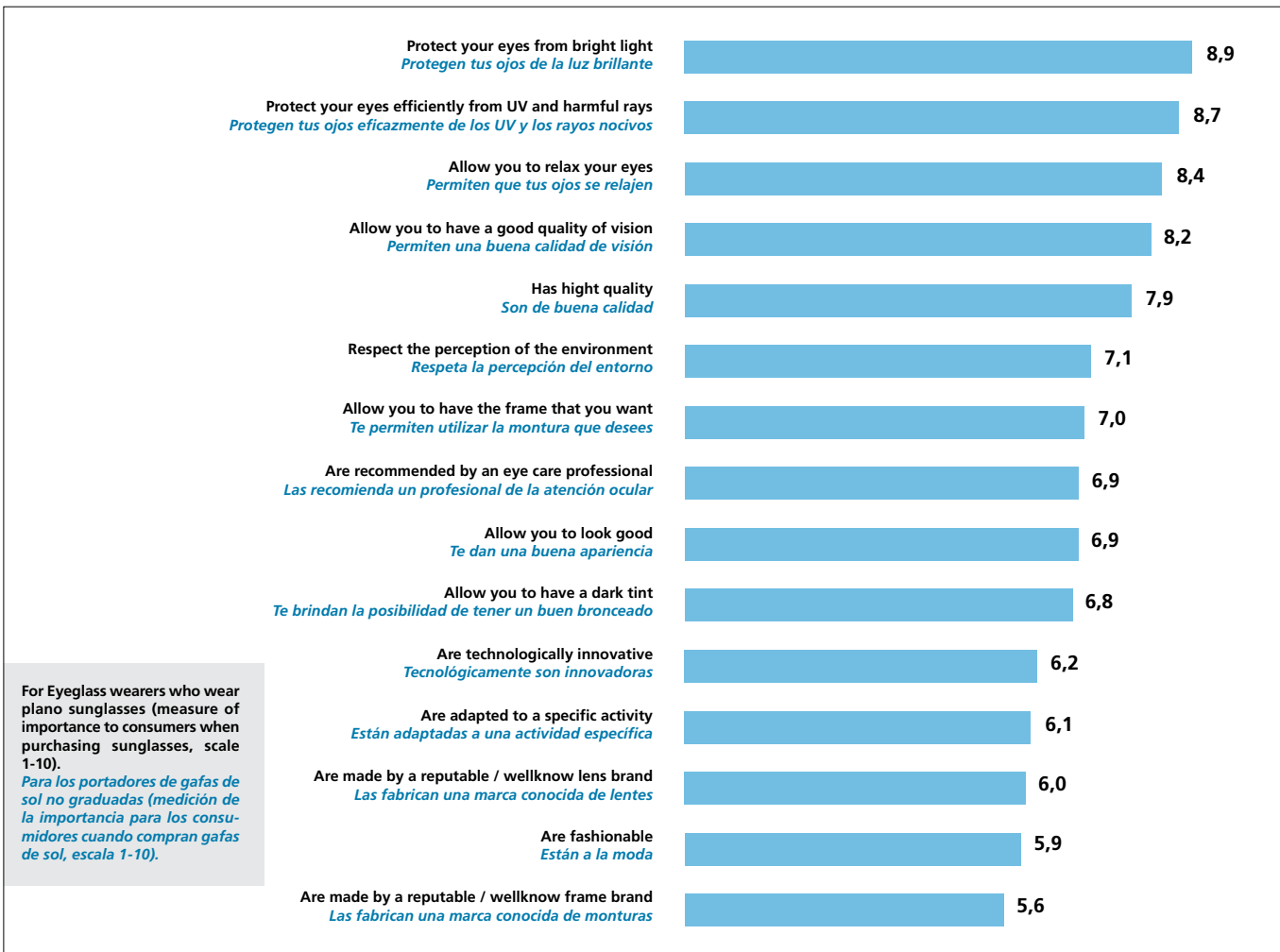
*Los expertos que contribuyen a la formulación de normas de protección ocular interpretan estos riesgos así como los elementos científicos y utilizan datos de fuentes reconocidas para formular los límites de los UV.*

*Es importante que las normas contengan márgenes amplios de seguridad para que el portador confíe en las gafas de sol y pueda gozar de una buena protección en todas circunstancias y lugares.*

### 3/ Concienciación del consumidor y expectativas

*En una reciente encuesta de consumidores sobre sus comportamientos de compra, realizada en todos los mercados principales, se obtuvieron los resultados a continuación.*

*Estas gafas de sol :*



This indicates that UVR protection is very important for consumers.

Standards provide a reference for regulation against which the performance of products can be determined. The standards set a benchmark for performance based on the best scientific information available.

Good standards are an agent to prevent the sale and use of sunglass products which perform badly or give poor protection.

Confidence created by the active use of standards generates increased sales of sunglasses. Sales volumes are underpinned by standards which guarantee good performance.

In parallel with the increased awareness for plano sunglass consumers, we also see an increase in the use of prescription tinted lenses or Rx sunglasses. The eye care professionals and their patients are becoming more aware of the protective benefits from providing a second pair of Rx sunglasses for times when exposure to the sun may be higher than usual.

#### 4/ The standards for sunglasses

##### PLANO POWER

##### AUSTRALIA: AS/NZS1067:2003 (with amendments)<sup>21</sup>.

Australia published the first general purpose sunglass standard in 1971 which is the only sunglass standard enacted in law. (Australian Federal Government Trade Practices Act).

Compliance is assessed and enforced by the ACCC (Australian Competition and Consumer Commission). It is therefore mandatory.

Australia has a combination of a geographic location much of which is close to the equator, with a high number of sunny days/year, and is influenced by the fact the earth is always nearer to the sun in the Australian summer than during the Northern Hemisphere summer. In addition, the air is cleaner in the Southern Hemisphere than in the North, so more UVR reaches the earth's surface. In addition, the lifestyle is very much outdoors-oriented in Australia. The combination of these effects means that Australians receive approximately 15% more solar UVR than those living in equivalent locations in the Northern Hemisphere.

It explains why Australia's standards have a very strong focus on protecting its citizens by maintaining tough UV protection requirements for sunglasses, and enforcing that by law.

Australia maintains 400 nm as its defined upper limit of the range considered to be UV, while the other sunglass standards use 380 nm.

Regulation in the Australian sunglass industry imposes large fines, and non-compliant sunglasses banned from sale – sometimes involving big brand names.

##### USA: ANSI Z80.3:2010 Non-prescription sunglasses and fashion eyewear<sup>11</sup>

This standard was created and is regularly updated by an ANSI-accredited committee of experts, and the Sunglass Association of America is the chair for the committee.

*Esto indica que los consumidores consideran la protección contra los rayos UVR algo muy importante.*

*Las normas son una referencia para la elaboración de normativas y la eficacia de los productos puede determinarse con arreglo a las mismas. Las normas establecen un comparativo de eficacia basado en la mejor información científica disponible.*

*Las buenas normas son el medio adecuado para evitar la venta y la utilización de gafas de sol que tienen poca eficacia o baja protección.*

*La confianza que se genera a través de la utilización activa de las normas también aumenta las ventas de las gafas de sol. Los volúmenes de venta se ven potenciados por normas que garantizan una buena eficacia.*

*Paralelamente a la mayor concienciación de los consumidores de gafas de sol no graduadas, también se observa un aumento en la utilización de lentes tintadas con prescripción o gafas de sol Rx. Tanto los profesionales de la atención ocular como sus pacientes son cada vez más conscientes de los beneficios de protección que brinda un segundo par de gafas de sol graduadas para aquellos momentos en los que la exposición solar pueda ser más elevada de lo habitual.*

#### 4/ Las normas para las gafas de sol

##### LA IMPORTANCIA DE LAS GAFAS DE SOL NO GRADUADAS

##### AUSTRALIA: AS/NZS1067:2003 (y sus anexos)<sup>21</sup>.

*Australia publicó la primera norma de gafas de sol de uso general en 1971 y constituye la única norma de gafas de sol promulgada en ley. (Australian Federal Government Trade Practices Act).*

*La Comisión Australiana para los Consumidores y la Competencia ACCC (Australian Competition and Consumer Commission) es el organismo a cargo de evaluar la conformidad y de asegurar su aplicación. Esta norma es, por lo tanto, de obligado cumplimiento.*

*Australia combina una ubicación geográfica cercana al ecuador, con un número elevado de días de insolación al año; además, la Tierra siempre se encuentra más cerca del sol en el verano australiano con respecto al verano del hemisferio norte. Cabe añadir que el aire es más limpio en el hemisferio sur que en el hemisferio norte, de manera que hay una mayor cantidad de radiación UVR que alcanza la superficie terrestre. A esto hay que añadir que, en Australia, el estilo de vida está muy orientado hacia actividades exteriores. La combinación de todos estos factores significa que los australianos reciben aproximadamente el 15% más de radiaciones solares UVR que las poblaciones que viven en sitios equivalentes en el hemisferio norte.*

*Esto explica por qué las normas australianas hacen un fuerte hincapié en la protección de sus ciudadanos al exigir niveles de protección muy exigentes contra las radiaciones UV en las gafas de sol e incluso han sido incorporados en la ley.*

*Australia mantiene los 400 nm como límite superior del rango considerado UV, mientras que otras normas relativas a las gafas de sol llegan a los 380 nm.*

*La normativa que rige la industria de las gafas de sol australiana impone multas considerables y las gafas de sol no conformes quedan prohibidas a la venta. Ya se han visto algunos casos, incluso de grandes marcas.*



The standard is not mandatory, but relies on voluntary manufacturer-regulation. However, nonprescription sunglasses are classified and regulated by FDA as Class I devices in accordance with Title 21 of the Code of Federal Regulations (CFR). Sunglasses that are imported into the US must comply with country of origin marking requirements in the United States Tariff Act. Manufacturers and initial importers/distributors must register their establishments with the FDA annually and foreign manufacturers must also designate a U.S. Agent.

Nonprescription sunglasses are generally marketed as “Over The Counter” medical devices and are subject to general labeling and OTC labeling requirements outlined in Title 21 CFR Part 801 - Labeling

There are 4 classifications in Z80.3-2010 used to define the UV transmittance and traffic signal recognition requirements.

Sunglasses which comply with the traffic signal recognition requirements are categorised as cosmetic (luminous transmittance  $T_v > 40\%$ ), or General Purpose ( $T_v$  from 8 to 40%). If sunglasses in these two categories don't meet the traffic signal recognition requirements, they must be labeled “not intended for driving”

#### EUROPEAN UNION: EN1836:2005 + A12007 Sunglasses and fashion spectacles<sup>[3]</sup>

Sunglasses cannot be sold in Europe without the CE mark. The CE mark is a claim of compliance with the PPE EU Directive 89/686/EEC. The normal way to comply with the Directive is to comply with the EN1836:2005 standard.

Compliance is by self-declaration and there is little evidence of surveillance of compliance.

EN1836 has 4 transmittance or tint categories requiring different UV transmittance limits.

The standard has means to verify claims about UV transmittance (and absorption) for Solar UV, UV-A, UV-B and for blue light.

While a study in UNSW Australia found that 17% of CE marked sunglasses did not comply with the EN1836 standard, only a small 1.8% failed for the UV requirements.

This is a vast improvement on past surveys, and indicates the sunglass manufacturers have responded well to the demand for good UV protection.

#### China (PRC) GB xxxx-1-20xx<sup>1</sup> Eye and face protection - Sunglasses and related eyewear -Part 1 Sunglasses for general use<sup>[4]</sup>.

This is a newly developed draft standard awaiting approval before publishing.

It supersedes an Industry Sunglass Standard and is based on EN1836. It has been adapted to be close to ISO12312.1, but notably with tougher UV requirements.

<sup>1</sup> The standard has not been published in China so it doesn't have a number or year of publication.

#### EEUU: ANSI Z80.3:2010 Gafas de sol sin prescripción y gafas de moda<sup>[1]</sup>

*Una comisión de expertos acreditados por la ANSI elaboró esta norma que es objeto de actualización regular. La Asociación de Gafas de Sol de EEUU (Sunglass Association of America) preside dicha comisión.*

*Esta norma no es obligatoria pero se basa en un cumplimiento voluntario por parte de los fabricantes. No obstante, las gafas de sol no graduadas son clasificadas y reglamentadas por la FDA como dispositivos de Categoría I de conformidad con el Título 21 del Código Federal de Regulación (CFR). Las gafas de sol que se importan en territorio EEUU deben estar conformes con los requisitos de marcado del país de origen como lo estipula la Ley de Aranceles de EEUU (United States Tariff Act).*

*Los fabricantes y distribuidores/importadores iniciales deben registrar su establecimiento con la FDA anualmente y los fabricantes extranjeros deben, además, designar un agente en EEUU.*

*Las gafas de sol no graduadas son generalmente comercializadas como dispositivos médicos en venta libre (“Over The Counter”) y están sujetas a etiquetado general y, por lo tanto, a los requisitos de etiquetado OTC incluidos en el Título 21 CFR Sección 801 - Etiquetado.*

*Existen 4 categorías en Z80.3-2010 que se utilizan para definir la transmitancia de los UV y los requisitos de reconocimiento de las señales de tráfico.*

*Las gafas de sol conformes a los requisitos de reconocimiento de las señales de tráfico son clasificadas como dispositivos cosméticos (transmitancia luminosa  $T_v > 40\%$ ), o de Uso General ( $T_v$  de 8 a 40%). Si las gafas de sol de estas dos categorías no cumplen con los requisitos de reconocimiento de las señales de tráfico, éstos deben tener la mención “no utilizar para conducir”*

#### UNIÓN EUROPEA : EN1836:2005 + A12007 Gafas de sol y filtros solares<sup>[3]</sup>

*Las gafas de sol no pueden venderse en Europa sin el marcado CE. El marcado CE significa que las gafas son conformes a la Directiva PPE EU 89/686/CEE. La manera normal de cumplir con esta Directiva es cumplir con la norma EN1836:2005.*

*La conformidad se determina mediante auto-declaración y existen pocas pruebas de comprobación de dicha conformidad.*

*La EN1836 tiene 4 transmitancias o categorías de tinte con diferentes límites de transmitancia de los UV.*

*La norma está dotada de los medios para comprobar la afirmación sobre la transmitancia (y absorción) de los UV solares, UV-A, UV-B y la luz azul.*

*Mientras que un estudio de la UNSW de Australia reveló que el 17% de las gafas de sol con marcado CE no cumplían con la norma EN1836, sólo un pequeño 1.8% no cumplía con los requisitos relativos a los UV. Esto constituye una gran mejora con respecto a estudios anteriores y es una indicación de que los fabricantes de gafas de sol han respondido bien a la demanda de una buena protección contra los UV.*

<sup>1</sup> La norma no ha sido publicada en China y, por lo tanto, no tiene un número que corresponda al año de publicación.

## ISO 12312.1 Eye and face protection – Sunglasses and related eyewear<sup>51</sup>

ISO TC94/SC6/WG3 has almost completed its work to create an International Standard for Sunglasses (and related Test Methods standard). See § 9.

### 5/ UV requirements in the major standards

The following is an informative Annex in the ISO12312.1 Sunglass standard.

“The eyes have a natural aversion response to bright light that limits outdoor filter exposure when one is not

wearing sunglasses. This aversion response that provokes squinting limits filter exposure greatly, but

sunglasses without side shields may permit peripheral exposure of biological significance due to the Coroneo effect: The analytic characterization of ultraviolet skylight, as adapted for calculating corneal irradiance show that the largest influence on filter exposure in temperate regions is the seasonal variation of solar irradiance as adjusted by ground reflectance and the time from solar noon. Diffuse sky radiation decreases with increasing altitude, and corneal irradiation varies significantly with lid opening and ground cover.

The adopted transmittance limits are based on calculations of the biologically weighted exposure doses. The

ultraviolet transmittance limits for sunglasses will keep these doses below a recognized safe limit even for

exceptional daily exposure except over snow. Further margins of safety to account for tropical conditions

or walking over snowfields in late spring have been incorporated. This has been done by adding additional

safety factors to those implicit in the exceptional exposure experiences at mid-latitudes over normal terrain.

The specification of spectral (instead of average or weighted) transmittance limits provides a further very large increase in the margin of safety.”

There are some differences in the way the UV requirements are defined in the various sunglass standards. Some specify spectral transmittance limits for specified wavelength bands, while others set integrated transmittance limits.

But in practice, studies show that the number of sunglasses passing one standard and failing another is exceedingly small. UV protection is almost guaranteed with modern sunglass lens materials.

*China (RPC) GB xxxx-1-20xx<sup>1</sup> Protección de los ojos y del rostro - Gafas de sol y dispositivos asociados - Sección 1 Gafas de sol de uso general<sup>41</sup>.*

*Este es un nuevo borrador de norma recién redactada y que está en espera de aprobación antes de su publicación. Va a sustituir a la Norma de la Industria Gafas de Sol y se basa en la EN1836. Se ha adaptado para acercarse a la ISO12312.1 pero con requisitos netamente más exigentes relativos a los UV.*

### ISO 12312.1 Protección de ojos y rostro - Gafas de sol y dispositivos asociados<sup>51</sup>

*La ISO TC94/SC6/WG3 casi ha terminado su trabajo de elaboración de una Norma Internacional para las Gafas de Sol (y su norma asociada sobre los Métodos de Prueba). Véase § 9.*

### 5/ Requisitos relativos a los uv en las normas principales

*El texto siguiente es un Anexo informativo de la ISO12312.1 sobre la norma de gafas de sol*

*“El ojo tiene una respuesta natural de aversión a la luz brillante lo que limita la exposición del filtro en exteriores cuando uno no lleva gafas de sol. Esta respuesta de aversión que provoca la necesidad de entrecerrar los ojos limita ampliamente la exposición al filtro, pero las gafas de sol sin protectores laterales pueden permitir exposición periférica de significancia biológica debido al efecto Coroneo: la caracterización analítica de la luz ultravioleta del cielo, adaptada para el cálculo de la irradiancia córnea, muestra que la mayor influencia de la exposición del filtro en regiones templadas es la variación estacional de la irradiancia solar ajustada a la reflectancia del suelo y el tiempo transcurrido desde el mediodía solar. La radiación difusa del cielo disminuye con mayor altitud y la irradiación corneal varía significativamente con la apertura de los párpados y el recubrimiento del suelo.*

*Los límites de transmitancia adoptados se basan en cálculos de las dosis biológicas de exposición ponderadas. Los límites de transmitancia ultravioleta para las gafas de sol mantendrán estas dosis por debajo de un límite seguro reconocido incluso en una exposición diaria excepcional, salvo cuando hay nieve. Se han incorporado márgenes de seguridad adicionales en caso de condiciones tropicales o de marcha en campos nevados hacia finales de la primavera al añadir factores de seguridad adicionales a los implícitos en las experiencias de exposición extraordinaria en latitudes medias en terrenos normales. La especificación de los límites de transmitancia espectrales (en vez de una media o un valor ponderado) brinda un aumento significativo adicional en el margen de seguridad”.*

*Existen algunas diferencias en la forma en la que se definen los requisitos UV en las diversas normas de gafas de sol. Algunas especifican los límites de transmitancia espectral para las bandas de longitud de onda específicas, mientras que otras establecen límites de transmitancia integrados.*

*Pero en la práctica, los estudios muestran que el número de gafas de sol que aprueban una norma y fallan en otra es ínfimo. La protección contra los UV es prácticamente garantizada con los materiales modernos de las gafas de sol.*

Comparison of the major sunglass standards for UV requirements.

The categories

Generally sunglasses and Rx sunglasses are categorised according to the luminous transmittance.

- Category 0 is where  $0v \geq 80\%$
- Category 2 is  $43\% < Tv \leq 80\%$
- Category 3 is  $18\% < Tv \leq 43\%$
- Category 4 is  $3\% < Tv \leq 18\%$

Comparación de los requisitos relativos a los UV de las principales normas de gafas de sol.

Las categorías

De manera general, las gafas de sol no graduadas y las gafas de sol graduadas caen en diferentes categorías según la transmitancia luminosa.

- Categoría 0 es cuando  $0v \geq 80\%$
- Categoría 2 es  $43\% < Tv \leq 80\%$
- Categoría 3 es  $18\% < Tv \leq 43\%$
- Categoría 4 es  $3\% < Tv \leq 18\%$

Tab. UV-B Protection Requirements.  
Requisitos de Protección contra los UV-B.

EN 1836: 2005 <i>EN 1836: 2005</i>	AS/NZS 1067: 2003 <i>AS/NZS 1067: 2003</i>	ANSI Z80.3: 2001 <i>ANSI Z80.3: 2001</i>	ISO DRAFT 12312.1 <i>ISO DRAFT 12312.1</i>
<p><b>280 - 315 nm</b> <math>Tf(\lambda) \leq 0.1Tv</math></p> <p><b>280 - 315 nm</b> <math>Tf(\lambda) \leq 0.1Tv</math></p> <p><b>315 - 350 nm</b> <math>Tf(\lambda) \leq Tv</math> for categories 0-2</p> <p><math>Tf(\lambda) \leq 0.5Tv</math> for categories 3 and 4</p> <p><b>315 - 350 nm</b> <math>Tf(\lambda) \leq Tv</math> <i>para categorías 0 a 2</i></p> <p><math>Tf(\lambda) \leq 0.5Tv</math> <i>para categorías 3 y 4</i></p>	<p><b>280 - 315 nm</b> <math>Tf(\lambda) \leq 0.05Tv</math></p> <p><b>280 - 315 nm</b> <math>Tf(\lambda) \leq 0.05Tv</math></p> <p><b>315 - 350 nm</b> <math>Tf(\lambda) \leq Tv</math> for categories 0-2</p> <p><math>Tf(\lambda) \leq 0.50Tv</math> for categories 3 and 4 at all points in 28 mm diameter circle</p> <p><b>315 - 350 nm</b> <math>Tf(\lambda) \leq Tv</math> <i>para categorías 0-2</i></p> <p><math>Tf(\lambda) \leq 0.50Tv</math> <i>para categorías 3 y 4</i> <i>en todos los puntos de un círculo de 28 mm de diámetro</i></p>	<p><b>280 - 315 nm</b> <math>T_{SUVB} \leq 0.125Tv</math> for normal use</p> <p><b>280 - 315 nm</b> <math>T_{SUVB} \leq 0.125Tv</math> <i>de uso normal</i></p>	<p><b>280 - 315 nm</b> <math>T_{SUVB} \leq 0.05Tv</math> for categories 0 and 1</p> <p><math>T_{SUVB} \leq 0.05Tv</math> or 1% absolute, which ever is the greatest for</p> <p><math>T_{SUVB} \leq 1\%</math> absolute for categories 3 and 4</p> <p><b>280 - 315 nm</b> <math>T_{SUVB} \leq 0.05Tv</math> <i>para las categorías 0 y 1</i></p> <p><math>T_{SUVB} \leq 0.05Tv</math> ó el 1% absoluto, <i>lo que sea mayor en la categoría 2</i></p> <p><math>T_{SUVB} \leq 1\%</math> absoluto <i>para las categorías 3 y 4</i></p>
<p><math>Tv</math> is the luminous transmittance <math>Tf(\lambda)</math> is the spectral transmittance <math>T_{SUVB}</math> is the solar UVB transmittance</p>		<p><math>Tv</math> es la transmitancia luminosa <math>Tf(\lambda)</math> es la transmitancia espectral <math>T_{SUVB}</math> es la transmitancia de los UVB solares</p>	

Tab. UV-A Protection Requirements.  
Requisitos de Protección contra los UV-A.

EN 1836: 2005 <i>EN 1836: 2005</i>	AS/NZS 1067: 2003 <i>AS/NZS 1067: 2003</i>	ANSI Z80.3: 2001 <i>ANSI Z80.3: 2001</i>	ISO DRAFT 12312.1 <i>ISO DRAFT 12312.1</i>
<p><b>315 - 380 nm</b> <math>T_{SUVA} \leq Tv</math> for categories 0-2</p> <p><math>T_{SUVA} \leq 0.5Tv</math> for categories 3 and 4</p> <p><b>315 - 380 nm</b> <math>T_{SUVA} \leq Tv</math> <i>para categorías 0 a 2</i></p> <p><math>T_{SUVA} \leq 0.5Tv</math> <i>para categorías 3 y 4</i></p>	<p><b>315 - 400 nm</b> <math>T_{SUVA} \leq Tv</math> for categories 0-2</p> <p><math>T_{SUVA} \leq 0.50Tv</math> for categories 3 and 4 at all points in 28 mm diameter circle</p> <p><b>315 - 400 nm</b> <math>T_{SUVA} \leq Tv</math> <i>para categorías 0-2</i></p> <p><math>T_{SUVA} \leq 0.50Tv</math> <i>para categorías 3 y 4</i> <i>en todos los puntos de un círculo de 28 mm de diámetro</i></p>	<p><b>315 - 380 nm</b> <math>T_{SUVA} \leq Tv</math></p> <p><b>315 - 380 nm</b> <math>T_{SUVA} \leq Tv</math></p>	<p><b>315 - 380 nm</b> <math>T_{SUVA} \leq Tv</math> for categories 0 and 1</p> <p><math>T_{SUVA} \leq 0.5Tv</math> for categories 2-3</p> <p><math>T_{SUVA} \leq 1\%</math> absolut or <math>\leq 0.25Tv</math> for categorie 4</p> <p><b>315 - 380 nm</b> <math>T_{SUVA} \leq Tv</math> <i>para categorías 0 y 1</i></p> <p><math>T_{SUVA} \leq 0.5Tv</math> <i>para categorías 2-3</i></p> <p><math>T_{SUVA} \leq 1\%</math> absoluto ó <math>\leq 0.25Tv</math> <i>para categoría 4</i></p>
<p><math>T_{SUVA}</math> is the solar UVA transmittance</p>		<p><math>T_{SUVA}</math> es la transmitancia de los UVA solares</p>	

### Claims for UV transmittance or absorption

All sunglass standards have the means to verify claims for a specific % transmittance or absorption.

For example, the ISO standard has **“In the case where it is claimed that a filter has x % UV absorption, the solar UV transmittance of the filter TSUV shall not exceed (100.5 - x) %.”**

So for a sunglass claimed to absorb 99% UV, the solar UV transmittance shall not exceed 1.5%.

### Prescription Sunglasses

ISO 8980.3:2003<sup>[7]</sup> Transmittance for finished uncut spectacle lenses is the international reference for prescription tinted lenses and Rx sunglasses. It was formulated and maintained by ISOTC172/SC7/WG3.

The UV requirements are not as tough as for plano sunglasses.

UVB – for category 0,  $T_{SUUV} \leq T_v$ , for categories 1 to 3,  $T_{SUUV} \leq 0.125T_v$ , and category 4  $T_{SUUV} \leq 1\%$  absolute

UVA – For categories 0 to 2,  $T_{SUVA}$  shall be  $\leq T_v$ , and for categories 3 and 4,  $T_{SUVA} \leq 0.5T_v$

For photochromic lenses the UV requirements must be met both in the dark and light states.

There is a constant challenge for the committees in ISOTC94/SC6 eye protection and ISOTC172/SC7/WG3 spectacle lenses to ensure that the requirements in the sunglass standards are not in conflict with those in the prescription transmittance standard.

### 6/ How is UV performance measured?

There are some differences between the standards but the most up-to-date methodology is in the latest draft of ISO12311 Test methods for sunglasses<sup>[6]</sup>.

Measurement is permitted with spectrophotometric equipment capable of measuring spectral transmittance with specified uncertainties.

Measurements are made normal to the surface of the lens.

The spectral values are measured at no more than 5nm intervals and the solar UV values calculated by integrating over the specified range of wavelengths taking into account the spectral distribution of sunlight and the spectral sensitivity of the eye. Data is provided in the standard to calculate

- Luminous transmittance  $T_v$
- Solar UV transmittance  $T_{SUUV}$
- Solar UV-A transmittance  $T_{SUVA}$
- Solar UV-B transmittance  $T_{SUVB}$

### 7/ How do the standards define UV?

Since spectacle lens and sunglass standards define 380 nm as the upper limit of the UV range, there is opportunity for manufacturers to make claims like “UV400” – or similar for another wavelength.

### Afirmaciones de la transmitancia o absorción de los UV

*Todas las normas de gafas de sol deben contar con los medios para comprobar las afirmaciones sobre un porcentaje específico de transmitancia o absorción. Por ejemplo, en la norma ISO: “En el caso de que se afirme que un filtro tiene el x % de absorción de los UV, la transmitancia UV del filtro TSUV no debe exceder el (100.5 - x) %.”*

*Es decir, para unas gafas de sol de las que se afirma que absorben el 99% de los UV, la transmitancia de los UV solares no debe exceder el 1.5%.*

### Gafas de sol graduadas

*La ISO 8980.3:2003<sup>[7]</sup> sobre la transmitancia de lentes de gafas sin cortar, acabadas, es la referencia internacional para las lentes tintadas graduadas y las gafas de sol graduadas. Fue formulada y mantenida por la ISOTC172/SC7/ZG3.*

*Los requisitos sobre los UV no son tan exigentes como en el caso de gafas de sol no graduadas.*

*UVB – para la categoría 0,  $T_{SUUV}$  deberá ser  $\leq T_v$ , para categorías 1 a 3,  $T_{SUUV} \leq 0.125T_v$ , y categoría  $T_{SUUV} \leq 1\%$  absoluto*

*UVA – para categorías 0 a 2,  $T_{SUVA}$  deberá ser  $\leq T_v$ , y para categorías 3 y 4,  $T_{SUVA} \leq 0.5T_v$*

*Para las lentes fotocromáticas, los requisitos UV deben cumplirse tanto en estado claro como en estado oscuro.*

*Se plantea un reto constante a las comisiones en la ISOTC94/SC6 sobre protección ocular y en la ISOTC172/SC7/WG3 de lentes de gafas para asegurarse de que los requisitos en las normas de gafas de sol no estén en conflicto con los requisitos de la norma de transmitancia de lentes graduadas.*

### 6/ ¿Cómo se mide la eficacia contra los uv?

*Existen algunas diferencias entre las normas pero la metodología más actualizada se encuentra en el último borrador de la ISO12311 sobre los métodos de prueba para las gafas de sol<sup>[6]</sup>.*

*Se permite realizar las mediciones con equipo espectrofotométrico capaz de medir la transmitancia espectral con ciertos márgenes especificados.*

*Normalmente, las mediciones se llevan a cabo en la superficie de la lente.*

*Los valores espectrales se miden en no más de 5nm de intervalo y los valores de los UV solares se calculan integrando en un rango específico de longitudes de onda tomando en consideración la distribución espectral de la luz solar y la sensibilidad espectral del ojo. En la norma se proporcionan los datos para realizar el cálculo de:*

- La transmitancia luminosa  $T_v$
- La transmitancia de los UV solares  $T_{SUUV}$
- La transmitancia de los UV-A solares  $T_{SUVA}$
- La transmitancia de los UV-B solares  $T_{SUVB}$

### 7/ ¿Cómo se definen los uv en las normas?

*Puesto que las lentes de gafas y las normas de gafas de sol definen los 380 nm como el límite superior del rango UV, se deja cabida para que los fabricantes afirmen “UV400”, o algo similar en otra longitud de onda.*

Because it wasn't possible in the ISO forums to agree a definition for UV400, it was decided to write a Technical Report called "Short Wavelength Visible" This is intended to explain and educate those who are interested in the effects on the eye in this interface range and how lenses attenuate these effects.

The Technical Report is currently in formulation with contributions from experts around the world.

#### 8/ A challenge for manufacturers

Increased public awareness of UV and the harmful effects has driven manufacturers to eliminate more and more UVR, to create sharper cutoff lenses, and to cut more and more of the blue light region.

The consequence of removing blue light is a possible yellowing of clear lenses and failure to comply with the coloration limits for traffic signal recognition.

The challenge is to create superior products recognising these limitations.

#### 9/ ISO Sunglasses standard 12312.1<sup>[5]</sup>

Since 2004, ISO committee TC94/SC6/WG3 has been developing the sunglass standard ISO12312.1 and its supporting test methods standard ISO12311. These standards are intended to be published simultaneously.

The UVR values in EN1836 were used as a starting point for 12312.1. The spectral values were replaced by integrated values, which are tougher, and the UVA requirements have been tightened also.

The ISO standards for sunglasses are close to completion and are expected to be published during 2012.

When the ISO standards are published, EN1836 will be withdrawn and the ISO standard will become the reference for claiming conformity to the EU Directive, allowing CE marking and sale in Europe.

#### 10/ Trends for the future

The most significant event in the near future will be the publishing and adoption of the ISO sunglass standards.

Countries will need to decide about adoption of these new standards to replace their national standards – where they exist.

If there is a wide acceptance of the ISO standard that will benefit those engaging in cross-border trade in sunglasses since only one international standard will need to be respected.

Further in the future it is expected that UV protection requirements will become tougher. We can also expect labelling requirements to increase which will better inform consumers at point of sale about the protective level of products.

*Puesto que no ha sido posible, en el marco de la ISO, llegar a un acuerdo de definición de UV400, se adoptó la decisión de elaborar un Informe Técnico denominado "Radiación Visible de Longitud de Onda Corta" ("Short Wavelength Visible"). Este informe tienen como objetivo explicar e instruir a aquellos que estén interesados en los efectos en el ojo de este rango de interfaz y cómo las lentes atenúan dichos efectos.*

*Actualmente, el Informe Técnico ha sido elaborado con contribuciones de expertos de todo el mundo.*

#### 8/ Un desafío para los fabricantes

*La mayor concienciación del público en general sobre los efectos nocivos de los UV ha conducido a que los fabricantes eliminen cada vez más los UVR, a que fabriquen lentes que bloqueen más nítidamente y que bloqueen cada vez más los rayos de la zona de la luz azul.*

*Como consecuencia de la eliminación de la luz azul, se puede producir un posible amarilleo de las lentes transparentes y no cumplir así con los límites de coloración para el reconocimiento de las señales de tráfico.*

*El desafío consiste pues en elaborar productos superiores a la vez que se cumplen dichas exigencias.*

#### 9/ La norma iso 12312.1 para gafas de sol<sup>[5]</sup>

*Desde 2004, la comisión ISO TC94/SC6/WG3 ha venido elaborando la norma ISO12312.1 para las gafas de sol y su norma de métodos de prueba ISO12311. Se tiene la intención de que dichas normas sean publicadas simultáneamente.*

*Se utilizaron los valores UVR de la EN1836 como punto de partida para la 12312.1. Los valores espectrales fueron sustituidos por valores integrados, más estrictos, y los requisitos UVA también son más exigentes.*

*Las normas ISO para las gafas de sol están a punto de ser terminadas y se espera su publicación en el transcurso del año 2012.*

*Cuando se publiquen las normas ISO, se retirará la EN1836 y la norma ISO se convertirá en la referencia para afirmar la conformidad con la Directiva EU, que permite el marcado CE y su venta en Europa.*

#### 10/ Tendencias futuras

*El acontecimiento más significativo en el futuro próximo será la publicación y la adopción de las normas ISO de gafas de sol.*

*Los países tendrán que decidir sobre la adopción de estas nuevas normas para sustituir sus normas nacionales, en donde éstas existan.*

*Si existiera una amplia aceptación de la norma ISO, esto acarrearía beneficios a los que realizan actividades comerciales transfronterizas de gafas de sol puesto que sólo será necesario respetar una norma internacional.*

*En un futuro más lejano, se espera que los requisitos de protección de UV serán más exigentes. También es de esperarse mayores requisitos de etiquetado que puedan informar mejor a los consumidores en el punto de venta sobre el nivel de protección de los productos.*

### Acknowledgements

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### *Agradecimientos*

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### *references- referencias*

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3. Europe -EN1836:2005 Sunglasses and sunglare filters for general use and filters for direct observation of the sun
4. China - GBxxxx.1 20xx Sunglasses and related eyewear – Part 1 Sunglasses for general use
5. ISO12312.1 Sunglasses and related eyewear
6. ISO12311 Test methods for sunglasses and related eyewear
7. ISO8980.3 Uncut finished spectacle lenses – transmittance specifications and test methods
8. ISO 20473:2007 Optics and photonics - Spectral bands.
9. ISO4007-2010 Eye and face protection - Vocabulary

## Risk of UV exposure with spectacle lenses

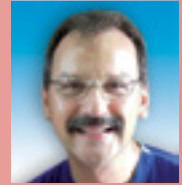
### Riesgo de exposición a los UV con las lentes de gafas



To read on / Para leer en : [www.pointsdevue.net](http://www.pointsdevue.net)

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Anti-reflection (AR) coating is an excellent spectacle lens option for increasing luminous transmission of the lens, reducing glare, and enhancing the cosmetic appearance of the wearer<sup>[4]</sup>. It is recommended for virtually all types of eyewear, including clear lenses for general, everyday use as well as nighttime driving; photochromic lenses for patients who frequently move between indoors and outdoors throughout the day; and occupational near and intermediate lenses for computer users indoors. AR coating should be applied to both lens surfaces, since it will decrease the direct and internal reflections that can occur at each surface. This will reduce glare from light sources both in front of and behind the wearer.

By the very nature of how AR coatings work, they will generally increase reflection of non-visible wavelengths, notably ultraviolet (UV) and infrared (IR)<sup>[5]</sup>. At typical levels in the natural environment, IR from sunlight gives the sensation of warmth on the skin, but poses little risk to the structures of the eye<sup>[12,4]</sup>. On the other hand, short exposure of several hours to normal UV levels, or brief exposure to high levels of UV, can cause immediate and painful problems such as sunburn to skin and keratitis<sup>[12,13,16,4]</sup>. Continued long-term exposure over months and years can cause or exacerbate conditions such as pre-mature aging of the skin, cancer, pterygium, cataract, and macular degeneration.

For an AR coating applied to the front surface of a lens, the coating provides additional protection beyond the UV-absorbing properties of the lens itself. Different AR coatings can reflect 25% or more UV, depending on wavelength<sup>[5]</sup>. By comparison, lenses with scratch-resistant coatings usually reflect no more than about 5% of any UV wavelengths, what would be expected of a typical uncoated ophthalmic material. Thus, with an AR coating on the front lens surface, harmful UV radiation now will be reflected back into the environment and away from the wearer's eye. But the same AR coating on the back surface of the lens can actually increase the amount of UV incident at the eye. In addition, this will happen under viewing conditions and times of day when the wearer is least likely to be aware of any danger.

Many patients are familiar with the risk of sunburn in mid-day hours, from about 10 AM to about 2 PM, especially during summer months. However, Sasaki et al.<sup>[15]</sup> demonstrated that most of the direct exposure

*El tratamiento antirreflejante (AR) es una excelente alternativa para las lentes de gafas ya que permite aumentar la transmisión luminosa de las lentes, reducir el deslumbramiento y mejorar la apariencia cosmética del portador<sup>[4]</sup>. Este tratamiento se recomienda para prácticamente todos tipos de gafas, incluyendo las de lentes transparentes de uso general y diario y para conducir de noche, para las lentes fotocromáticas de pacientes que circulan frecuentemente del interior al exterior durante el día; y lentes de trabajo para visión de cerca e intermedia para los usuarios de ordenadores en interiores. El tratamiento AR debería aplicarse en ambas superficies de las lentes para reducir así los reflejos directos e internos que puedan llegar a cada superficie. Esto permitirá reducir el deslumbramiento de fuentes de luz que lleguen al usuario tanto de frente como detrás del mismo.*

*Dada la naturaleza misma del funcionamiento del tratamiento AR, generalmente éste aumentará el reflejo de las longitudes de onda no visibles, particularmente los ultravioleta (UV) e infrarrojos (IR)<sup>[5]</sup>. En niveles normales en el entorno natural, los IR de la luz solar dan la sensación de calor en la piel, pero plantea poco riesgo para las estructuras del ojo<sup>[12,4]</sup>. Por otra parte, la corta exposición de varias horas a los niveles normales de UV, o exposición breve a los niveles elevados de los UV, puede causar problemas inmediatos y dolorosos en la piel como quemaduras de sol o queratitis<sup>[12,13,16,4]</sup>. La exposición continua a largo plazo durante meses y años puede ocasionar o acentuar problemas como envejecimiento prematuro de la piel, cáncer, pterigion, cataratas y degeneración macular.*

*En el caso de que se aplique un tratamiento AR en la superficie frontal de la lente, este tratamiento proporciona protección adicional más allá de las propiedades absorbentes de los UV de la lente misma. Diferentes tratamientos AR pueden reflejar el 25% o más UV, dependiendo de la longitud de onda<sup>[5]</sup>. Por comparación, las lentes con tratamientos resistentes a los arañazos habitualmente no reflejan más del 5%, aproximadamente, de cualquier longitud de onda UV, lo cual podría esperarse de un material oftálmico típico sin tratamiento. Por lo tanto, con un tratamiento AR en la superficie frontal de la lente, la radiación ultravioleta dañina va a reflejarse de vuelta hacia el medio ambiente y alejándose del ojo del portador. Pero el mismo tratamiento AR en la superficie posterior de la lente, de hecho, puede aumentar la cantidad de UV que inciden en el ojo. Además, esto sucederá en condiciones de visión y momentos del día cuando el portador tendrá una menor probabilidad de darse cuenta del peligro.*

of the eye to UV will occur mid-morning (before 10 AM) and mid-afternoon (after 2 PM) throughout the year, when the sun is lower in the sky and close to the wearer's horizontal viewing plane. The potential risk of UV exposure is present either from the front, if the lens does not adequately block UV, or from the side, if the combined lens and frame do not provide appropriate coverage of the wearer's face<sup>[16,9,14]</sup>. With the consideration of possible UV reflection from the back surface of the lens, the risk is also greatest at these hours, but now when the wearer actually faces away from the sun! A recent study demonstrates that the UV reflection risk is greatest when the wearer is about 145 degrees from the sun, that is, with sunlight coming from behind the wearer, just over his or her shoulder<sup>[6]</sup>. Figure 1 demonstrates eyewear that leaves the wearer's eye exposed from the side and from behind.

The various international standards for prescription and non-prescription lenses address UV exposure only in terms of limiting or minimizing transmission through the lens<sup>[1,2,7,10,11,3]</sup>. None of the standards address UV exposure caused by a lens that does not adequately cover the eye, thus leaving the eye exposed from the side or above.

Also, none of the standards address UV reflection from the back surface of the lens, which will depend not only on the AR coating but the size, curvature, wrap (faceform) angle, and vertex distance of the lens. This could leave the patient – and the practitioner! – with the mistaken impression that UV transmission through a finished lens is the only hazard that needs to be considered.

What can eyecare practitioners do to provide the best possible UV protection for their patients? In addition to minimizing visible wavelength reflection, the AR coating applied to the back surface of all prescription lenses intended for daytime use outdoors should minimize UV reflection, down to the wavelengths expected from sunlight in the natural environment at about 290 nm. A new index, the Eye-Sun Protection Factor (E-SPF)<sup>[6]</sup>, informs the practitioner and the wearer about the UV protection provided by such a lens. It takes into account UV transmission through the lens and UV reflection from the back surface of the lens, as well as the varying sensitivity of the cornea to different wavelengths within the UV spectrum. Technically, E-SPF can be determined empirically by measuring the UV incident at the eye first without and then with the lens in place, or it can be estimated by calculating the inverse of the sum of the UV transmittance and reflectance<sup>[6]</sup>.

E-SPF is an index similar to that used for sunscreen products (see Urbach, 2001<sup>[17]</sup>, for an excellent historical review) and ultraviolet protective clothing (see Gambichler et al., 2006<sup>[8]</sup>, for a review of the development of the European standard, EN 13758), in that a higher category value indicates greater UV protection. The category value specifies the approximate multiple units of time necessary to receive a given exposure dosage: for example, with an E-SPF 25 lens, it would take about 25 minutes to receive the equivalent total dosage as 5 minutes for an E-SPF 5 lens.



Fig. 1 / Fig. 1

*Muchos pacientes están familiarizados con el riesgo de quemaduras de sol en las horas alrededor del mediodía, desde las 10 AM hasta las 2 PM aproximadamente, especialmente durante los meses de verano. No obstante, Sasaki et al.<sup>[15]</sup> han demostrado que la mayoría de la exposición directa a los UV del ojo ocurrirán a media mañana (antes de las 10 AM) y a media tarde (después de las 2PM) a lo largo del año, cuando el sol está más bajo en el cielo y cerca del plano de visión horizontal del portador. El riesgo potencial de la exposición a los UV está presente ya sea de frente, si la lente no bloquea de manera adecuada los UV, o por los lados, si las lentes combinadas con las monturas no proporcionan la cobertura adecuada del rostro del portador<sup>[16,9,14]</sup>. Si tomamos en consideración el hecho de que se reflejen los UV desde la superficie posterior de la lente, el riesgo también es mayor en estas horas y además ¡cuando el portador está dándole la espalda al sol! Un estudio reciente demuestra que el riesgo de recibir reflejos UV es mayor cuando el portador se sitúa a 145 grados con respecto al sol, es decir, cuando la luz solar viene por detrás del portador, justo por encima de su hombro<sup>[6]</sup>. La figura 1 demuestra algunas gafas que dejan al ojo del portador expuesto lateralmente y por detrás.*

*Las diversas normas internacionales para las lentes de prescripción y las no prescritas abordan el tema de la exposición a los UV sólo en términos de limitación o reducción al mínimo de la transmisión a través de las lentes<sup>[1,2,7,10,11,3]</sup>. Ninguna de las normas abordan la exposición a los UV ocasionada por lentes que no cubren adecuadamente el ojo y, por lo tanto, dejando al ojo expuesto lateralmente o por encima de las gafas.*

*Del mismo modo, ninguna de las normas trata del reflejo de los UV desde la superficie posterior de la lente, lo cual dependerá no solamente del tratamiento antirreflejante sino del tamaño, curvatura, ángulo de envolvimiento del rostro y la distancia al vértice de la lente. Esto puede dejar al paciente -y al profesional- con la impresión errónea de que la transmisión de los UV a través de las lentes finalizadas es el único riesgo que cabe tomar en consideración.*

*¿Qué pueden hacer los profesionales del cuidado ocular para suministrar la mejor protección posible a sus pacientes contra los UV? Además de minimizar el reflejo de longitudes de onda visibles, el tratamiento antirreflejante aplicado a la superficie posterior de todas las lentes de prescripción cuya utilización es de día y en exteriores, debería minimizar la reflexión de los UV, hasta longitudes de onda correspondientes a un día soleado en un entorno natural en aproximadamente 290 nm. Un nuevo índice, el Factor de Protección Solar (E-SPF)<sup>[6]</sup>, informa al profesional y al portador sobre la protección que proporciona dicha lente. Éste toma en consideración la transmisión de los UV a través de las lentes y los UV reflejados desde la parte posterior de la lente, así como la sensibilidad variable de la córnea a diferentes longitudes de onda dentro del espectro de los UV. Técnicamente, se puede determinar empíricamente el E-SPF al medir los UV incidentes en el ojo, primero sin la lente y luego con la lente colocada, o puede estimarse calculando lo inverso de la suma de la transmitancia y reflectancia de los UV<sup>[6]</sup>.*

*El E-SPF es un índice similar al utilizado para los productos de protección solar (véase Urbach, 2001<sup>[17]</sup>, para una excelente reseña histórica) y la ropa protectora contra los ultravioleta (véase Gambichler et al., 2006<sup>[8]</sup>, para una reseña del desarrollo de la norma europea, EN*



The eyecare practitioner also should make appropriate frame recommendations to the patient, and adjustments to any dispensed eyewear, all of which derive from the proper positioning of the lens with respect to the eye<sup>[16,9,14]</sup>. This is especially relevant for over-the-counter non-prescription sun eyewear for contact lens wearers and patients who otherwise do not need a prescription. The best protection will be provided by a frame that is contoured with sufficient faceform and pantoscopic angles to fit closely to the wearer's face and head (see Fig. 2). Such a frame often requires that the lens have a steep base curve, usually 6 D or greater. This may not be possible or practical for certain prescription powers.

If the frame has a relatively flat front, or when a high faceform angle is not possible or desirable, then it should have a wide temple or sideshield. But the frame horizontal dimension should not extend significantly past the side of the wearer's face or head, even if the temple is wide. The frame vertical dimension should be large enough to fully cover the eye and extend upward to cover the brow, thus minimizing direct exposure of the eye from above. Finally, nose pads should be correctly chosen or adjusted to minimize the vertex distance.

Eyewear can be fashionable and functional. For patients who spend much of their time outdoors, it also needs to be protective. An appropriate AR coating on each lens surface, indicated by a high E-SPF value, as well as proper frame choice and fitting techniques, will contribute to the patient's long-term eye health. □



Fig. 2 / Fig. 2

13758), en la medida en la que un valor de categoría superior indica una mayor protección contra los UV. El valor de la categoría determina las unidades de tiempo aproximativas necesarias para recibir una dosis de exposición dada, por ejemplo, con una lente de E-SPF 25, serán necesarios unos 25 minutos para recibir la dosis total equivalente de 5 minutos con una lente E-SPF 5.

El profesional del cuidado ocular también debe dar las recomendaciones adecuadas al paciente sobre la montura y realizar los ajustes correspondientes a cualquier tipo de gafas prescritas, relativas al posicionamiento adecuado de las lentes con respecto al ojo<sup>[16,9,14]</sup>. Esto

es particularmente pertinente para las gafas solares sin prescripción, para los portadores de lentes y los pacientes que no necesitan una prescripción. La mejor protección será proporcionada por una montura cuyo contorno se ajusta lo suficientemente bien a la forma del rostro y con ángulos pantoscópicos para ajustarse bien al rostro y cabeza del portador (Fig. 2). Una montura de este tipo supone que la lente tenga una base con una curva pronunciada, habitualmente de 6D o superior. Esto puede no ser posible o práctico en algunas potencias prescritas. Si la montura tiene una parte frontal relativamente plana, o cuando no es posible o deseable un ángulo elevado de contorno del rostro, entonces debería tener patillas anchas o protecciones

laterales. No obstante, las dimensiones horizontales de la montura no deberían extenderse más allá de la parte lateral del rostro o cabeza del portador, incluso si las patillas son anchas. La dimensión vertical de la montura debe ser lo suficientemente grande para cubrir el ojo y extenderse hacia arriba para cubrir la ceja, por lo tanto, disminuyendo al mínimo la exposición directa del ojo desde arriba. Finalmente, se deben seleccionar cuidadosamente los soportes nasales o ajustarlos para minimizar la distancia al vértice.

Las gafas pueden ser funcionales y estar a la moda. Para aquellos pacientes que pasan una gran parte de su tiempo en el exterior, éstas también deben ser protectoras. Un tratamiento antirreflejante adecuado en la superficie de cada lente, indicado por un valor E-SPF, así como una selección adecuada de la montura y técnicas de ajuste, contribuirán a la preservación de la salud ocular del paciente a largo plazo. □

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# Crizal UV: the new anti-reflection lens that protects against UV radiation

## Crizal UV: la nueva lente anti-reflejante que protege de los UV



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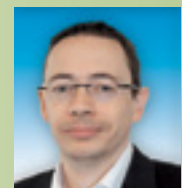
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### UV danger to the eyes

Chronic exposure of the eyes to UV radiation is a widely established<sup>1</sup> public health problem (cortical cataract, pterygium, pinguecula, eyelid cancers...), and over 40% of our exposure to UV occurs during low to moderate sunshine situations<sup>11</sup>, in which we can wear our colourless spectacle lenses comfortably. However, due to the lack of information regarding the dangers of UV radiation and in the absence of a recognised protection factor for lenses which could help in their choice, it is still rare for consumers to take protection of their eyes into consideration when purchasing lenses for their spectacles.

Indeed, the foremost expectation expressed by spectacle wearers is clarity of vision.

Therefore, to meet this requirement, anti-reflective lenses have gradually become the standard lenses offered.

What level of UV protection is really offered by the lenses which are currently on the market?

Organic materials, which absorb UV rays, offer near-complete protection against all frontal UV exposure. But recent studies<sup>2</sup> show that the UV rays arriving from the sides and back of the lens, where they are reflected strongly by the anti-reflective treatment on the inner side, can represent up to 50% of the UV exposure suffered by the eye and its surroundings.

Indeed, although the anti-reflective lenses on the market are designed to be efficient against the reflection of visible light, they reflect on average 25%<sup>121</sup> of the ultraviolet spectrum!

Crizal UV lenses were therefore created from the need to develop a new AR treatment ensuring protection for the wearer against UV light arriving on both sides of the lens!

<sup>1</sup> See the articles in this issue referring to the dangers of UV for the eye and its surroundings.

<sup>2</sup> Read the article in this issue by Karl Citek.

### El peligro de los UV para los ojos

*La exposición crónica de los ojos a la luz UV es un problema de salud pública ampliamente establecido<sup>1</sup> (catarata cortical, pterigion, pingüecula, cánceres de párpados...); además, el 40% de nuestra exposición a las UV ocurre en situaciones de insolación baja a moderada<sup>11</sup>, cuando se pueden llevar confortablemente gafas con lentes transparentes. No obstante, debido a la falta de información sobre el peligro de los UV y en ausencia de un índice de protección reconocido de las lentes que pudieran orientar las decisiones de los consumidores, éstos rara vez toman en consideración la protección ocular en la compra de las lentes de sus gafas.*

*Efectivamente, la prioridad n°1 expresada por los portadores de gafas es la claridad de la visión. Para responder a esta necesidad, las lentes anti-reflejantes se han venido imponiendo paulatinamente como un estándar.*

*¿Cuál es el verdadero nivel de protección contra los UV que aportan las lentes que encontramos en el mercado hoy?*

*Los materiales orgánicos, que absorben los UV, aportan una protección casi-completa en cualquier exposición frontal a los UV. No obstante, estudios recientes<sup>2</sup> muestran que los rayos UV que llegan por los lados y por detrás de la lente, cuya superficie interna los refleja muy fuerte, pueden representar hasta el 50% de la exposición a los UV del ojo y su contorno.*

*Efectivamente, aunque los tratamientos AR del mercado son diseñados para ser eficaces contra la reflexión de la luz visible, éstos reflejan una media del 25%<sup>121</sup> del espectro ultravioleta!.*

*Las lentes Crizal UV nacieron de la necesidad de desarrollar un nuevo tratamiento AR que permitiera asegurar una protección del portador contra la luz UV que llega de ambas caras de la lente.*

<sup>1</sup> Leer los artículos en este número que hacen referencia a los peligros de los UV para el ojo y su contorno.

<sup>2</sup> Leer el artículo de Karl Citek en este número.

## Designing the first anti-reflective lens that protects against UV Spectral considerations: The Thelen formula

The foremost function of an anti-reflective treatment is to improve the transparency of the spectacle lens, reducing reflection from both sides of the lens.

Anti-reflective lenses, as designed and made in the ophthalmic industry, are based on the laws of interference. The principle consists of alternating layers of low index and high index materials in order to create destructive interference and therefore reduce as far as possible the level of reflection for the desired spectral range. Optimisation to wavelengths close to the visible involves depositing thin layers, the thickness of which is around a few tens of nanometres.

The main parameters used to improve the efficiency of anti-reflective treatment are now well known in the business. There is a mathematical formula, defined empirically by Thelen<sup>[3]</sup>, which shows their respective impact on the average reflection level of a stack of anti-reflective layers. In this formula it appears that reflection is an exponential function of the spectral band width on which one is seeking to optimise an anti-reflective coating. This shows that it is all the more difficult to reduce average reflection because it has to be optimised across an extended spectral range.

In the case of Crizal UV, the aim is specifically to achieve reduced UV reflection whilst maintaining the optimal level of transparency that characterises Crizal, Essilor's premium range of anti-reflective lenses. To achieve this we have succeeded in identifying a limited number of groups of multi-layer stacks characterised by highly specific combinations of thicknesses of these layers. Identification of these groups of stacks has resulted in an application for an international patent.

### Geometric considerations

In addition to spectral considerations, optimisation of the performances of Crizal UV also meets considerations of a geometric or angular nature.

Figure 1 clearly illustrates that the share of light coming from behind the wearer and reflected by the rear side of the lens is contained in a solid angle of between 30° and 45°. This angular range has been defined by measurements made in experimental conditions representative of real life wearing conditions, and corresponds to the values given in scientific literature<sup>[4,5]</sup>.

In summary, Crizal UV is a multilayer anti-reflective stack whose optical performance meets a twofold requirement, spectral and angular. This product is characterised by an optimal level of visual transparency in the direction facing the wearer, typically between 0° and 30° and by minimum reflection in terms of UV light arriving on the rear surface of the lens, at an angle of between 30° and 45°.

In order to explain and demonstrate the innovation brought by Crizal UV, we have designed a new demonstrator, which has been made available to the group's various subsidiaries (see Fig 2).

## Diseño de la primera lente anti-reflejante que protege de los UV Consideraciones sobre el espectro: fórmula de Thelen

La función principal de un tratamiento antirreflejo consiste en mejorar la transparencia de las lentes de gafas, disminuyendo la reflexión en ambas caras de la lente.

Los tratamientos antirreflejo diseñados y realizados en la industria oftálmica se basan en las leyes de la óptica interferencial. El principio consiste en alternar capas de materiales de índice bajo y de índice alto con el fin de crear interferencias destructoras y, por lo tanto, bajar así al máximo el nivel de reflexión en el tramo espectral deseado. La optimización en longitudes de onda cerca de lo visible implica depositar capas finas cuyo espesor es de algunas decenas de nanómetros de magnitud.

Los parámetros principales que permiten mejorar la eficacia de un antirreflejo son actualmente bien conocidos por los profesionales del oficio. Existe una fórmula matemática determinada empíricamente por Thelen<sup>[3]</sup> y que muestra su impacto respectivo en el nivel de reflexión media de una superposición de antirreflejos. Según esta fórmula, la reflexión resulta ser una función exponencial de la longitud de banda espectral en el que se trata de optimizar un antirreflejo. Esto demuestra que es mucho más difícil disminuir la reflexión media en la medida en la que éste debe optimizarse en un tramo espectral extendido.

En el caso de Crizal UV, el objetivo es precisamente conseguir disminuir la reflexión de los UV a la vez que se mantiene el nivel de transparencia óptima que caracteriza a Crizal, la gama de lentes antirreflejos premium de Essilor. Para conseguirlo, hemos podido identificar un número limitado de familias de superposiciones multicapas caracterizadas por combinaciones muy específicas de espesores de capas finas. La identificación de estas familias de superposiciones ha dado lugar a una petición de patente internacional.

### Consideraciones geométricas

Además de consideraciones sobre el espectro, la optimización de la eficacia de Crizal UV responde también a consideraciones geométricas o angulares.

En la figura 1 se ilustra claramente la proporción de la luz que llega por detrás del portador, la que la cara interna de la lente refleja y que está contenida en un ángulo sólido entre 30° y 45°. Este tramo angular fue determinado por mediciones en condiciones experimentales representativas de las condiciones de porte en

la vida real y que corresponde a los valores que también menciona la literatura científica<sup>[4,5]</sup>.

En resumen, Crizal UV es una superposición de capas anti-reflejantes cuyas eficacias ópticas responden a una exigencia doble, espectral y angular. Este producto se caracteriza por un nivel de transparencia visual óptima en la dirección delante del portador, típicamente entre 0° y 30° y por un nivel de reflexión mínima de la luz UV que llega a la superficie de la cara interna de la lente entre 30° et 45°.

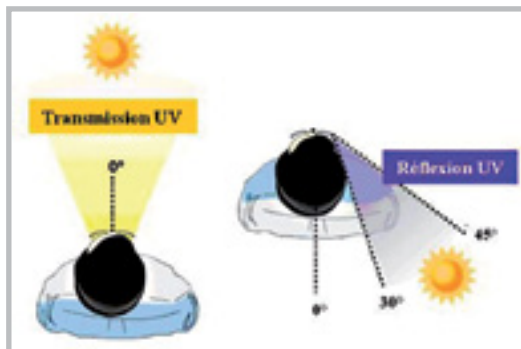


Fig. 1 Diagram illustrating, as seen from above, the share of UV radiation transmitted by the lens when the light source is opposite the wearer and the share reflected by the rear side of the lens when the source is behind the wearer.

Fig. 1 Esquema que ilustra, en una vista desde arriba, la proporción de la radiación de UV que transmite la lente cuando la fuente luminosa está delante del portador y la que refleja la cara interna de la lente cuando la fuente está por detrás del portador.

### UV reflection factor

The requirement for low UV reflection implies being able to quantify it properly, taking account of the health risks associated with UVA radiation (315 nm - 380 nm) and UVB radiation (280 nm - 315 nm) on the human eye. To do this we used the existing international standard (standard ISO 8980-3

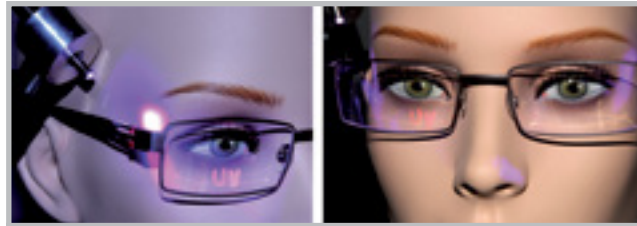


Fig. 2 Photos of the model used as a demonstrator by Essilor subsidiaries.  
Fig. 2 Fotografías del maniquí que utilizan las filiales Essilor para fines de demostración.

:2003) which proposes a calculation of the UV transmission factor applied to ophthalmic lenses. In this standard, the UV performance calculation is carried out using a weighting function  $W(\lambda)$  (Fig. 3) which depends on:

- the direct sun radiation spectrum  $ES(\lambda)$  received at the Earth's surface – small amount of UVB compared to UVA, due to absorption by the ozone layer of rays between 200 and 300 nm,
- the relative efficiency spectral function  $S(\lambda)^{61}$  or "function of UV risk", which shows that UVB is more dangerous than UVA. This latter function  $S(\lambda)$  expresses the biological risk linked to photochemical deterioration of the cornea, when it is exposed to UV.

We have therefore applied this function to evaluate reflection  $R(\lambda)$  in UV, using the formula:

This factor is used in the calculation of the E-SPF<sup>3</sup> which is used to evaluate the level of UV protection offered by ophthalmic lenses (Fig. 3).

### Characterisation of performances

The development of Crizal UV has required new characterisation methods. Firstly in the R&D phase, spectral ellipsometry and variable angle spectrophotometry, in both UV and visible, were used to characterise all materials, from the substrates to the thin layers. Measurement methods based on the same principles were adapted and deployed at production sites in order to guarantee the performance levels of this new product, from both a spectral and an angular point of view.

The UV protection provided by low level UV reflection, ( $R_{UV}$ ), from 5 to 10 times less than that measured on the anti-reflection coated lenses of the main manufacturers<sup>4</sup>, thus means an E-SPF protection factor of 25 for colourless **Crizal Forte UV** lenses, and 50+ for **Crizal Sun UV** sun lenses.

$$R_{uv} = \frac{\int_{280}^{380} R(\lambda) \cdot W(\lambda) \cdot d\lambda}{\int_{280}^{380} W(\lambda) \cdot d\lambda}$$

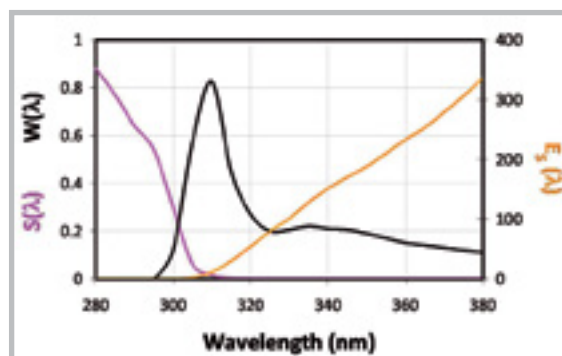


Fig. 3 Sunlight energy spectrum function  $ES(\lambda)$ [orange] in  $W.m^{-2}.nm^{-1}$  and spectral relative efficiency function  $S(\lambda)$ [pink] in arbitrary units in UV. Normalised weighting function  $W(\lambda)$ [black] ( $\times 5$ ), resulting from the product of  $ES(\lambda)$  and  $S(\lambda)$ .

Fig. 3 Función de la emitancia energética espectral solar  $ES(\lambda)$ [naranja] en  $W.m^{-2}.nm^{-1}$  y función espectral relativa de eficacia  $S(\lambda)$ [rosa] en unidad arbitraria en los UV. Función de ponderación  $W(\lambda)$ [negro] normalizada ( $\times 5$ ), producto de  $ES(\lambda)$  y de  $S(\lambda)$ .

Para explicar y concretar la innovación que Crizal UV aporta, hemos diseñado un nuevo dispositivo de demostración que ponemos a disposición de las diferentes filiales del grupo (véase la Fig 2).

### Factor de reflexión UV

La exigencia de un nivel bajo reflexión en los UV supone poder cuantificarla de manera pertinente tomando en consideración los riesgos de salud asociados a las radiaciones UVA (315 nm - 380 nm) y UVB (280 nm - 315 nm) en el ojo humano. Para ello, nos hemos apoyado en la norma internacional existente (norma ISO 8980-3 :2003) que propone un cálculo del factor de transmisión en los UV aplicado a las lentes oftálmicas. En esta norma, el cálculo de la eficacia contra los UV se realiza utilizando una función de ponderación  $W(\lambda)$  (Fig.3) que depende:

- del espectro de la radiación solar directa  $ES(\lambda)$  recibida en la superficie terrestre - pocos UVB con respecto a los UVA, debido a la absorción de la capa de ozono entre 200 y 300 nm,

- de la función espectral relativa de eficacia  $S(\lambda)^{61}$  o «función de riesgo UV» que muestra que los UVB son más peligrosos que los UVA. Esta última función  $S(\lambda)$  expresa el riesgo biológico asociado al deterioro fotoquímico de la córnea, cuando ésta está expuesta a los UV.

Por lo tanto, hemos aplicado esta función para ponderar la reflexión  $R(\lambda)$  en los UV según la fórmula siguiente:

Se utiliza este factor en el cálculo del E-SPF<sup>3</sup> que permite evaluar el nivel de protección UV de las lentes oftálmicas (Fig. 3).

### Caracterización de las eficacias

El desarrollo de Crizal UV ha requerido nuevos medios de caracterización. Primero, en la fase de I&D, la espectroelipsometría y la espectrofotometría de ángulo variable, en los UV y en lo visible, han sido útiles para caracterizar el conjunto de los materiales, desde los substratos hasta las capas finas. Se han adaptado y desplegado medios de medición basados en los mismos principios en los medios de producción con el fin de garantizar la eficacia de este nuevo producto, tanto de un punto de vista espectral que angular.

<sup>3</sup> Read the article in this issue by Karl Citek.

<sup>4</sup> Best UV protection for Crizal Forte UV lenses according to the E-SPF factor compared with colourless anti-reflective lenses in equivalent materials with the best anti-reflective properties produced by other main manufacturers on the market. Lens performance measurement only: the E-SPF factor does not include UV radiation that enters the eye directly without interaction with the lens, which depends on external factors (the wearer's morphology, frame shape, wearing conditions, ...). E-SPF measurements: independent body, USA, 2011.

<sup>3</sup> Leer el artículo de Karl Citek en este número.

<sup>4</sup> Mejor protección contra los UV en las lentes Crizal Forte UV según el índice E-SPF en comparación con las lentes anti-reflejantes transparentes, en materiales equivalentes, de los mejores anti-reflejantes de los principales fabricantes del mercado. Medición de la eficacia de las lentes únicamente: el índice E-SPF no incluye a los UV que entran directamente en el ojo sin interacción con la lente, que depende de factores externos (morfología del portador, forma de la montura, condiciones de porte...) Mediciones E-SPF: organismo independiente, Estados Unidos, 2011.

The usual optical characterisations confirm that anti-reflection efficiency remains unchanged in the visible spectrum for Crizal Forte UV lenses compared to previous generations of Crizal lenses.

#### Conclusion

Associated with organic materials, Crizal UV lenses bring to the market for the first time protection against UV radiation incident at the back of the lens, whilst ensuring optimum visual clarity for the wearer.

Crizal Forte UV colourless lenses are associated with an E-SPF protection factor of 25<sup>5</sup>, the best on the market.

In sun lenses, Crizal Sun UV offer an even higher level of protection, with an E-SPF factor of 50+.

With a complete offer available and based on an E-SPF factor that is explicit for consumers, vision professionals can convey an important prevention message and help wearers to make the right choice in terms of protection for their vision health. □

*La protección UV aportada por la baja reflexión UV ( $R_{UV}$ ), de 5 a 10 veces inferior a la medida en las lentes anti-reflejantes de los fabricantes principales<sup>4</sup>, se traduce así por un índice de protección E-SPF de 25 en las lentes transparentes **Crizal Forte UV** y 50+ en las lentes solares **Crizal Sun UV**.*

*Los métodos de caracterización óptica habituales confirman la eficacia antirreflejo sin modificación en lo visible de Crizal Forte UV con respecto a las generaciones precedentes de lentes Crizal.*

#### Conclusión

*Las lentes Crizal UV, asociadas a materiales orgánicos, aportan por la primera vez en el mercado una protección contra los rayos UV que llegan por detrás de la lente, a la vez que se garantiza una mejor claridad de visión para el portador.*

*Las lentes transparentes Crizal Forte UV contienen un índice de protección E-SPF de 25<sup>5</sup>, el mejor del mercado.*

*En las gafas de sol, Crizal Sun UV aporta un nivel de protección aún superior con un índice E-SPF de 50+.*

*Al disponer de una oferta completa y basándose en un índice E-SPF explícito para el consumidor, los profesionales de la visión pueden transmitir un mensaje importante de prevención y ayudar a los portadores a realizar la mejor decisión de protección para su salud visual. □*

<sup>5</sup> E-SPF of 10 for Essilor Orma® Crizal Forte UV lenses

<sup>5</sup> E-SPF de 10 en las lentes Essilor Orma® Crizal Forte UV

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# Maximizing Protection from Ultraviolet Radiation Hazards: Assessing the Risks; Finding Solutions

Exposure to the ultraviolet component of sunlight causes damage to ocular tissues that can accumulate over a lifetime. This chronic ultraviolet radiation (UVR) exposure has been associated with pterygium, cataract, climatic droplet keratopathy, and other serious ocular conditions. As a result, many spectacle lenses now offer effective blocking of UVR transmission. However, recent work by Karl Citek, OD, PhD, and others has found that UVR can be reflected from the backside of clear, photochromic, and tinted/polarized lenses; and that No-Glare (antireflective, or AR) technology actually increases the level of backside UVR reflection. Maximum protection from UVR requires that all lenses—including clear lenses intended primarily for indoor wear—effectively shield wearers from both transmitted and reflected UVR. This is now possible with Essilor's new Crizal UV lenses with patented Broad Spectrum Technology; these lenses maximize long-term eye health by shielding eyes from exposure to transmitted and reflected UVR.

## INTRODUCTION

Sunlight is the primary source of ultraviolet radiation (UVR) to which humans are exposed. Although a portion of the sun's UVR is absorbed by the ozone layer of the atmosphere, significant UVR penetrates the ozone to strike the surface of the earth. For most people, the total amount of UVR received (the cumulative dose) increases linearly over time.<sup>1</sup>

Documentation that cumulative sunlight exposure causes irreversible eye damage has been part of the medical literature for more than 100 years, but public awareness of the need to protect eyes from sunlight has lagged far behind. And new findings about the nature of solar UVR hazards underscore the importance of continuous UVR protection, which for eyeglass wearers is possible only if every pair incorporates effective UVR protection.

For example, we now know that a significant portion of the solar UVR incident on the cornea comes from indirect sources, including UVR striking from the side rather than the front (called "albedo") and UVR reflected by

This paper will further document that the problem of reflected UVR is not limited to sunglass wearers. Rather, studies have found that, on average, people receive over 40% of their annual UVR dose at times of day when they are unlikely to wear sunglasses; and up to 23% of people never protect their eyes from the sun at all (Table 1).<sup>2</sup> Clearly, eyeglass wearers need both their everyday glasses and their sunglass lenses to provide complete UVR protection.

## CHRONIC UVR EXPOSURE AND LONG-TERM EYE HEALTH

Although acute photokeratitis can occur from a single very high dose of UVR (eg, from skiing without eye protection) most UVR damage is cumulative—it is chronic UVR exposure and the lifetime UVR dose that are of greatest importance in UVR-associated diseases. This is as true with eyes as it is with skin, where solar UVR is known to contribute to aging and the development of cancer.

UVR that reaches the eye can cause serious damage. Epidemiologic studies have linked chronic UVR exposure

TABLE 1 Sources of UVR Exposure

Condition	Sunlight Exposure (Lx)	Percent of Annual UVR exposure
Indoor	500	~7%
Cloudy sky	5,000	5%
Clear sky	25,000	30%
Summer sky	100,000	58%
TOTAL		100%

the backside of spectacle lenses. (All types of spectacle lenses can reflect UVR, including clear, photochromic, and tinted/polarized lenses). As this paper will document, the hazard to eyes from UVR reflected by the backside of spectacle lenses is a serious problem that until now has had no solution.

with serious ocular pathology, including climatic droplet keratopathy, pterygium, cortical cataract, and pinguecula (Table 2). Although the relationship has not been definitively proved, solar UVR exposure has also been implicated in the development of age-related macular degeneration (AMD).

**UVR EXPOSURE AND THE EYE**

It was once thought that ocular UVR exposure rose and fell in parallel with the intensity of ambient UVR — as is true of skin exposure — but this is not the case. Set deep within the orbit, the eye is effectively shaded by the brow and upper lid when the sun is directly overhead. Thus, when the sun reaches its zenith at solar noon (and ambient UVR peaks), only a fraction of this radiation reaches the eye.<sup>3</sup>

Sasaki and colleagues demonstrated this relationship between solar angle and the quantity of solar radiation striking the eye by using a specially designed mannequin with UVR sensors installed on both the top of the head and within the eye socket at the position of the cornea. As expected, UVR exposure at the top of the head rose and fell with solar angle, but the in-eye sensor registered the highest levels of UVR in the mid-morning (from 8:00AM to 10:00AM) and mid-afternoon (2:00PM to 4:00PM), leading these researchers to conclude that UVR exposure in the eye peaks at times other than solar noon and suggests a need for all-day UVR protection.<sup>4</sup>

Ocular anatomy has other effects on UVR exposure. The human skull is configured to allow a large temporal field of vision. As a result, a significant amount of sunlight can strike the eye from the side. This exposure to oblique light creates a particularly significant hazard due to the peripheral light focusing (PLF) effect, also known as the Coroneo effect.<sup>5,6</sup>



Figure 1 Focused peripheral light reaches the nasal limbus.

In PLF, light incident from the side is refracted by the peripheral cornea, which focuses it on the nasal limbus where the corneal stem cells reside (Figure 1). Although the limbal stem cells are protected by the sclera from direct UVR exposure, PLF bypasses this protection and concentrates sunlight (including its UVR component)

**TABLE 2 Ophthalmic conditions associated with UVR/sun exposure**

Eyelid	Basal cell carcinoma; squamous cell carcinoma; wrinkles; sunburn; photosensitivity reactions
Ocular Surface	Pterygium; climatic droplet keratopathy; photokeratitis (“snow blindness”); pinguecula; dysplasias and malignancies of the cornea and conjunctiva
Crystalline Lens	Cortical cataract
Uvea	Melanoma; pigment dispersion; uveitis; blood/ocular barrier incompetence
Vitreous	Liquifaction
Retina	Age-related macular degeneration (not definitely proved)

at the nasal limbus, increasing exposure there as much as twenty-fold.<sup>5</sup> Epidemiologic evidence indicates that this concentrated sunlight plays a critical role in the development of pterygium.<sup>7</sup>

**BACKSIDE UVR REFLECTIONS: A NEWLY RECOGNIZED HAZARD**  
Antireflective lens technology (sometimes referred to as “No-Glare” or “AR” technology) is widely used in

**CONTRIBUTION OF LIGHT SCATTERING AND REFLECTION**

Short wavelengths of solar radiation, including UVR, are scattered by clouds and by particles in the atmosphere—this scattering of blue wavelengths makes the sky appear blue. High levels of UVR can also be reflected from surfaces such as sand, snow, water, and grass (See Table). This reflected and scattered UVR accounts for more than half of the UVR that strikes the cornea.<sup>8</sup>

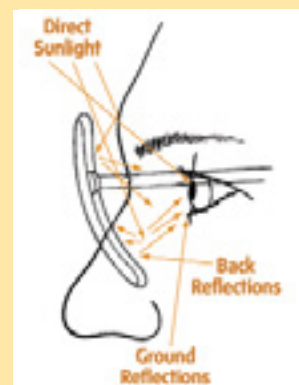
**UVR Reflectance of Different Surfaces**

Surface	UVA	UVB
Snow	94%	88%
Sand	13%	9%
Water	7%	5%
Grass	2%	2%

At times close to solar noon, when the brow and upper eyelid shield the eye from direct sunlight, scattered and reflected sunlight becomes the primary source of ocular UVR exposure. This scattered and reflected UVR can strike the eye from any direction, including directions that bypass spectacle frames and lenses (see Figure). (The exception is full-wrap sunglasses and goggles.)

If the individual is wearing glasses, a significant portion of this UVR can be reflected directly into the eye by the backside of the lenses. This is true whether the lenses are clear, photochromic, or tinted/polarized.

Depending on the geometry of the lens, the frame, and environmental conditions, up to 50% of UVR exposure comes from the back and sides of the lens. Thus, even if the lens is capable of blocking 100% of UVR transmission, the eye can still receive a substantial dose of UVR due to side and back exposure. This light scattering (which enables UVR to come at the eye from the side and behind) and reflection from the backside of spectacle lenses must be taken into account in any consideration of UVR protection.



UVR can still reach the cornea, even if the patient is wearing a UVR-blocking lens.

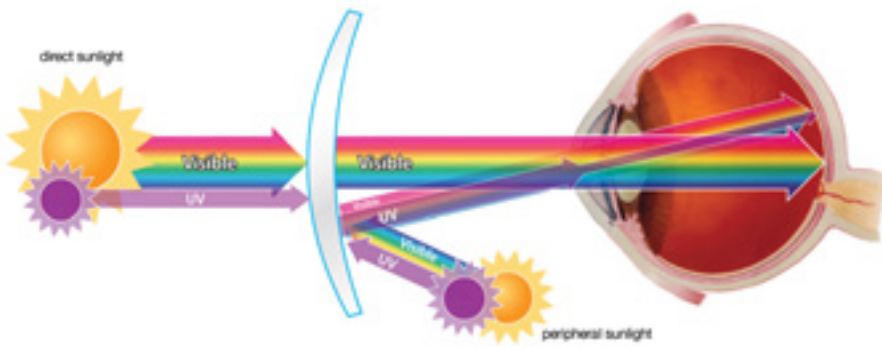


Figure 2 Antireflective lenses that are not Crizal® UV reflect UVR off the backside, so significant UVR can strike the cornea (even if the lens protects against transmitted UVR). Today, only Crizal® UV lenses (Crizal Forte® UV, Optifog™ with Crizal® UV, Crizal Sun™ UV, Optifog Sun™ with Crizal® UV) protect against reflected UVR.

spectacle lenses to enhance the cosmetic and optical performance of the lens by increasing light transmission and eliminating visible reflections and glare. Unexpectedly, Antireflective treatments have recently been found to increase the reflectance of UVR. While clear lenses without antireflective treatment reflect approximately 4% to 6% of UVA (380-315 nm) and UVB (315-280 nm), antireflective lenses reflect an average of 25% of most UVR wavelengths.<sup>9</sup> And

some AR lenses reflect close to 90% of individual UVR wavelengths.<sup>9</sup>

This high level of UVR reflectance makes scattered and reflected UVR a particular concern since they can strike the back surface of a spectacle lens and be reflected into the eye (Figure 2). UVR reflected by the backside of a lens can enter through the central cornea. It can also reach the temporal limbus and do harm through the PLF mechanism.

Heretofore, backside reflection could

be prevented only by goggles or high-wrap frame designs that allow little or no light to strike the back surface of the lens. Current photochromic, sun lenses, and clear lenses do not address this particular hazard. Some clear lenses (eg, those made from polycarbonate) and all photochromic lenses block transmission of 100% of UVR that is directly incident on the front of the lens; materials that do not inherently absorb UVR can be treated to block UVR transmission. However, the backside reflection of UVR remains the Achilles heel of UVR protection and safer vision.

**NEW CRIZAL® UV LENSES ELIMINATE BACKSIDE UVR REFLECTION**

To address the significant hazard of backside UVR reflection, Essilor has developed new Broad Spectrum Technology that extends the superior Crizal® antireflective lens efficacy from the visible light spectrum to the ultraviolet spectrum (Figure 3). Essilor's new Crizal Forte® UV and Optifog™ with Crizal® UV lenses are the first to feature this new technology for clear, everyday lenses, in which UVA and UVB reflections from the backside of the lens are reduced — without loss of the other benefits of Crizal® AR lenses. This means that Crizal® UV lenses not only maximize visible light transmission for enhanced visual clarity, they also provide protection from reflected UVR — in addition to resisting and repelling scratches, smudges, dust, and water (Table 3).

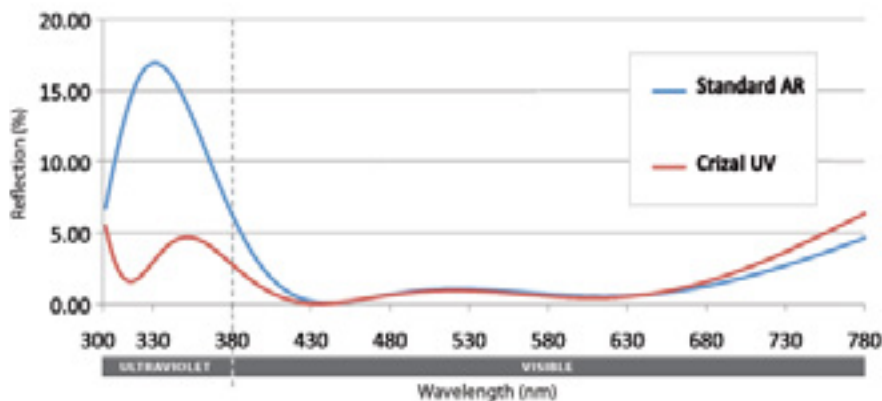


Figure 3 Crizal® UV extends effective blocking of UVR reflections deep into the UVR spectrum, while within the visible light spectrum Standard AR and Crizal UV provide virtually identical reflection blocking.

**PUTTING UVR IN PERSPECTIVE**

Long-term exposure to solar UVR causes cumulative damage to ocular tissues that can harm eye health. Environmental factors like depletion of the ozone layer will increase levels of UVR on the surface of the earth for decades to come, and prevention of UVR-associated eye diseases will become correspondingly more important.

Recent studies show that reflection of UVR from the backside of spectacle lenses represents a significant source of ocular UVR exposure. Other investigations have found that peak times of ocular UVR exposure are mid-morning and mid-afternoon — times when indi-

TABLE 3 Benefits of new Crizal® UV and Crizal Sun™ UV (designed specially for sunwear)	
Superior visual clarity	Glare reduction
	Improved contrast sensitivity and visual acuity
	Resists scratches and smudges
	Repels dust and water
	Easy cleanability
Maximum UV protection	Blocks transmission of UVR (100%) through the lens*
	Reduces backside UVR reflection
*when paired with a photochromic or higher-quality lens material.	



## THE EYE-SUN PROTECTION FACTOR



People purchasing sunscreens know exactly how much UVR protection they are getting because sunscreens all carry a number on the label. This provides a precise indication of the sun-blocking strength of a given sunscreen and makes it easy to compare one sunscreen with another. Although UVR protection is as critically important to eyes as it is to skin, until now nothing like that has existed to indicate the UVR protection offered by specific spectacle lenses.

With this in mind, Essilor has worked with independent experts to develop the Eye-Sun Protection Factor (E-SPF). Defined as the ratio of UVR at the cornea with and without lenses in place, E-SPF measures the amount of protection provided by a lens as compared to no protection at all. (The ratio is weighted to take in consideration the impact of UVR at different wavelengths on the cornea.)

Calculation of E-SPF takes into account both transmission of UVR through the lens and backside UVR reflection. By integrating these two aspects of UVR protection, E-SPF provides a readily understandable measure of the UVR protection offered by a given lens. As with the reference index of the skincare industry, higher values of E-SPF indicate better UVR protection. For example, new Crizal® UV lenses, with minimal backside UVR reflectance, have higher E-SPF values than competitive antireflective lenses (see Table).

Perhaps the most important aspect of the E-SPF is that it gives eyecare professionals a simple way to tell patients how they can maximize protection—without lengthy, complex explanations or recommending specific products. Now telling patients how to protect their eyes is as straightforward as telling them how to protect their skin. Pick the highest number for the best protection. It's that simple.

E-SPF of different AR Lenses	
Main AR Lenses	E-SPF
Crizal Sun UV Optifog Sun with Crizal UV	50+
Crizal Forte UV Optifog with Crizal UV	25
Competitor A	3
Competitor B	5
Competitor C	5

tients receive the most protection with the highest E-SPF (see box). Choosing the most complete eye protection becomes as simple as choosing a sunscreen: just look at the numbers.

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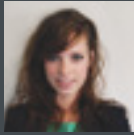
viduals are not likely to wear sunglasses. Hence, to achieve the goal of minimizing ocular UVR exposure, spectacle-wearing patients should be well protected in every pair of glasses they have, whether the lenses are clear, photochromic, or tinted/polarized.

Today's higher quality lens materials provide 100% blocking of UVR transmission, but the AR technology on the back surface of a lens can reflect unexpectedly high levels of UVR and significantly increase the eyes' dose of UVR. The most complete solution for everyday UVR protection, thus, is lenses that protect against both UVR transmission and reflection.

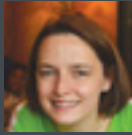
This is now possible for clear, everyday lenses with the patented Broad Spectrum Technology in Essilor's Crizal Forte® UV and Optifog™ with Crizal® UV lenses; and for sunwear with Crizal Sun® UV and Optifog Sun™ with Crizal UV. These lenses reduce backside UVR reflection to offer the most complete protection possible against ocular UVR exposure.

One of the reasons that eye protection from UVR has lagged behind skin protection has been the lack of an easy way for eyecare professionals to talk about it. The new Eye-Sun Protection Factor (E-SPF) takes care of this problem. Now, ECPs can explain that pa-

# CRIZAL® PREVENCIA™ : THE FIRST PREVENTIVE NON-TINTED LENSES FOR EVERYDAY WEAR WITH PROTECTION FROM UV RAYS AND HARMFUL BLUE LIGHT



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## \_\_ WE ARE LIVING BETTER AND FOR LONGER

We gain an extra three months life expectancy every year, around 6 hours per day.... one in every two little girls born today in France will reach the age of one hundred. Progress in the health field, although unequally distributed throughout the regions of the world, means overall that we are living better and for longer. But what about ocular health? Is the human eye prepared for working in good health for over 100 years?

## \_\_ THE PREVENTION OF EYE DISEASES IS A MAJOR PUBLIC HEALTH CHALLENGE

With the increase in life expectancy, some eye diseases and afflictions such as cataract or age-related macular degeneration (AMD) are unquestionably rapidly on the increase. Today the number of people affected by cataract is estimated at 250 million worldwide, with 100 million suffering from AMD, and these figures are set to double over the next 30 years *Fig. 1* Within this context, the importance of preventing eye diseases becomes clear and the main objective is to minimise the risk of diseases occurring by taking direct action on the causes. (*Fig. 1*)

## \_\_ UV AND HARMFUL BLUE LIGHT ARE INVOLVED, AMONGST OTHER CAUSES, IN THE APPEARANCE OF CATARACT AND AMD

Age, tobacco smoking, diet and environmental factors such as prolonged exposure to ultraviolet rays are extensively noted in scientific literature as being risk factors in the occurrence of senile cataract. In addition to UV, visible light can also have a cumulative impact on ocular health and particularly play a part in the development of AMD. In fact, in addition to age, genetic factors or tobacco smoking, several epidemiological studies, including the „Beaver Dam Eye Study“ and the „Chesapeake Bay Study“ conclude that the risk of AMD is greater in case of cumulative exposure to visible blue light <sup>[3]</sup>.

And yet, within blue light, which is in wavelengths of between 380 and 500 nanometres (nm), it is important to distinguish the *BAD* blue from the *GOOD* blue <sup>[4]</sup>. The combined work of the Essilor International and the Vision Institute recently resulted in definition of the precise spectrum of retinal phototoxicity <sup>[5]</sup> and concluded that it is Blue-violet light, which is the closest to UV and centred at 435nm, which is the most harmful for the retina. This „bad blue“ can be of solar or artificial origin. Several independent studies undertaken by health agencies are

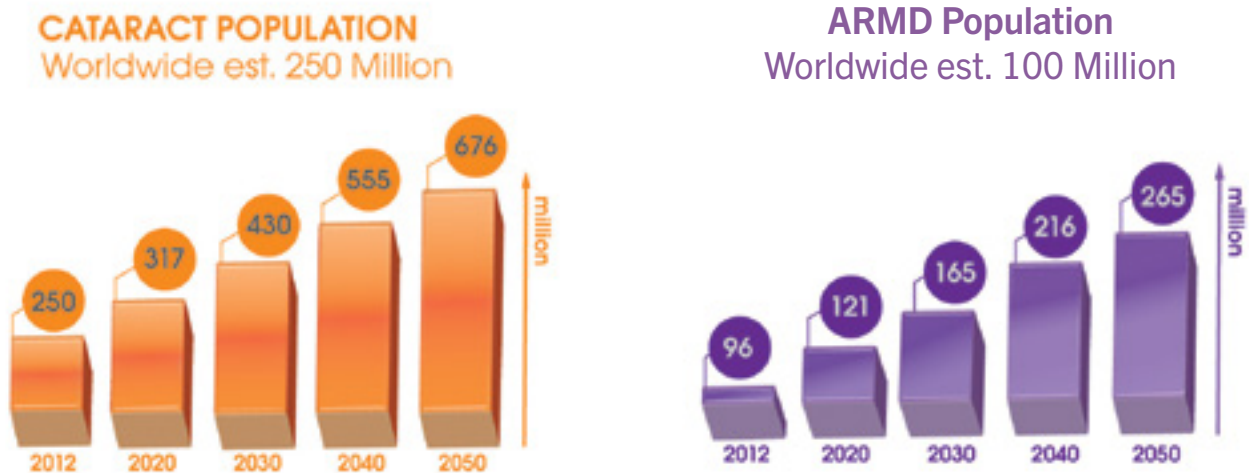


FIG. 1 | An extrapolation of the prevalence of cataract and AMD (known epidemiological studies carried out in developed countries) in world population (UN World Population Prospects, 2013-2050). This projection does not take into account any progress that may be made in the health field, prevention or therapy, or genetic, environmental or other differences between the various regions. (Source: Simplified Extrapolation model, Essilor International, DMS, EL, Jan. 2013).

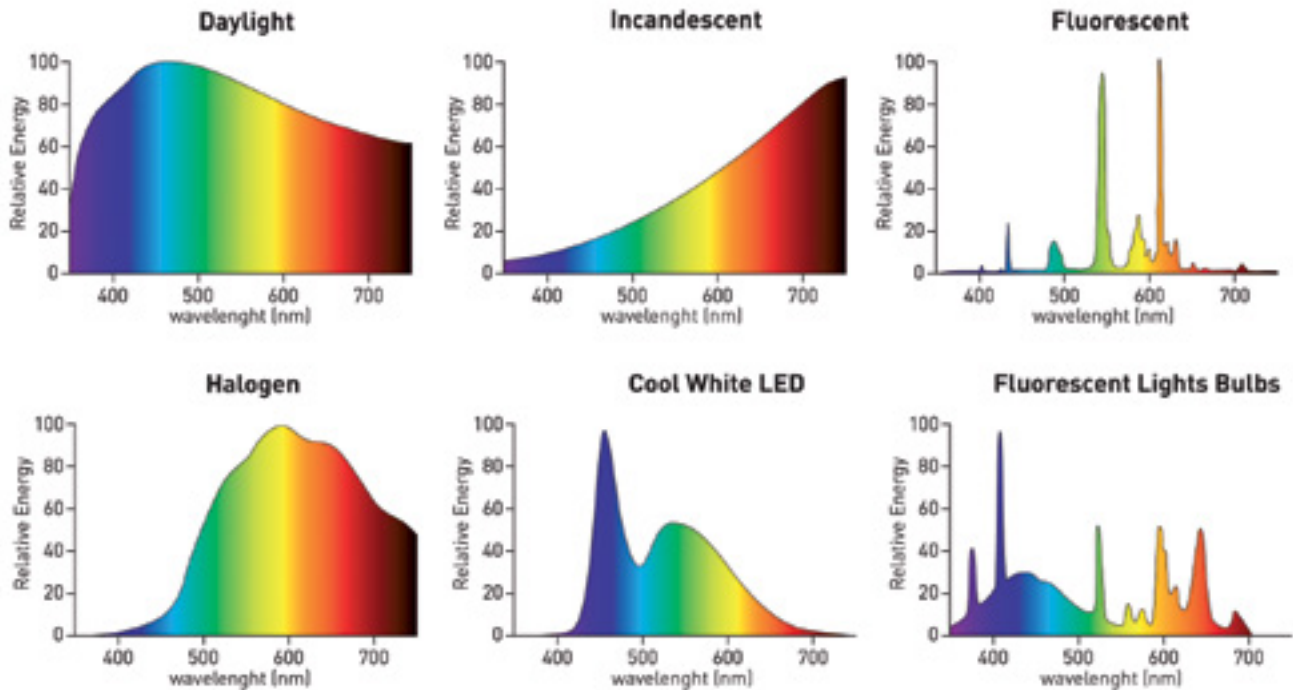


FIG. 2 | Emission spectrums of various light sources.

now looking at the risks linked to new sources of artificial light, such as electroluminescent diodes or LED [6], because the latter have an emission peak situated in the „bad blue“ range (Fig. 2).

On the other hand, Blue-Turquoise light, at wavelengths of between 465 and 495 nanometres (nm) is known as the „good blue“ because it acts on many non-visual functions that are essential for the body to function well [7].

Research programmes aimed at discovering new solutions to prevent or treat AMD must take account of this distinction between good and bad blue and attack harmful rays in a selective manner.

**SELECTIVE PHOTO-PROTECTION USING INTERFERENTIAL FILTERS**

Various products offer protection against Blue-Violet light, such as therapeutic filters and sun lenses. Although the protection level is high, their colour can be an obstacle to permanent everyday wear (distortion of colours, appearance, vision in low indoor light) and also they necessarily cut out both bad and good blue light, making no selection between the two.

In order to offer selective photo-protection and a high degree of visual comfort for everyday wear, the use of interferential filter technology would seem to be the ideal solution for a clear lens. It cuts out the Blue-Violet light that is harmful for the retina, whilst maintaining optimal transmission of the Blue-Turquoise light in the neighbouring spectral band.

Twenty years of expertise in anti-reflective treatments and two years of research have enabled Essilor to achieve the design of the Crizal® Previncia™ lens, an interferential filter that reflects light in order to:

**1. Filter out harmful rays, the Blue-Violet that contributes to AMD as well as UV rays which play a part in the appearance of cataract**

The various anti-reflective coatings on both sides of the Crizal® Previncia™ lens filter out harmful light selectively:

- 20% of Blue-Violet light, [400-450 nm], is cut out thanks to optimised reflection of these wavelengths on the front side. The residual

colour of the reflection proves its efficiency in the Blue-Violet range.

- On the back side, the interferential layers have been created to minimise the reflection of UV rays into the eye.

This unique combination today offers the most complete eye protection available in a clear lens.

**2. Allow beneficial blue light to pass through** Crizal® Previncia™ transmits 96% of Blue-Turquoise light, [465-495 nm], thus preserving visual functions as well as some non-visual functions such as:

- stimulation of the pupil reflex, the retina's natural protection against over-exposure to light, centred at 480 nm,
- synchronisation of the biological clock (waking/sleep cycles, hormonal cycles, memory, cognitive performance, etc.) centred on a 30 nm bandwidth, [465-495 nm].

**3. Whilst guaranteeing excellent lens transparency** Crizal® Previncia™ ensures optimal vision clarity with overall visual transmission of 98%. This lens also retains the benefits offered by former generations of the Crizal range: the most efficient dirt-resistance on the market as well as excellent resistance to scratching, dust and water. (Fig.3)

**CRIZAL® PREVICIA™, EFFICIENCY PROVEN IN VITRO.**

Essilor and the Vision Institute carried out an experiment on the retinal pigmentary epithelium (RPE) cells involved in the macular degeneration process, in order to model the protection offered by the Crizal® Previncia™ lens.

These retinal cells were photosensitized and exposed for 18 hours to narrow 10 nm bands of illumination in the blue light spectrum range between 400 nm and 500 nm, in the physiological conditions of sunlight on the retina. Photobiological work showed an average reduction in cell mortality by apoptosis of 25% compared to the naked eye in the spectrum range [400 nm, 450 nm]. Figure 4 shows the comparative levels of apoptosis between the naked eye (grey) and Crizal® Previncia™ (purple) for each of the bands of blue illumination. This level of protection would therefore mean a reduction in the long term in the cumulative risk linked to harmful blue light and therefore the onset of AMD.

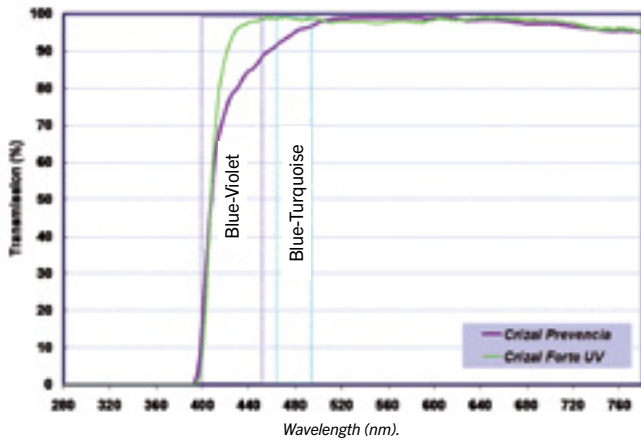


FIG. 3 | Illustration of the protection offered by the Crizal Previncia lens on both the front and back.

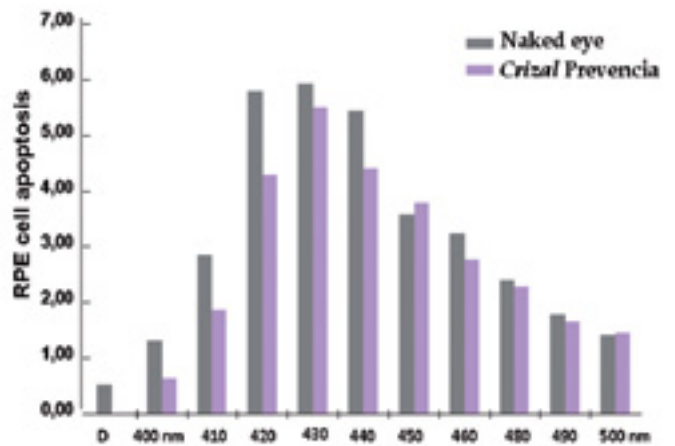


FIG. 4 | Comparative results between Crizal Previncia and the naked eye of RPE cell death by apoptosis, exposed for 18 hours in vitro to normalised sunlight for a 40 year old human eye.

→ **The combination of the UV barrier** provided by the material and the anti-reflective coatings on the back side of the lens offered 25 times more protection against UV rays, compared to the naked eye (E-SPF 25).

— **CRIZAL® PREVENCIATM, THE EVERYDAY PREVENTION SOLUTION**

The new Crizal® Previncia™ lens therefore reduces the damaging, cumulative effects of harmful lights (Blue-Violet and UV).


**This preventive lens is for everyone**, and specifically for more particularly vulnerable populations such as children and adults aged over 45.

- Before the age of 10, the eye's extreme transparency allows bands of harmful light to penetrate more deeply. The retinal cells are therefore more highly exposed to UV rays and Blue-Violet light.
- After the age of 45, the eye's defence system weakens and the sensitivity of retinal cells increases. This means that the risk of eye disease increases.

**Crizal® Previncia™ can** also be combined with a photochromic technology used to obtain optimal protection for outdoor activities whilst offering the desired transparency for indoor wear.

- When the lens is clear protection against Blue-Violet light is reinforced thanks to additional absorption by the photochromic pigments.

- When activated the photochromic lens is tinted and protection is then at its maximum, at over 80% whatever the material used.

**Crizal® Previncia™ is the ideal** preventive solution against the dangers of harmful light, which are still relatively unknown amongst the general public. The role of vision professionals and Essilor is therefore key in creating awareness and recommending this product. 

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# PROTECT CHILDREN'S EYES EVERY DAY: CRIZAL® PREVENENCIA® FOR KIDS

Annual exposure to solar radiation is three times higher in children than adults. Moreover, because of their physiology, children's eyes are more vulnerable and require special protection against UV rays and blue-violet light. Designed for children as well as adults, the new Crizal® Prevenencia® lenses are completely transparent, providing optimal photo-protection from day to day. The use of sunglasses will ensure additional protection in direct sunlight.



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Luc Bouvier is a French engineer and a graduate of ESSTIN (Nancy, France). He joined Essilor International in 1998 in the R&D department. Luc has 16 years of experience in ophthalmic optics, and has managed global projects and key innovations centred on interferential thin film technology. For the last 5 years, Luc has been in charge of new product launches, and in particular the photo-protective Crizal® lenses designed to prevent UV and Blue Light hazards.

**KEYWORDS**

prevention, eye phototoxicity, UV radiation, blue light, Crizal® Prevenencia®, juniors, children

**T**he harmful effects of chronic exposure to ultraviolet radiation and the blue-violet component of visible light are now clearly established as factors in the development of ocular diseases such as cataracts and AMD.<sup>1</sup> The cumulative effect of this exposure over a lifetime contributes to accelerating onset of these serious conditions. And this process begins in early childhood: children are doubly exposed to the risks posed by these harmful light rays.

**The primary risk factor in children: overexposure**

To begin with, children spend three times longer outdoors than adults, which increases their exposure to the most powerful source of UV rays and blue light: the sun. LED screens (tablets, smartphones, computers, etc.), which are new sources of blue-violet light, intensify this exposure further, as children come to use them more and more frequently and at a signifi-

cantly earlier age. In the UK, the use of tablets at home among children aged 5 to 15 trebled between 2012 and 2013 (from 14% to 42%). One quarter (28%) of three- and four-year-olds use a tablet at home.<sup>2</sup> Nearly 20% of French children aged 7 to 12 were using a tablet in 2013<sup>3</sup> – a figure three times higher than in 2012 (Fig 1).

All these devices are undeniably tools for enhancing cognitive development, improving awareness and teaching children to master the digital world. However, they can also foster an addiction to virtual environments and lead to difficulty sleeping. Their use needs to be limited and supervised through parental controls on the content and length of each child's daily use. The growing number of screens that are backlit with cool white LEDs, which are known to generate potentially harmful blue-violet light, may increase the risk of chronic photo-toxicity over time.

**An additional risk factor in children: the permeability of the visual system**

In early childhood, the crystalline lens is much more permeable to harmful UV and blue-violet rays, a significant portion of which can reach the retina (Fig. 2). Retinal exposure to UV radiation may lead to rapid growth in the concentration of lipofuscin during the early years of life<sup>4</sup> (Fig. 3); lipofuscin can subsequently prove toxic to the retina when subjected to blue-violet light.

**The importance of risk prevention and education**

It seems appropriate, then, to create solutions for preventing this risk and protecting children from a very young age. The parallel with skin should serve as a warning: according to the WHO, excessive exposure to the sun

in childhood can contribute to skin cancer later in life.<sup>5</sup> Although there is growing knowledge of the need to protect children's skin from the sun, and a wider range of specially designed protective sun cream (SPF 50+) is available for their use, the same cannot be said for eye protection in children.

Adults, however, protect themselves better than their children: a U.S. study showed that just 48.4% of the parents surveyed use sunglasses to

protect their children's eyes.<sup>6</sup> A separate study in France revealed that 84% of parents own at least one pair of sunglasses, compared to 68% for their children.<sup>7</sup> But even among children who have sunglasses, the nuisance of using them means they are worn far less often than circumstances require. You need merely visit the beach in summertime to discover that the number of children wearing sunglasses remains quite small.

FIG. 1 | The spread of personal devices among children (ages 7 to 12) and teenagers (ages 13 to 19) in France (Source: Ipsos).

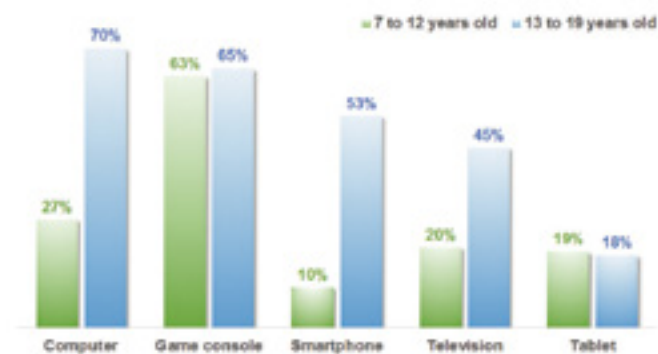


FIG. 2 | Total transmittance of clear ocular media of aging human eye. Fitted from the CIE 203:2012 data. Does not take into account cataract surgery beyond 60 years old.

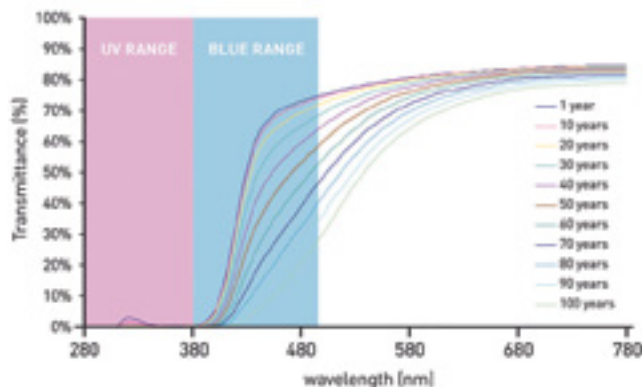
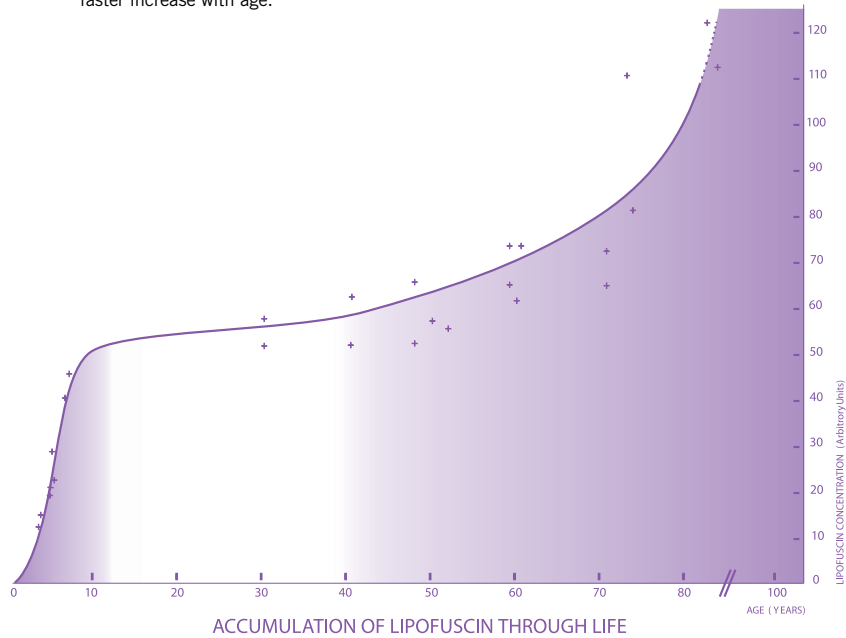


FIG. 3 | Rapid increase in lipofuscin concentration between the ages of 0 and 10.

Source: Adapted from (Wing et al., IOVS, 1978), ex vivo, in the total RPE.  
For the vivo, at fovea and 7° temporal to the fovea, see (Delori et al., IOVS, 2001), faster increase with age.



**“Crizal® Prevencia® Kids is a daily-wear lens that is especially tailored to the needs of children.”**

**Crizal® Prevencia® Kids: the solution offering everyday protection for children**

For children who already wear corrective lenses, there are increasingly effective solutions for daily protection.

Up until recently, the only consistent way to filter out both blue light and UV rays was to wear tinted filters (yellow, orange) inside and/or sun lenses outside. This solution already represents a

significant burden for older patients; the idea that this approach could be used with children on a daily basis, purely for protection, is unthinkable.

Moreover, these filters completely eliminate blue light, distorting our color perception and potentially depriving the eye of the benefits of the blue-turquoise component of the visible spectrum (465-495 nm), which regulates our biological clock and in particular our waking and sleeping phases. It was in response to this need for a simple and effective form

of prevention that Crizal® Prevencia® lenses were designed, for use by both adults and children.

These antireflective lenses come with a new interferential filter that provides selective protection (Fig. 4).

Harmful light rays are filtered so as to reduce the effects of UV rays and blue-violet light (415-455 nm) on the crystalline lens and retina.

The blue light that is beneficial to our bodies is maintained. Crizal® Prevencia® allows 96% of blue-turquoise light to pass through. The lens offers guaranteed transparency, with transmission of more than 98% of visible light to ensure optimal vision.

**Proven *in vitro* effectiveness**

Crizal® Prevencia® lenses mark the culmination of lengthy research conducted in cooperation with Paris Vision Institute (IDV), considered one of Europe’s premier integrated research centres specializing in eye disease. To demonstrate the efficacy of these lenses in protecting retinal cells, the IDV conducted an *in vitro*

experiment which revealed that in retinal pigment epithelium cells protected from blue-violet light by Crizal® Previncia®'s interferential filters, the rate of cell death through apoptosis fell by up to 25% in comparison with unprotected cells.<sup>1, 10</sup>

The most visible proof of the protection offered by Crizal® Previncia® lenses is the color of the residual reflection produced by its filter: blue-violet (Fig. 6). When the lenses are exposed to the harmful component of blue light, these rays are partially reflected, and that distinctive reflection – which can be shown to future wearers when they purchase the lens – is a reliable indicator that the eye is being protected.

**Certified UV protection (E-SPF™ 25)**

When it comes to protection against UV rays, Crizal® Previncia® Kids lenses offer the same level of protection as all the other untinted lenses in the Crizal® range, certified by an E-SPF® (Eye-Sun Protection Factor) of 25. Coupled with the Airwear® material that prevents any UV light rays from passing through, Crizal® Previncia® lenses include a filter on their inner surface that virtually eliminates UV reflection into the eye.

**“Children spend three times longer outdoors than adults, which increases their exposure to the most powerful source of UV rays and blue light: the sun.”**

FIG. 4 | The selective protection offered by Crizal® Previncia®. Harmful forms of light (UV, 400-450 nm blue-violet light) are filtered out, while the useful and beneficial portion of the spectrum is preserved virtually in its entirety.

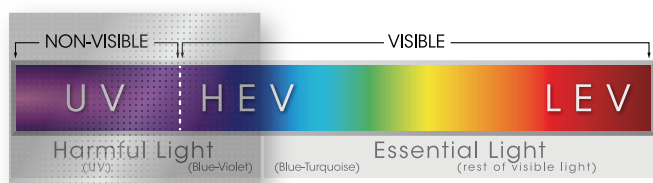
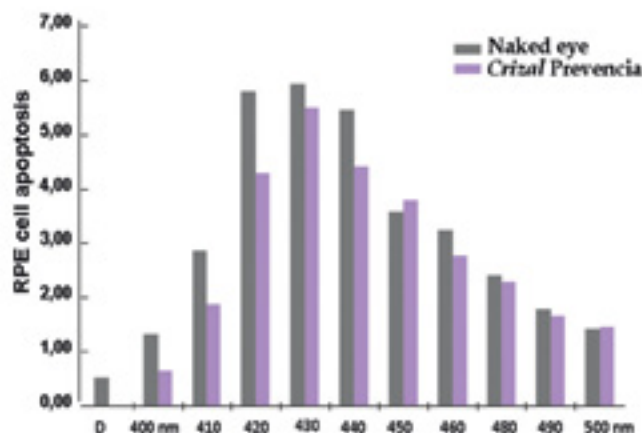


FIG. 5 | Comparative results between Crizal® Previncia® and the naked eye of RPE cell death by apoptosis, exposed for 18 hours *in vitro* to normalized sunlight for a 40 year old human eye.





This UV exposure from the rear of the lens can be quite significant, accounting for up to half of all UV exposure for unprotected eyes.<sup>8</sup> Before the introduction of the most recent Crizal<sup>®</sup> lenses, anti-reflective lenses on the market still reflected a substantial amount of UV radiation.<sup>9</sup>

The E-SPF<sup>®</sup> index, developed by Essilor, is the only international rating that measures the protection offered by a given lens on both its outer surface (for light transmission) and its inner surface (for reflection back into

the eye). A factor of 25, currently the highest on the market for an untinted lens, indicates that the eye receives 25 times greater protection than it would otherwise (the sun lens offers an E-SPF<sup>®</sup> of 50+). The E-SPF<sup>®</sup> index gives eye care professionals a standard they can use with children who wear lenses and their parents, who are already familiar with the SPF index used for sun creams.

**A lens designed for children**

In order to provide greater overall protection against harmful light rays, Crizal<sup>®</sup> Previncia<sup>®</sup> Kids is a daily-wear lens that is especially tailored to the needs of children. Its effective anti-reflective treatment ensures perfect transparency, which means

**“In early childhood, the crystalline lens is much more permeable to harmful UV and blue-violet rays, a significant portion of which can reach the retina.”**

FIG. 6 | Crizal<sup>®</sup> Previncia<sup>®</sup> lenses have an unobtrusive residual blue-violet reflection that provides proof of effectiveness

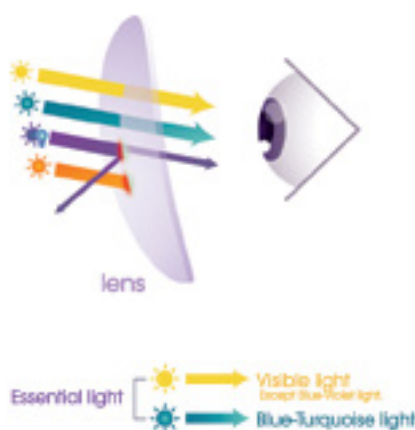


Crizal<sup>®</sup> PREVENCIA

FIG. 7 | The selective light protection of Crizal® Prevencia® on front and back sides.

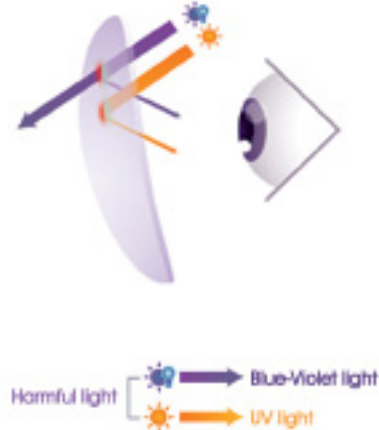
**Front side protection**

Cut 20%<sup>(1)</sup> blue-violet light and 100%<sup>(2)</sup> UV



**Back side protection**

Backside reflection virtually eliminated (≈ 4%)



(1) The blue-violet light cut may slightly differ depending on lens material.  
 (2) For any Crizal® Prevencia® lens material other than clear 1.5 plastic.

vision quality and comfort, notably for classroom learning and when viewing a screen.

When used with Airwear® material, Crizal® Prevencia® lenses are the most shock-resistant on the market, 12 times more resistant than standard lenses – which will reassure parents of even the most daredevil children. They also have the advantage of being 30% lighter and 20% slimmer to suit fragile noses, so children are more likely to accept them. In addition, Crizal® Prevencia® lenses are treated to provide maximum resistance to two things much feared by parents: scratches and smudges. These lenses – easier to clean than any other lens on the market – are ideal for children whose lenses quickly become dirty.

**Conclusion**

We need to take steps as early as possible to protect eye health and prevent the risks posed by the harmful effects of UV rays and blue-violet light, because young children are especially vulnerable to the damage they can do. All children’s eyes need to be protected in the outdoors with appropriate equipment that provides good coverage against the sun when sunlight is strongest, alongside the proper precautions for protecting their skin: sun cream, a wide-brimmed hat, avoiding exposure when the sun is at its most intense.

For children who wear eyeglasses at all times, vision health professionals can now recommend the kids’ version of Crizal® Prevencia® lenses.

**CORRECTIVE LENSES TO PROTECT AGAINST UV**



**CLEAR LENSES**

For everyday protection against the cumulative effects of exposure to UV rays, lenses with protection factor E-SPF™ 25 offer the highest level of protection available for clear lenses. Crizal® lenses were the first in this category to offer this level of protection. They are available in an extensive range for all wearers, both children and adults (Crizal® Kids UV, Crizal® Prevencia®, Crizal Forte® UV, Crizal® Alizé® UV, Crizal Easy® UV). Associated with materials that absorb UV, Crizal® lenses benefit from technology that considerably reduces the eye’s exposure to UV due to reflection from the inner side of the lens.



**CORRECTIVE SUN LENSES**

For optimal protection from the sun, Crizal Sun® UV lenses have protection factor E-SPF™ 50+. They offer the essential level of protection when conditions demand the wearing of sun lenses (strong sunlight, altitude, beach, etc). Crizal Sun® UV can be associated with tinted lenses or Xperio® polarizing lenses.

They are clear, completely transparent lenses that provide maximum protection against harmful UV and blue-violet rays, both outdoors and in the presence of harmful light from new sources such as LED screens. They also include all the necessary features for meeting the special needs

of children and helping them learn to live with their eyeglasses at all times: clear and comfortable vision; thin, lightweight equipment; lenses that are easy for parents to maintain and that hold up better against the rough and tumble life that children sometimes lead. •



**AWARDS / HONORS / SUCCESSES**

**Crizal® Previncia® lenses received numerous honors worldwide in 2014:**

- in Canada: they were voted “Product of the Year” (the most innovative product of 2014 in the Optics category) by a panel of experts and consumers
- in France: Essilor’s R&D team accepted

an award for technological innovation – the “Prix Fibre Innovation 2014” – given to Crizal® Previncia® lenses at a daylong event hosted by Opticsvalley, an optics trade group, at the Université Pierre-et-Marie-Curie in Paris

- in Australia: the entire range of Crizal®

UV treatments won certification from Cancer Council Australia, an organization that is unmatched worldwide for its experience in preventing risks from UV radiation. This is the first seal of approval of its kind for an interferential treatment in the history of ophthalmic optics



**KEY TAKEAWAYS**

- Crizal® Previncia® lenses for kids are an effective form of protection for children who wear glasses every day.
- Equipped with an interferential filter, Crizal® Previncia® lenses provide selective photo-protection:
  - > Harmful UV and blue-violet (415-455 nm) light rays are filtered out to protect the crystalline lens and retina.
  - > Essential light, including 96% of blue-turquoise light (465-495 nm), passes through the lens.
  - > The transparency of the lens is guaranteed, and more than 98% of the visible spectrum can pass through.
- The efficacy of Crizal® Previncia® lenses has been proven by *in vitro* photobiology testing that revealed a 25% reduction in cell death (via apoptosis) among cells of the retinal pigment epithelium.


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# SCIENTIFIC QUEST FOR PERSONALIZED RISK PREVENTION


Light is suspected of being a risk factor for major vision-threatening diseases. Yet an equal light exposure can unequally affect people. Multiple intricate factors are responsible for a distinct personal risk profile. The scientific quest in understanding both eye phototoxicity and individual risk profiles can set a turning point towards personalized prevention in the future.



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Coralie joined Essilor in 2011, after a physics/optics engineer degree from Institut d'Optique Graduate School ParisTech and two Master degrees with honours from Paris XI in fundamental physics and in optics for new technologies. Her research is centred on photobiology of the eye, photometry and interferential physics for new ophthalmic healthcare lenses.



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As Vice President R&D Disruptive at Essilor, Denis cultivates innovations, covering many technical domains and leveraging academic partnerships. With a Master in Quantum Mechanics from Ecole Normale Supérieure and an MBA from INSEAD, after ten years' experience with BCG, Denis joined Essilor ten years ago.



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Thierry joined Essilor in 2007 to develop biomedical collaborative research, especially with Paris vision Institute: photobiology, low vision and visual neurosciences are among his active topics. Thierry is a French engineer (ESPCI ParisTech) who specialized in medicinal chemistry (PhD, Pierre & Marie Curie University, Paris). He spent 20 years in the pharmaceutical and biotech industry in R&D and business development positions. Thierry also has an MBA from HEC.

## KEYWORDS

prevention, eye phototoxicity, UV radiation, blue light, in vitro, in vivo, cataracts, pterygium, conjunctivitis, pinguecula, AMD, retinitis pigmentosa, glaucoma, diabetic retinopathy, oxidative stress, photo-ageing, risk profile

Each day, our retina absorbs millions of billions of photons with an expected increased magnitude due to our new light exposure behaviors. Day after day, these streams of photons can induce irreversible eye damage and contribute to the onset or development of debilitating eye diseases. The phenomenon is aggravated by the accelerated ageing of the world population, since an ageing eye is more photosensitive along with altered defense.

A better understanding of the pathogenesis of vision-threatening diseases, a sharp analysis of light/eye interactions, and an individual risk profiling for these eye conditions are now urgent to provide appropriate and personalized eye photo-protection solutions, starting with eyewear, for efficient and long-term prevention.

### 1. EYE PHOTOTOXICITY

While light is necessary and beneficial to visual and non-visual functions, any optical radiation might potentially be hazardous to the eye if it is received and absorbed by eye tissues at doses capable of causing photomechanical, photothermal or photochemical reactions. On the one hand, brief and extreme bright light exposure may induce mechanical or thermal permanent and rapid eye injuries. On the other hand, moderate light exposure for an extended period of time may result in progressive biochemical changes and ultimately induce irreversible cell death. For this chronic lifelong eye light-damage, the spectral specificity of light is critical. In particular, UV radiations and high-energy visible light are pointed out as high risk spectral bands respectively for the anterior eye and the retina.

### UV radiations and the anterior eye

Chronic eye exposure to solar UV radiations has been progressively associated with the pathogenesis of numerous cornea and crystalline lens diseases. If additional photobiology studies would be of interest to better dissect the intricate link between UV and the eye, sufficient *in vitro*, *in vivo* and epidemiology data confirm the contributory role of UV in numerous diseases of the anterior eye, such as cataracts, pterygium, conjunctivitis, pinguecula, climatic droplet keratopathy, ocular surface squamous neoplasia, etc. (for more details, see *Points de Vue* no. 67<sup>1</sup>).

In 1956, Kerkenezov observed an early clinical indication of the role of UV in pterygium.<sup>2</sup> Later, Minas Coroneo evidenced that peripheral light focusing by the anterior eye to the sites of usual locations of pterygium and cataract is involved in the pathogenesis of these eye conditions.<sup>3</sup> The Chesapeake Bay study reported a significant correlation between the spatial zone affected by the climatic droplet keratopathy and the average annual UV exposure. Corinne Dot *et al.* evidenced that mountain professionals are at higher risk for cataracts. The POLA, Beaver

Dam Eye and Chesapeake Bay epidemiology studies revealed a higher prevalence of cortical cataracts in populations living in bright sunny plains.

Public awareness has rapidly been high on the UV eye hazard since skin UV protection has now long been encouraged and normalized (SPF factors).

### Blue light and the retina

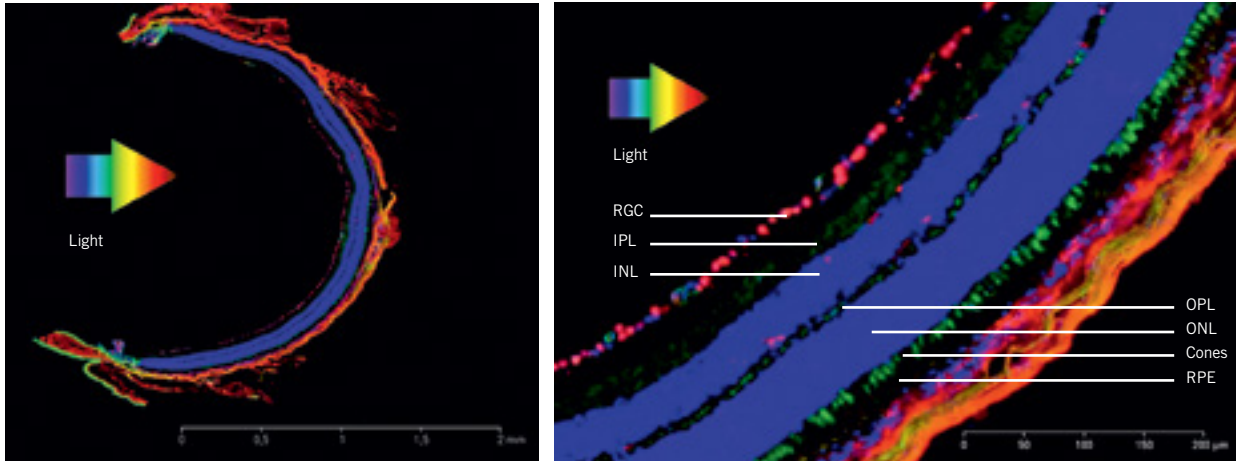
Since UV radiations are totally absorbed by the cornea and the crystalline lens after the age of 20, the most energetic light reaching the retina is blue light.

Photobiology studies on blue-light eye damage started half a century ago, with the landmark paper of Noell evidencing blue retinal phototoxicity in rodents exposed to white fluorescent lamps.<sup>4</sup> In 1972, Marshall, Mellerio and Palmer observed blue light damage in the pigeon cones.<sup>5</sup> Since then, with the advent of lasers, the number of photobiology studies on blue light has soared. Ophthalmologists themselves have been encouraging such phototoxicity and exposure threshold studies for their patients' exposure when conducting laser surgery (for retinal procedures, also for refractive surgery) or for themselves considering

**“Light protection should be part of a personalized prophylactic program instructed by eye care practitioners.”**

FIG. 1 | Retinal tissues

Paris Vision Institute images by confocal microscopy. RGC=Retinal Ganglion Cells; IPL=Inner Plexiform Layer; INL=Inner Nuclear Layer; OPL=Outer Plexiform Layer; ONL=Outer Nuclear Layer; RPE=Retinal Pigment Epithelium



the light intensity of ophthalmic instruments (slit-lamp and others). More recently, in the 1990s, the IOL industry has funded phototoxicity research to support the benefits and safety of the blue-light filtering IOLs implanted during cataract procedures.

*In vivo* experiments revealed that photochemical damages to the retina exhibit lower dose thresholds in the blue range compared to green and red<sup>6</sup> as evidenced in monkeys<sup>7, 8</sup>, rats<sup>9, 10, 11</sup> and rabbits<sup>12, 13, 14, 15, 16</sup>.

Blue light hazards were further studied on the outer retina (photoreceptors and retinal pigment epithelium (RPE) (Fig. 1), on immortalized RPE cells loaded with either oxidized photoreceptor outer segment<sup>17</sup>, purified lipofuscin<sup>18</sup> or synthesized A2E.<sup>19, 20, 21, 22, 23</sup>

A greater toxicity of blue light was demonstrated by exposing human RPE loaded with lipofuscin during 48 hours upon violet-blue-green light (390 nm – 550 nm, 2.8 mW/cm<sup>2</sup>) and yellow-red light (550 nm – 800 nm, 2.8 mW/cm<sup>2</sup>).<sup>18</sup> This cell death was mediated by apoptotic processes involving caspase-3 and p-53 activation.

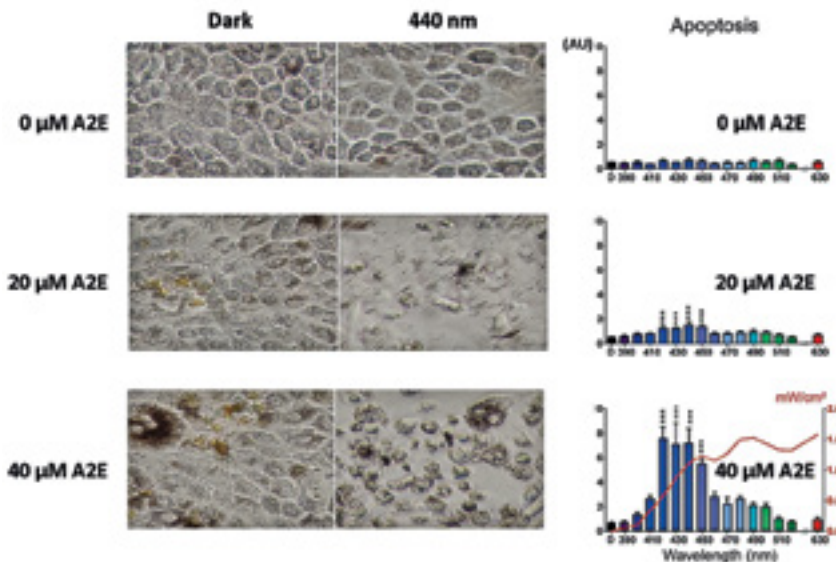
Many of these studies suffer limitations such as not being precise enough on the light dose sent, or illu-

minating with very high irradiances that trigger acute light-toxicity mechanisms rather than lifelong cumulative exposure damage. Moderate irradiances and longer exposure should be sought when studying the pathogenic mechanisms of Age-Related Macular Degeneration (AMD) or diabetic retinopathy. Under the supervision of Professor Sahel and Dr. Picaud, Paris Vision Institute and Essilor researchers joined skills to go a step further from a photometry standpoint. By developing innovative cell illumination protocols and systems, we together have studied various phototoxic action spectra involved in the pathogenesis of severe vision-threatening diseases (AMD, retinitis pigmentosa, glaucoma, etc.). For instance, we have evidenced the precise phototoxic action spectrum of RPE within the blue-green range in sunlight physiological retinal exposure on an established *in vitro* model of AMD.<sup>24</sup> The 415 nm - 455 nm narrow spectral range was highlighted as the greatest phototoxic risk to RPE cells (Fig. 2).

*In vitro* and *in vivo* studies have progressively revealed a strong scientific rationale for cumulative blue toxicity on the outer retina. The understand-

ing of cell mechanisms involved has provided crucial inputs on the pathogenesis of outer retina diseases, in particular AMD. First, cumulative exposure to blue light favors the accumulation of all-*trans*-retinal in the photoreceptor outer segments (POS). All-*trans*-retinal interacts with blue-violet light with a decreasing profile between 400 nm and 450 nm. Its blue photo-activation induces oxidative stress within the POS. This stress is normally compensated by retinal antioxidants and enzymes, but age progressively reduces anti-oxidative defenses, thus failing to compensate for the oxidative stress. The POS progressively oxidize, and their renewal into the RPE is more challenging as their membrane components are difficult for the RPE to break down. Thus, intracellular digestion is incomplete and generates an accumulation of residual lipofuscin in the RPE.<sup>25</sup> Lipofuscin is sensitive to blue-violet light. Blue photoactivation may generate reactive oxygen species. When the number of these species exceeds cellular defence capacity, RPE cells die by apoptosis. Deprived of these support cells, the photoreceptors deteriorate in turn, contributing to the

**FIG. 2 |** Phototoxic action spectrum on A2E-loaded RPE cells, ageing and AMD cell model  
 A representative imaging of RPE cells loaded with 0, 20 or 40  $\mu\text{M}$  of A2E and exposed for 18 hours to a 10 nm illumination band centered at 440 nm or maintained in darkness.  
 B Apoptosis after 18 h exposure to 10 nm illumination bands centered from 390 to 520 nm and at 630 nm for RPE cells treated with 0, 20 or 40  $\mu\text{M}$  of A2E. Values were averaged from 4 wells for each illumination band and each A2E concentration (n=4 to 6 independent experiments) and were normalized to the control value in darkness. Apoptosis is expressed as the ratio of caspase-3/7 activity signal to cell viability signal (left vertical axis). \* $p < 0.05$ , \*\* $p < 0.01$  and \*\*\* $p < 0.001$ .  
 Each lighting condition is designated on graphs by its central wavelength in nm (abscissa legend indicates one wavelength in two from 390 to 630 nm). Control cells were maintained in darkness (left black bar, D for dark). The red curve represents the mean light irradiances ( $\text{mW}/\text{cm}^2$ , right vertical axis).



loss of vision diagnosed in patients suffering from AMD. Age and light-related accumulation of lipofuscin in the RPE are major pathogenesis features of AMD.

Numerous epidemiology studies confirm the correlation between blue light exposure and AMD.<sup>26, 27, 28, 29, 30, 31, 32</sup> The EUREYE study found significant association between blue light exposure and neovascular AMD in individuals having the lowest antioxidant level. In the Chesapeake Bay study performed on 838 watermen, AMD patients – compared with age-matched controls – were significantly higher exposed to blue over the preceding 20 years but equally exposed to UV, suggesting that blue light exposure is related to AMD. The Beaver Dam Eye Study reported a correlation between sunlight and 5-year inci-

dence of early AMD changes. Leisure time spent outdoors while persons were teenagers (13 – 19 years) and in their 30s (30 – 39 years) was significantly associated with the risk of early age-related macular changes. A recent meta-analysis led by Sui *et al.* interestingly concluded that light is a risk factor for AMD.<sup>33</sup>

Beyond the outer retina, photobiologists have recently suspected that high energy visible light could also affect inner layers of retina, such as retinal ganglion cells (RGC). Specific blue light may be absorbed by chromophores located in mitochondria. As an abundance of mitochondria are localized in RGC and these cells are involved in the degenerative processes of glaucoma, we suspect that blue light is a risk factor for glaucoma as well. In ageing retina,

where functional mitochondria are no longer in an optimum homeostatic state<sup>34</sup>, blue light might dramatically precipitate the onset of glaucoma and other optic neuropathies. It could even contribute to accelerating glaucoma once diagnosed.<sup>35, 36</sup>

### Light, a risk factor for major vision-threatening diseases

Light is suspected of being a risk factor in many debilitating eye diseases. For cataract and AMD, it is now well established: UV radiations accelerate the cataract onset while in AMD, blue-violet light exposure is a precipitating factor. For other diseases such as diabetic retinopathy or glaucoma, photobiologists suspect cumulative lifetime exposure to blue light contributes to the oxidative stress of specific retinal cells. In all cases, the contribution of light among other pathogenic factors grows with age and when the defence and repair mechanisms against photochemical damage are less effective, which is the case when the eye disease is already diagnosed (e.g. antioxidant enzymes such as SOD-2 or catalase are less effective).

### Normative data

European and ISO standards for sunglasses (EN 1836 and ISO 12312-1) and for tinted ophthalmic lenses (ISO 8980-3) have, for many years, used a relative spectral effectiveness weighting function  $S(\lambda)$  to characterize UV hazards. This was originally published in ICNIRP guidelines 1989 and is derived from an action spectrum for skin erythema.

A sister function in the blue range was proposed later,  $B(\lambda)$ , derived from the seminal work by Ham *et al.* for the acute hazard on aphakic monkey eyes.  $B(\lambda)$  was defined by multiplying the spectral values of Ham *et al.*'s research with the spectral transmittance of the human lens. Nevertheless, there is no standard on cumulative

blue light toxicity. New identification of phototoxic action spectra<sup>24</sup> should be advantageously used to create and/or revise normative data on phototoxicity.

#### **From *in vitro* and *in vivo*... to clinical data**

*In vitro* phototoxicity studies bring valuable and robust information on the light action spectrum as well as on the light-associated specific cell and disease biomarkers. The Essilor and Paris Vision Institute study with 10 nm step illuminations is a good illustration. Animal models (*in vivo*) are interesting living and integrative models of a disease. They make it possible to study the role of a specific gene (transgenic knock-out animals), the involvement of a specific toxicity pathway (e.g. inflammation, oxidative stress) or a disease target. They are essential in correlating disease with imaging, biology testing, immunohistochemistry or behaviour. But they have limitations: pathogenic mechanisms can differ from humans (e.g. using rodents in AMD models while rodents do not have a macula); light illumination is more intense and of a shorter duration than in real life<sup>6</sup>. While *in vitro* and *in vivo* experiments raise the understanding of a disease-specific light action spectrum and pathogenic mechanisms, the only clinical evidence of light-associated eye diseases is brought by longitudinal epidemiological studies. It is therefore necessary, when studying real-life eye chronic phototoxicity, to find light-specific markers of disease early-signs and disease progression.

## **2. INDIVIDUAL RISK PROFILING**

Now that cataract is being better treated in eastern and southern countries, AMD, glaucoma and diabetic retinopathy are becoming the three major vision-threatening diseases. This threat is largely worsened by the world ageing and by lifestyle risk fac-

tors such as poor antioxidant diet. From a public health perspective, considering that it is now urgent to optimize the disease management for these three eye conditions, all efforts should be paid to raise awareness in the general population, especially in the sub-populations considered more at risk, to develop and select the most relevant tests for early diagnosis and disease profiling, ultimately to monitor the disease progress and to apply the most appropriate therapeutic strategy. This sounds obvious but we believe we have now reached a more mature stage of understanding of the disease mechanisms associated with the availability of a set of new diagnostic tools including eye imaging, biological testing of biomarkers and psychophysical methods. In order to manage effectively a multifactorial disease, there is an utmost need of disease profiling and monitoring and if applicable of multi-faceted therapy – aiming at multiple mechanistic targets – as well as prevention. Individual risk profiling is defined by multiple intricate factors, source-, patient- and environment-dependent (Fig. 3).

#### **Individual light exposure profile**

Our own light exposure profile is defined by the correlation of the number of light sources, their localization, their spatial distribution,

their radiance including directivity, but, critically, also their spectral distribution, the exposure duration and repetitions.

There is no doubt that solar radiations are the most harmful ones, since sun radiance is more than 100 times higher than the radiance of standard artificial lighting<sup>37</sup> and since daylight is rich in UV and blue light. The physical environment (ground reflectances, altitude, latitude, etc.) significantly modifies the amount of light received by the eye. The eye UV dose increases by 10% every 1,000 metres. While sand reflects 10% of UVB, water reflects 20% and snow more than 80%. Therefore, populations exposed to bright sunlight in high ground reflectance environments (mountain professionals, etc.) or living in very sunny plains are at higher risk of UV and blue-light related eye damage, including cataracts and AMD.

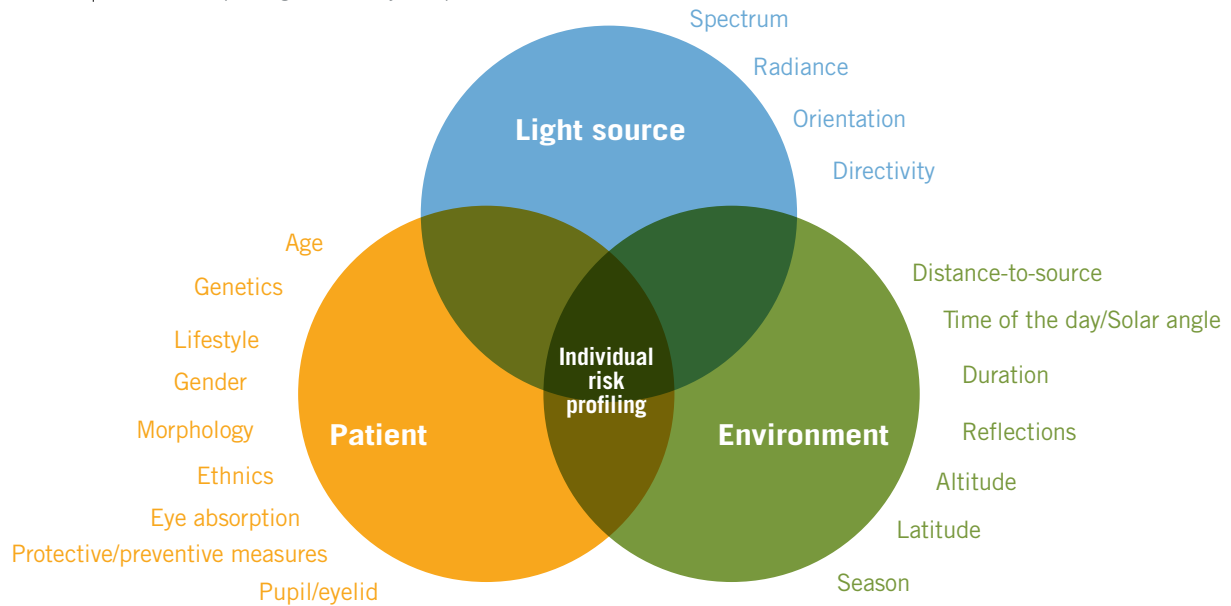
In addition to daylight, in our ageing and connected digital world illuminated by new solid-state lighting, our light exposure profile is rapidly and dramatically evolving. Starting at increasingly younger ages of our existence, our eyes are subjected to longer and simultaneous exposures, at shorter distances, with higher radiance and higher energy than with former incandescent sources.

Since they produce light with much lower energy consumption, these new solid state lighting sources have be-

**“Each day, our retina absorbs millions of billions of photons”**



FIG. 3 | Individual risk profiling is defined by multiple intricate factors.



come the dominant domestic lighting technology. In Europe, by 2016, no traditional incandescent light sources will be available. The European lighting industry estimates that over 90% of the total luminaires world market will be based on solid state lighting products by 2020.<sup>38</sup> Beyond domestic lighting, the LED compactness plus the wide spectral range they can cover (monochromatic LEDs) have generated many new lighting applications, for mobile phone and tablet back lighting or even for toys and clothes.

New LED-based light sources may emit more blue than former incandescent lamps.<sup>39</sup> Current white LEDs are combining a blue pumped LED with a phosphor emitting at higher wavelengths. For mass production of white LEDs, blue diodes based on InGaN or GaN crystals are combined with a yellow phosphor (YAG:Ce or similar); they produce “cold-white” with a color temperature CCT equal or higher than 5500 K<sup>39</sup>. They may emit up to 35% of blue light within the visible range, much more than incandescent lamps (< 5%). To produce “warm-white” with a CCT <3200 K, with less than 10% of blue, an extra layer of

phosphor emitting red light is needed, which significantly reduces the luminous efficacy of the LED.

At retinal level, received irradiance is directly proportional to the radiance of the light source. By having a small light emission area, LEDs have a higher radiance, which makes them brighter, even for the same irradiance level.

Worldwide initiatives have been launched to conduct a health risk assessment on systems using LEDs. A task group was for instance mandated by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) in 2008. They concluded that a photochemical blue light risk could exist, consecutive to prolonged white LED exposure. Risky light exposure profiles may be identified and related to high-risk populations (for more details, see *Points de Vue* no. 68<sup>40</sup>):

- the daily adjustment and testing of high power cold white LEDs, by lighting installers, operators in lighting manufacturing facilities, show technicians and collectors, dentists, surgeons, etc.;
- the use of toys with LEDs, since children have a crystalline lens more

transparent to blue light;

- automotive LED daytime running lights, when activated near children or photosensitive persons (aphake, pseudo-aphake eyes, people suffering from ocular photosensitive pathology or using photosensitive drugs, etc.);
- some directional LED lamps sold for home applications, if viewed at distances equal or shorter than 200 mm;
- the prolonged and repeated use of cold white LED-based devices by children and teenagers, especially in the evening, etc.

#### Individual characteristics

Each person is unique. We do not respond to equal light exposure the same way. Genetics, morphology, ethnicity, gender, age, behaviors (smoking, diet, etc.), squinting effects, eye protection (eyewear, shadow cap, nutraceuticals, etc.) are all contributors to a distinct personal risk profile.

Age, for instance, is largely involved in the progressive deterioration of visual functions such as dark adaptation.<sup>41, 42, 43</sup> These findings are supported by the histological observations that rods degenerate early in both ageing and AMD.<sup>44, 45</sup> With age, the

number of photosensitizers is rapidly increasing in the retina, particularly in the RPE where the lipofuscin age pigment builds up. This increase is partly due to blue photo-ageing processes. Age plus cumulative blue light exposure may irreversibly alter the classical visual cycle in the outer retina, progressively leading to AMD.

#### **New tools for personalized early diagnosis**

In the case of AMD, Erica Fletcher *et al.* have interestingly reviewed the new means of detecting the signs of early-stage disease.<sup>46, 47</sup> AMD has genetic and environmental risk factors. Genetic testing is now readily available using a combination of 16 genes to help predict the risk profile of an individual. Among the genes associated with an increased risk of developing AMD is complement factor H (CFH), the mutations of which contribute to explain immune dysregulation in AMD. Considering retinal imaging, Hogg *et al.* have recently highlighted that a particular form of drusens called reticular pseudo-drusen, at a subretinal level, is a risk-factor for progression to late-stage disease.<sup>48</sup> A research team in the Netherlands has developed a software to analyze color fundus photographs so as to quantify and characterize drusens and determine a risk assessment. Using fundus autofluorescence (FAF), the RPE cell dysfunction can be detected through the accumulation of lipofuscin. Some scientists report that certain patterns in FAF imaging can help predict the evolution of AMD towards the choroidal neovascularization (CNV) late-stage form. Psychophysical methods can also help define if a subject is at greater risk of AMD or, later, of progressing to late-stage disease. Next, it would be helpful to monitor the light exposure in cohorts of patients and try to associate disease progression. Therefore, a comprehensive clinical

assessment and biomarker testing, including questionnaires (family history, lifestyle, etc.), visual examination and specific psychophysical methods, imaging, genetic testing and light exposure profiling can define an individual profile risk and help detect and characterize AMD at an early stage as well as monitor disease progression.

#### **3. PERSONALIZED PREVENTION**

For most eye diseases, an individual can undergo a complete assessment of his or her risk profile specifically related to a disease and then if needed, once informed and educated, decide to adopt a more thorough and frequent medical and self-surveillance so as to detect early enough the onset and progression of a disease and to take personalized prophylactic actions.

Light protection should be part of a personalized prophylactic program instructed by eye care practitioners. If a patient is profiled at risk of one of the vision-threatening diseases, and if the precise light spectrum incriminated as a risk factor is known (such as blue-violet light for AMD), then it is in the patient's interest to protect himself selectively, especially when a portion of visible light needs to be filtered out as part of the preventative measure. Contrary to UV radiations, which can be fully blocked with no compromise on vision, filtering out visible light is always a trade-off with color vision

and other physiological functions such as chronobiology or scotopic vision. Fortunately, the ophthalmic optics industry, in recent years, has fostered or benefited from the emergence of innovative narrow-band filtering technologies and has now started to develop photoselective and photoprotective ophthalmic filters. These new lenses offer practitioners an effective complementary tool to the armamentarium of prophylactic solutions available to their patients.

#### **4. CONCLUSION**

Major eye diseases, such as cataracts, AMD, glaucoma or diabetic retinopathy, have a tremendous impact on patients' quality of life but also significant implications on the cost of healthcare. The threat is enhanced by the accelerated ageing of the world population and by evolving behavioral and environmental factors. Photobiology research has progressively identified light as a risk factor for these multifactorial conditions. Further photobiology studies, *in vitro* and *in vivo*, with well-calibrated light conditions, along with epidemiology studies with proper spectral light exposure quantification, are now necessary to identify significant correlations between light action spectra and pathogenic mechanisms. As initiated in RPE and RGC models, Essilor and the Paris Vision Institute are pursuing their efforts in developing accurate photometric tools (devices and protocols) for controlled cell illu-

**“Major eye diseases have a tremendous impact on patients' quality of life.”**

mination. A better understanding of the pathogenesis of eye conditions would interestingly be complemented by a better disease management, including real-life phototoxicity studies to find light-specific early markers of a disease and individual risk profiling. In our digital world with huge technical tools in image analysis and miniaturized sensors, the personalized and early follow-up of an eye disease is now made possible and paves the way for relevant personalized prevention. In the meantime,

technology breakthroughs in the ophthalmic optics industry are meant to provide new effective solutions to design efficacious and personalized photo-protective and photo-selective eyewear. •

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## KEY TAKEAWAYS

- Moderate light exposure for an extended period of time may ultimately induce irreversible eye cell death.
- Chronic exposure to UV radiations is a risk factor for several eye diseases: cataracts, pterygium, pinguecula, etc.
- Chronic exposure to blue light is a risk factor for Age-Related Macular Degeneration (AMD).
- The 415 nm - 455 nm narrow spectral range has been highlighted as the greatest phototoxic risk to RPE cells.
- Individual risk profiling is defined by multiple intricate factors, source-, patient-, environment-dependent.
- Sun radiance is more than 100 times higher than the radiance of standard artificial lighting.
- With new solid state lighting artificial sources, our light exposure profile is evolving rapidly and dramatically.

# EYE-SUN PROTECTION FACTOR. A NEW UV PROTECTION LABEL FOR EYEWEAR



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**INTRODUCTION / ABSTRACT**

Ultraviolet radiation (UVR) potentially damages the skin, the immune system and structures of the eye.

Today there is no reliable and universal method to assess and compare protective properties of lenses.

Sunglasses as well as clear lenses can reduce transmission of UV effectively, however, an important share of the UV burden is attributed to reflection from the backside of the lenses.

To provide reliable labelling of the UV protection offered by lenses, an Eye-Sun Protection Factor (E-SPF™) has been developed by Essilor, encompassing both transmission and reflection.

A group of experts: ophthalmologists, optometrists and dermatologist, from 5 European countries reviewed existing literature on UV dangers and evaluated the relevance of E-SPF™.

Scientific articles have been submitted to Clinical Journal in Ophthalmology and Dermatology<sup>[1,2]</sup>.

**1- THE EYE AND UV EXPOSURE**

**UV definition**

Ultraviolet radiation is defined by the wavelengths 100 to 400 nm. UV-C (100-280nm) is essentially absorbed within the atmosphere. Of the UVR reaching earth UV-B (280-315nm) accounts for 5% and UV-A (315 nm and above) up to 95%.

The shorter the wavelength, the more spectral energy increases, and the higher the potential damage. The potential biological damage at 300 nm is 600 times greater than at 325 nm for example (Fig. 1).

**Sources of UV**

The main source of UVR is sunlight. Artificial lighting contributes to a lesser extent but may increase with the advent of energy efficient light sources<sup>[3]</sup>.

**Ambient UV: direct radiation, scatter, and reflection**

Direct sunlight only partly contributes to ambient UV. Under average conditions, more than 50% of ocular exposure comes from scattering and reflection from clouds and the ground.

The average annual UV dose is estimated to be 20,000 to 30,000 J/m<sup>2</sup> for Americans,<sup>[4]</sup> 10,000 to 20,000 J/m<sup>2</sup> for Europeans, and 20,000 to 50,000 J/m<sup>2</sup> for Australians. Vacations can add more than 30% to the UV dose.

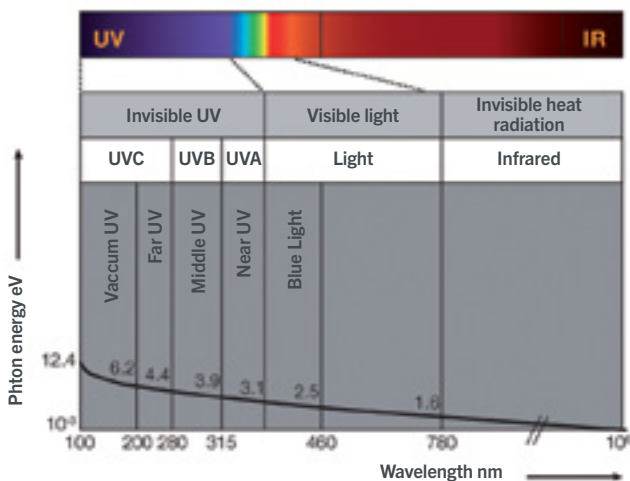


FIG. 1 | Radiation as a function of increasing photon energy.

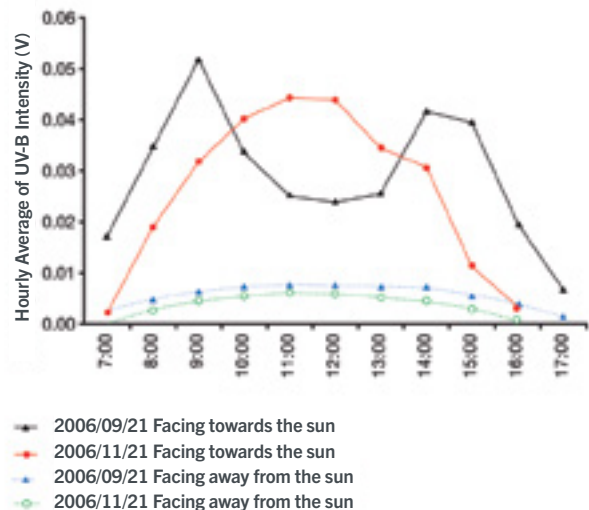


FIG. 2 | Hourly average of UV intensity in the eye when facing towards and away from the sun [Volt]<sup>[5]</sup>.

**PRINCIPAL HARM TO THE EYE AND THE AREA AROUND THE EYE CAUSED BY UV EXPOSURE**

**Eyelids and area around the eye**

Wrinkles: UV rays are the main cause of premature skin ageing, sun burn, cancer: between 5 and 10% of skin cancers appear in the area around the eye (actinic keratosis, spinocellular carcinoma and basal cell carcinoma, malignant melanoma).

**Ocular surface and cornea**

Pinguecula, pterygium, climatic keratopathy, ocular dryness, dysplasia, malignant tumour of the cornea or conjunctivitis.

**Crystalline lens**

Cortical cataract: UV rays accelerate its appearance. 20 million operations are performed every year worldwide.

**Uvea**

Melanoma, miosis, pigment dispersion, uveitis.

**Vitreous**

Liquifaction

**Ocular factors: exposure geometry and anatomy**

Ground reflection is a more significant factor for the eye. For the skin, greatest exposure is in the middle of the day, while for the eyes it can be early morning and later in the afternoon (Fig. 2).

**Back surface reflection of antireflective coatings**

UVR is reflected from the back surface of sunglasses and clear lenses into the eye. So even UVR coming from behind the wearer can reach the ocular surface (Fig. 3).

Citek demonstrated that AR coatings may reflect UVR at high levels<sup>[6]</sup>. Some lenses showed up to 40% reflection of UVA and UVB.

Outdoor measurements demonstrated that UVR proportion able to reach the eyes through lens reflexion is really substantial and may represent up to 50% of not protected eye exposure<sup>[7]</sup>.

**Indication of UV exposure**

The World Health Organisation's solar ultraviolet index (UVI), an international index of UV burden<sup>[8]</sup> assesses risk of UV damage to the skin. Several studies have shown that this is not a valid indicator of eye protection and potentially misleading<sup>[5]</sup>.

**2- ABSORPTION AND TRANSMISSION WITHIN THE EYE**

Identifying absorption and transmission of UVR within structures of the eye is key to understanding potential damage<sup>[9]</sup>.

**UV transmission is strongly** dependant on age. Below 9 years of age, a larger portion (2-5%) of UVA is transmitted by the cornea and the lens. Significant inter-individual differences have also been shown<sup>[10]</sup>.

**3- UV HAZARD TO EYE STRUCTURES**

Acute and chronic damage to the eye by UV and visible light has been extensively studied, including epidemiological studies, with greater significance on chronic exposure<sup>[11]</sup>.

**Cornea**

The cornea is most exposed, with the greatest level of UVR absorption from direct irradiation (Fig. 4). In addition oblique rays are reflected across the cornea and anterior chamber into the limbal area leading to elevated pathologies in this area. Most common diseases: Pterygium, pinguecula, climatic droplet keratopathy.

**Cortical cataract**

It is known that UV light induces cataracts<sup>[12]</sup> with a damage threshold at 350 nm of 60 mJ/cm<sup>2</sup>. With growing and aging populations and other changing demographic factors the incidence and prevalence of cataracts will increase. Reducing the risks that can lead to cataracts is therefore important.

**Dry eye, premature presbyopia, AMD**

Decreasing tear film production linked to ageing, reduces UV absorption and antioxidant production by tears.

**The association between** UVR and AMD remains controversial. Blue light is a more significant contributor to development of AMD.

**UV related skin aging and diseases of periorbital skin**

The acute response of the skin to UV is inflammation (sunburn). Clinical symptoms include erythema, swelling, pain and pruritus<sup>[13]</sup>.

**Chronic effects include** photoaging and photocarcinogenesis. Some clinical signs of photoaged skin include dryness, irregular pigmentation, lentigines, wrinkling and inelasticity. The delicate periorbital skin is particularly susceptible to effects of photoaging<sup>[14]</sup>.

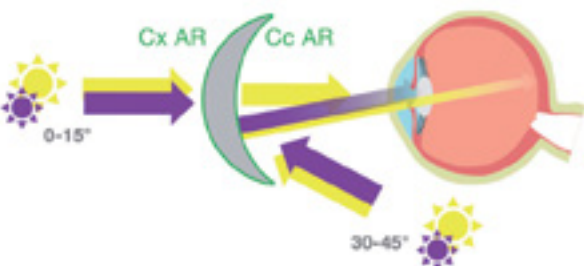


FIG. 3 | UV transmission is blocked efficiently by most lenses, but antireflective coatings increase back reflectance of UVR into the eye.

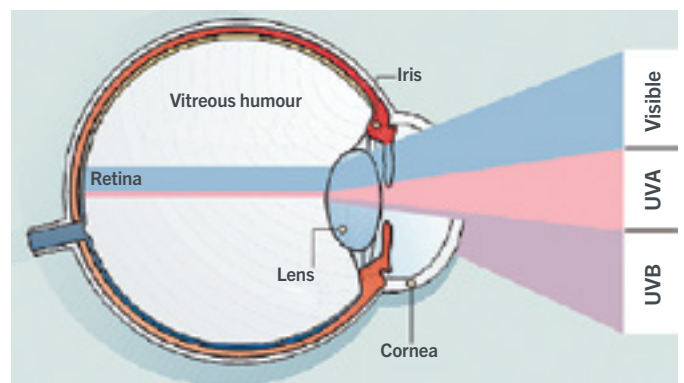


FIG. 4 | UV transmission within the eye. Visible light penetrates through to the retina, UVA is mostly absorbed by the lens, UVB is mostly absorbed by the cornea.

\* Myers M, Gurwood AS. Periocular malignancies and primary eye care. Optometry,2001;72(11):705-12

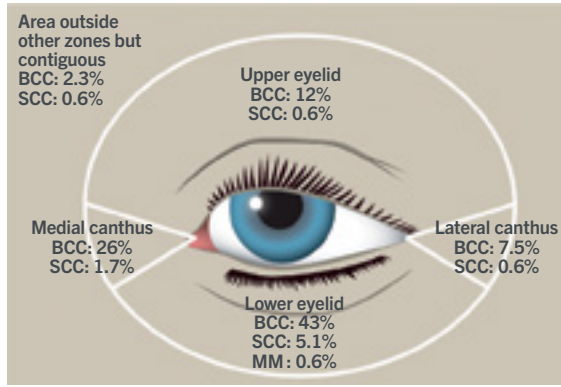


FIG. 5 | Location of eyelid malignancies. Percentages of n=174 tumors. BCC, basal cell carcinoma; SCC, squamous cell carcinoma; MM, malignant melanoma in the periorbital.

→ **Mitochondrial DNA** is a chromophore for UVA and UVB and subject to damage by UVR. DNA deletions are increased by up to 10-fold in photoaged skin compared to sun-protected skin of the same individual. <sup>[15]</sup>

**Photocarcinogenesis includes** the development of actinic keratosis, squamous cell carcinoma, basal cell carcinoma, and malignant melanoma (Fig. 5). 5% to 10% of skin cancers are appearing on the eyelids <sup>[17]</sup>.

#### 4- THE NEED FOR EYE PROTECTION

##### Populations at risk

With the increase of life expectancy and cumulative effect of UVR exposure during all the life, the protection of the eye against UVR concerns everyone, and should start at the earlier stage. As already indicated, UV transmission to the retina is greater in children <sup>[11]</sup>.

**For those spending time** at higher altitudes, outdoor workers, and those spending more leisure time outdoors, ocular UV exposure is greater <sup>[16]</sup>.

**Photosensitising drugs**, such as psoralenes, non-steroidal anti-inflammatory drugs, antiarrhythmics, tetracyclins, and chloroquine increase susceptibility to UVR damage.

##### Eye-Sun Protection Factor

The clothing industry employs UPF (Ultraviolet Protection Factor) to measure garment UV transmission <sup>[18]</sup>. While in the skincare industry, UV protection is defined by SPF (Sun Protection Factor) and is applied to sunscreens and some daily creams (European Standard EN 13758).

**Essilor developed** an Eye-Sun Protection Factor for lenses taking into account: transmission, reflection from the back surface, protection of structures of the eye and periorbital skin.

**An accepted E-SPF™** used by manufacturers, eye care professionals and consumers will enable identification and comparison of the UVR protective properties of lenses. This includes clear prescription lenses, contact lenses and sunglasses (prescription or non-prescription).

#### CORRECTIVE LENSES TO PROTECT AGAINST UV



##### Clear lenses

- For everyday protection against the cumulative effects of exposure to UV rays, lenses with protection factor E-SPF™ 25 offer the highest level of protection available for clear lenses. Crizal lenses were the first in this category to offer this level of protection. They are available in an extensive range for all wearers, both children and adults (Crizal® Kids™ UV, Crizal® Prevencia™, Crizal Forte® UV, Crizal Alizé® UV, Crizal Easy® UV). Associated with materials that absorb UV, Crizal lenses benefit from technology that considerably reduces the eye's exposure to UV due to reflection from the inner side of the lens.



##### Corrective sun lenses

- For optimal protection from the sun, Crizal® Sun UV lenses have protection factor E-SPF™ 50+. They offer the essential level of protection when conditions demand the wearing of sun lenses (strong sunlight, altitude, beach, etc). Crizal® Sun UV can be associated with tinted lenses or Xperio® polarizing lenses.

E-SPF™ figures are calculated using the following formula:

$$E - SPF^{TM} = \frac{1}{T_{UV}^{0^\circ} + R_{UV}^{145^\circ}}$$

**E-SPF™ was defined taking** into account transmission and reflection of UV and visible light at angles from 0° for light coming through the lens and from 145° incidence for light coming from the backside of the lens. It gives a clear understanding of its intrinsic ability to protect the eye.

**Table 1 shows that E-SPF™** values are similar to SPF labeling for sunscreens and for the consumer this familiarity could help them easily understand the level of protection provided by spectacles and sunglasses.

**Additional factors also** play a role such as the spectacle frame, anatomical features of the individual, solar angle, and UVR which might enter the space between the frame and the eye.

#### CONCLUSION

With increasing life expectancy and changing lifestyles, the cumulative effects of UVR in the periorbital region (malignancies), at the cornea and conjunctiva (pterygia) and the crystalline lens (cataracts), are of increasing relevance to public health.

**UV protection for the eye** and the periorbital area is often inadequate and not well defined.

Tuv	Ruv	E-SPF™
5%	5%	10
1.5%	5%	15
0%	4%	25
0%	<2%	50+

TAB. 1 | Tuv = Transmission of UV, Ruv = Reflection of UV, E-SPF™= Eye-Sun Protection factor.

This paper proposes an E-SPF™ to deliver a unified, easily understood index of UV protection for lenses. Lens manufacturers are encouraged to adhere to a shared standard.



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# NEW OPHTHALMIC LENSES FOR A CONNECTED LIFE: EYEZEN™ FOR AMETROPEES AND EMMETROPEES, AND VARILUX® DIGITIME™ \* FOR PRESBYOPEES

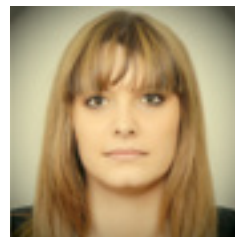
The advent of digital technology has not only changed methods of communication and information management, but also the visual and postural-motor habits of users.


To respond to these emerging needs, the ophthalmic industry has taken the path of innovation in the area of physical chemistry and optical design. This article presents a twofold technological breakthrough, which gave rise to a new category of ophthalmic lenses for a connected life. Designed by Essilor, a world leader in ophthalmic optics, these lenses are dedicated to users of all types of digital devices.



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#### KEYWORDS

Eyezen™, Varilux® Digitime™, mid-distance lenses, Crizal® Previncia®, power distribution technology, light filtering technology, blue light, blue-violet light, blue-turquoise light, UV, AMD, LED, ametropia, emmetropia, presbyopia, pre-presbyopia, digital screens, posture, digital devices, connected life, eyestrain, photobiology.

\* Product availability date may vary depending on the country



**“The use of these devices creates new visual and postural behaviours and modifies our light environment”**

The last ten years were marked by the emergence of digital devices, such as smartphones and tablets. Already indispensable to our daily lives, they are revolutionizing the way we communicate, learn, stay informed, work, entertain ourselves and relax. With an average of four different devices (computer, smartphone, tablet and TV), we tend to switch between them more frequently and at times even use them simultaneously (Fig. 1). The time spent using these devices has increased significantly and continues to grow: indeed, nine out of ten people state that they spend more time using them today than they did two years ago. Our daily lives have been turned upside down by this digital revolution, but everything has also changed for our eyes.

**Specific needs**

Indeed, the use of these devices creates new visual and postural behaviours and modifies our light environment. Ten years ago, there was only one reading distance: the distance at which we held a book or newspaper. On paper, characters have always been fixed in size and highly contrasted. Today, in addition to reading books, we also read on smartphones, tablets and computers at different distances (some of them quite short) and in various postures, as a study undertaken by the Essilor R&D has shown (page 22). On screens, characters are becoming smaller and more pixelated.

FIG. 1| Various usage of digital devices



**“Essilor designed Eyezen™,  
a new category of lenses  
for a connected life”**

Furthermore, our light environment has changed. Ten years ago, our eyes were exposed to natural light or artificial light emitted by incandescent lamps. Now, our eyes are constantly exposed to the bright light of screens and other light sources, such as LED or CFL bulbs, which strongly emit of diffusing and potentially harmful blue-violet light.

As a result, our eyes must focus more intensely and more often to adjust to the varying distances of use and to small pixelated characters found on screens. This not only causes eyestrain, but also postural aches and pain. In fact, a study<sup>1</sup> conducted in 2014 by the Ipsos institute on four thousand people in France, the United States, Brazil and China revealed that:

- Two out of three people feel that they must make an additional effort in front of screens to see well,
- Three out of four people suffer from eyestrain,
- 70% complain of neck and shoulders pain
- Over one out of two people are bothered by the strong brightness of their screens.

Lastly, the harmful blue-violet light emitted by screens can contribute to premature aging of the eyes.

This study showed that all users of digital devices – regardless of their age, the type of device used and the frequency of use, feel the same discomfort, related to the difficulty of reading small characters and screen brightness. However, the level of discomfort varies depending on the user’s age. In fact, for younger users, the main discomfort is screen brightness, while for older users, it is the effort required to decipher the small characters.

**A complete range designed for connected life**

To meet these new visual needs, Essilor designed a new category of lenses for a connected life. This all-new range of ophthalmic lenses provides a correction for each reading distance required by digital devices, relaxes users’ eyes and protects them against the potential dangers of blue-violet light:

- Advanced single-vision lenses combined with Crizal® Previncia® coating, called Eyezen™, for young adults (aged 20-34), pre-presbyopes (aged 35-44) and emerging presbyopes (aged 45-50), available for all prescriptions, and even for emmetropes,
- Mid-distance lenses combined with Crizal® Previncia® coating Varilux® Digitime™, for presbyopes (aged 45 and over), specifically designed for digital devices use.

Eyezen™ lenses are meant to replace standard single-vision lenses for wear by ametropic patients, but are also intended for occasional wear by emmetropes during their on-screen activities.

There are three different products optimized for three user profiles depending on their age (Fig. 2):

- For young adults (aged 20-34): Eyezen™ 0.4
- For pre-presbyopes (aged 35-44): Eyezen™ 0.6
- For emerging presbyopes (aged 45-50): Eyezen™ 0.85

# Eyezen™




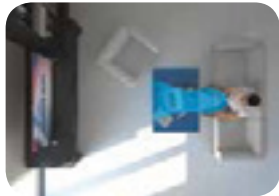









THE NEW SINGLE VISION LENSES AS PRIMARY PAIR FOR AMETROPES OR IN PLANO FOR EMMETROPES.  
WITH 3 OPTIMIZATIONS DEPENDING ON PROFILES:

<p><b>YOUNG ADULTS</b> 20 - 34 years old</p>	<p><b>PRE-PRESBYOPES</b> 35 - 44 years old</p>	<p><b>EMERGING PRESBYOPES</b> Without near vision correction 45 - 50 years old</p>
<p>EYEZEN™ 0.4</p> 	<p>EYEZEN™ 0.6</p> 	<p>EYEZEN™ 0.85</p> 
<p>STANDARD CORRECTION +  WITH <b>+0.4D</b> TO RELAX EYES OF <b>20-34 YO</b> FROM DIGITAL STRESS</p>	<p>STANDARD CORRECTION +  WITH <b>+0.6D</b> TO RELAX EYES OF <b>35-44 YO</b> FROM DIGITAL STRESS</p>	<p>STANDARD CORRECTION +  WITH <b>+0.85D</b> TO RELAX EYES OF <b>45-50 YO</b> FROM DIGITAL STRESS</p>
<p>PROTECTION FROM UV &amp; HARMFUL BLUE-VIOLET LIGHT EMITTED BY SCREENS. REDUCED SCREEN GLARE &amp; IMPROVED CONTRASTS.</p> <p>THANKS TO CRIZAL® PREVENICIA®</p>		

FIG. 2| Eyezen™ lens range for 20- to 50-year-olds, segmented by age (advanced single-vision lenses combined with Crizal® Prevenicia® coating)

**PRESBYOPES**

With near vision correction 45 - 65 years old

	<b>KEEN ON SMARTPHONES &amp; TABLETS</b>	<b>KEEN ON COMPUTERS</b>	<b>KEEN ON LARGE SCREENS</b>
	<b>Varilux® Digitime™ NEAR</b>	<b>Varilux® Digitime™ MID</b>	<b>Varilux® Digitime™ ROOM</b>
			
			
 <b>EXTENDED VISION</b>	○ ○ ○	○ ○ ○	● ● ○
 <b>INTERMEDIATE VISION</b>	● ● ○	● ● ●	● ● ○
 <b>NEAR VISION</b>	● ● ●	● ● ○	● ● ○
 <b>NEW ULTRA NEAR VISION</b>	 <b>RELAXED VISION FOR SMARTPHONE</b>	 <b>RELAXED VISION FOR SMARTPHONE</b>	 <b>RELAXED VISION FOR SMARTPHONE</b>

PROTECTION FROM UV & HARMFUL BLUE-VIOLET LIGHT EMITTED BY SCREENS.  
REDUCED SCREEN GLARE & IMPROVED CONTRASTS.

**THANKS TO CRIZAL® PREVENCIA®**

FIG. 3| The Varilux® Digitime™ mid-distance lens range for presbyopes aged 45 and over, segmented according to digital device use (occupational lenses, for occasional wear during on-screen activities or other activities requiring near or intermediate vision correction, combined with Crizal® Prevenicia® coating)

In addition to providing perfect correction for ametropia, Eyezen™ lenses also provide the necessary accommodative support to relieve eyes from stress while using digital devices, which differs depending on age. On top of that, they protect eyes from the harmful light emitted by screens, reduce glare and improve contrast thanks to their Crizal® Previncia® coating.

Lastly, the mid-distance lenses are intended for occasional wear by presbyopes during their on-screen activities or during any other activity requiring near or intermediate vision correction.

There are three different products optimized for three different categories of presbyopes, depending on the device they use most frequently (Fig. 3):

- For presbyopes keen on smartphones and tablets: Varilux® Digitime™ Near
- For presbyopes keen on computers: Varilux® Digitime™ Mid
- For presbyopes keen on large screens (TV or video projectors): Varilux® Digitime™ Room

Varilux® Digitime™ Near mid-distance lenses are optimized for smartphone or tablet use with wide near vision fields, but they also provide an intermediate vision field suitable for computer use. The minimum guaranteed depth of field is 80 cm, regardless of the prescription.

Varilux® Digitime™ Mid mid-distance lenses are optimized for computer use with wide intermediate vision fields, while also providing a near vision field suitable for smartphone or tablet use. The minimum guaranteed depth of field is 100 cm, regardless of the prescription.

Finally, Varilux® Digitime™ Room mid-distance lenses are optimized for large screens use with wider extended vision fields (delimited by room size) and offer intermediate vision and near vision fields suitable for computer, smartphone or tablet use respectively. The minimum guaranteed depth of field is 220 cm, regardless of the prescription.

**Response to emerging needs in the design of this new range of lenses for a connected life**

To respond to the emerging needs of wearers, Essilor brings its expertise in two areas: first, in optical lens design, to provide a perfectly suited correction, and secondly, in the area of protective lens coatings, to protect the eyes against the potential dangers of the blue-violet light emitted by screens. The range originated with a twofold technological breakthrough.

**A unique technology of power distribution**

Essilor R&D conducted a study on the emerging visual and postural behaviors engendered by the use of digital devices. The study revealed that the average reading distance is nearer on these devices than when reading on traditional paper media (33 cm for smartphones and 39 cm for tablets versus 40 cm for paper). Researchers also noted an average increase in the eye declination angle while reading on a smartphone (25° for smartphones versus 18° for a reading task on paper). These data (Fig. 4) reveal the need for a new **Ultra-Near Vision field**.

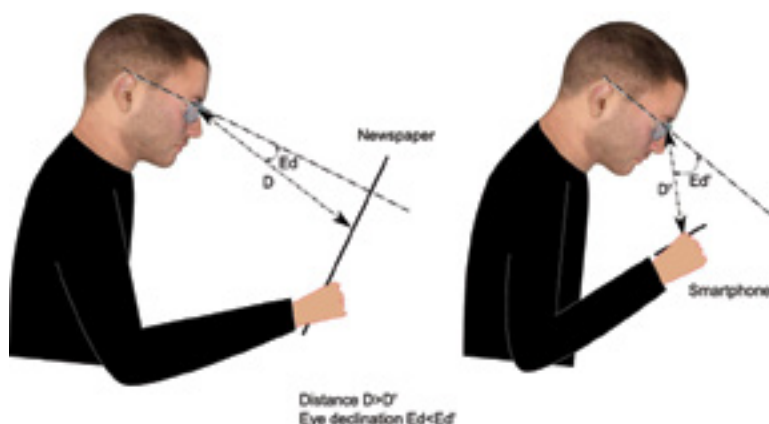


FIG. 4| Comparison of reading distances (D, D') and eye declination angles (Ed, Ed') between a paper medium (newspaper) and a digital screen (smartphone)

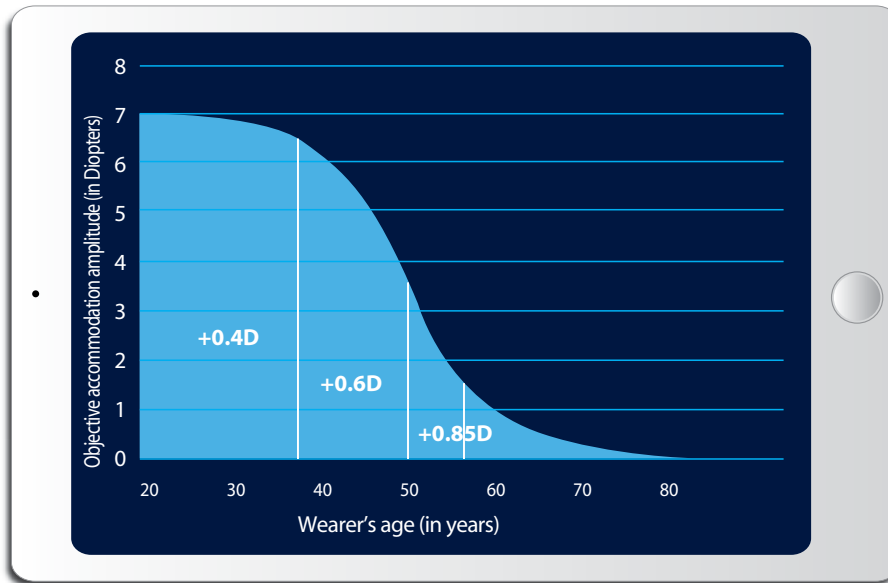


FIG. 5| Change in the amplitude of objective accommodation as a function of age

A unique **power distribution technology** was designed to respond to emerging needs. This technology distributes the power over the lens, including additional power in the bottom part of the lens to **support the eye's accommodation effort** when using digital devices, according to the physiological needs of each identified group of wearers.

It is important to point out that this additional power respects the physiological functioning of the visual system, without inhibiting the accommodative function of the wearer's eyes.

**How is this technology managed on Eyezen™ lenses?**

The additional power values selected are related both to the fact that the objective amplitude of accommodation decreases with age<sup>2</sup> (Fig. 5), and that accommodative power drops after sustained and prolonged near-vision work<sup>3</sup>. For example, a drop in accommodative power of 0.4D was observed after 20 minutes of near-vision work for a traditional reading task<sup>3</sup>. For this reason, the additional refractive power provided is **0.4D** for the **20-34** age group, **0.6D** for the **35-44** age group, and **0.85D** for the **45-50** age group.

**How is this technology implemented on Varilux® Digitime™ mid-distance lenses for presbyopes?**

Most near-vision exams are performed at a distance of 40 cm for reading tasks. This data is taken into account in the design of the new ophthalmic lenses for presbyopes connected life, so that wearers can effortlessly find their near-vision zone while reading. However, when using their smartphone, they bring it closer and naturally lower their gaze. At that point, their eyes encounter the additional power under the near-vision zone, thus relieving accommodative excess.

**This technology creates an additional field of vision: the Ultra-Near Vision zone**, which provides additional power. This zone, located under the near-vision zone, allows users to lower than gaze more than when they are reading on paper media. This additional power allows users to use their device at closer distances.

The additional power provided by the lens reflects users' specific characteristics, as well as their prescriptions and the widths of the fields of view of the target product. So the additional power will not exceed **0.50D** depending on the chosen lens and prescription.

Finally, the near-vision zone is not impacted by the additional power. The eye health practitioner's prescription is therefore always respected.

Since using a smartphone at a distance of less than 40 cm (Fig. 6) is likely to generate a substantial degree of discomfort and difficulty in focusing (i.e. blurred vision), the additional power under the near-vision zone provides support for accommodative effort, giving the wearer's vision more clarity.

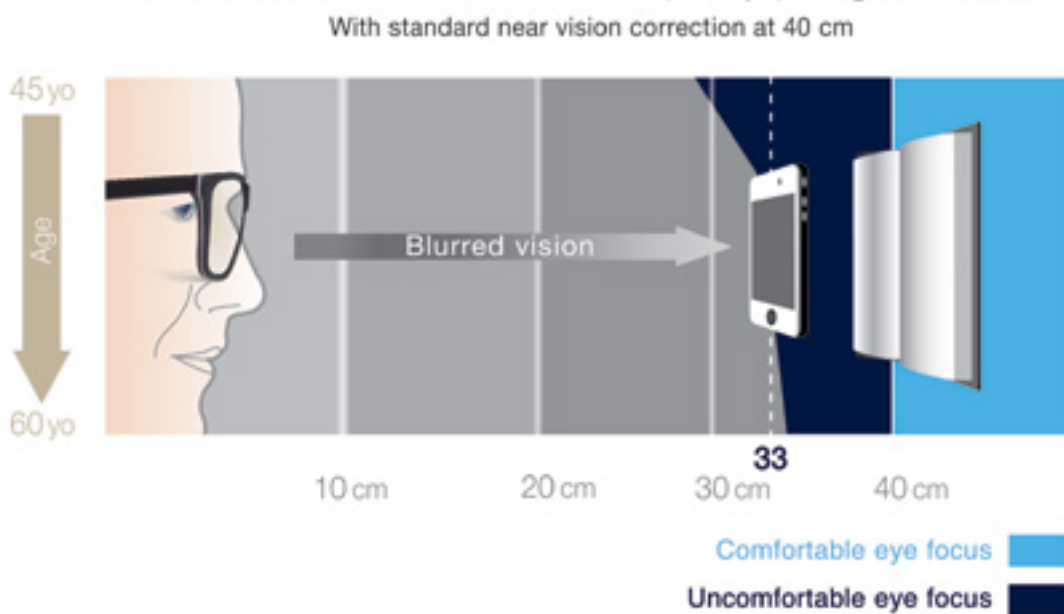
**What are the benefits of this technology for the wearer?**

The additional power **helps to reduce visual fatigue** for the wearer, even during prolonged smartphone use. It also **improves the readability of small characters**. Finally, it allows presbyopes to adopt a more **natural posture** when using their smartphone.

**Ergonomics of visual field positioning on Varilux® Digitime™ mid-distance lenses for presbyopes**

**Positioning of visual zones on mid-distance Varilux® Digitime™ lenses.** The ultra-near, near, intermediate and

Ultra-near distance vision discomfort for presbyopic digital device user



Ultra-near distance vision comfort with Varilux® Digitime™ mid-distance lenses

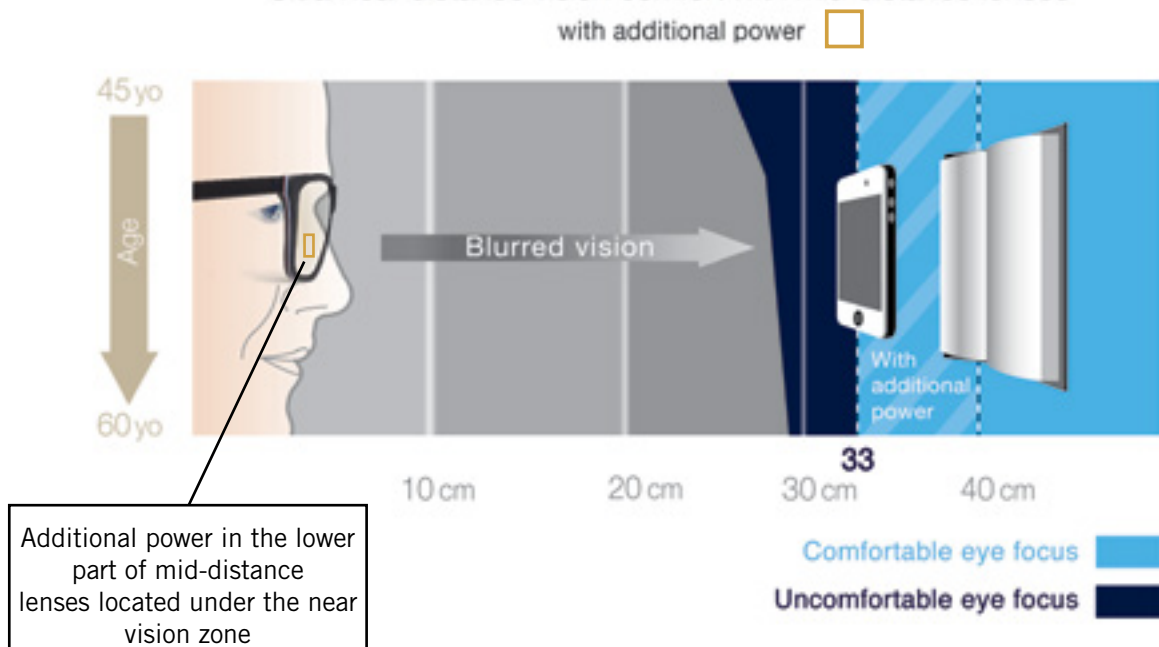


FIG. 6| Benefits of the Ultra-Near Vision zone provided by additional power. Smartphone use without additional power (above). With additional power (below).

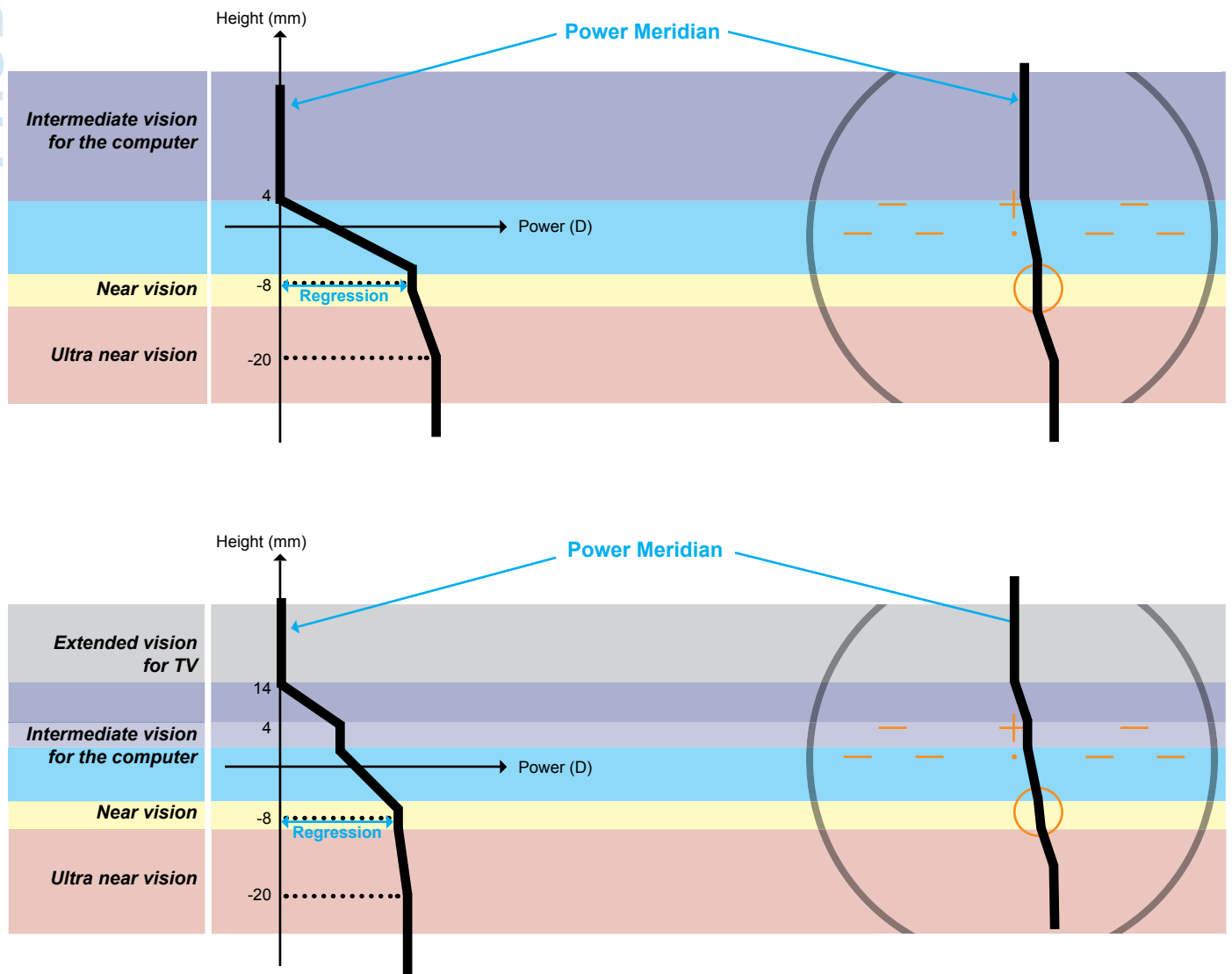


FIG. 7 | Schematic diagram of the (meridian) power profile for Varilux® Digitime™ Near and Varilux® Digitime™ Mid mid-distance lenses (above) and Varilux® Digitime™ Room mid-distance lenses (below)

extended visual zones are positioned optimally – in view of design constraints (fields of view width, prescription, minimal guaranteed depth of field, etc.) natural gaze lowering of the wearer and average use distances for each specific digital device (Fig. 6). With the exception of the ultra-near vision zone, which includes a progressive zone followed by an area of stable power, all zones are stable in power, therefore improving wearer comfort.

The positioning of these zones is customized to the prescription to follow the wearer’s natural convergence and provide good binocular vision. In this regard, the zones are properly positioned in the lens, vertically and horizontally, to minimize visual fatigue for the wearer.

**Characteristics of the intermediate vision zone.** Between the near vision zone and the intermediate vision zone, or extended vision zone depending on the case, there

is a variation in power known as degression (Fig. 7). This helps to ensure a given minimum depth of field (Fig. 3). The value of this degression is set according to the prescribed addition value, the desired minimum guaranteed depth of field and the wearer’s subjective accommodation.

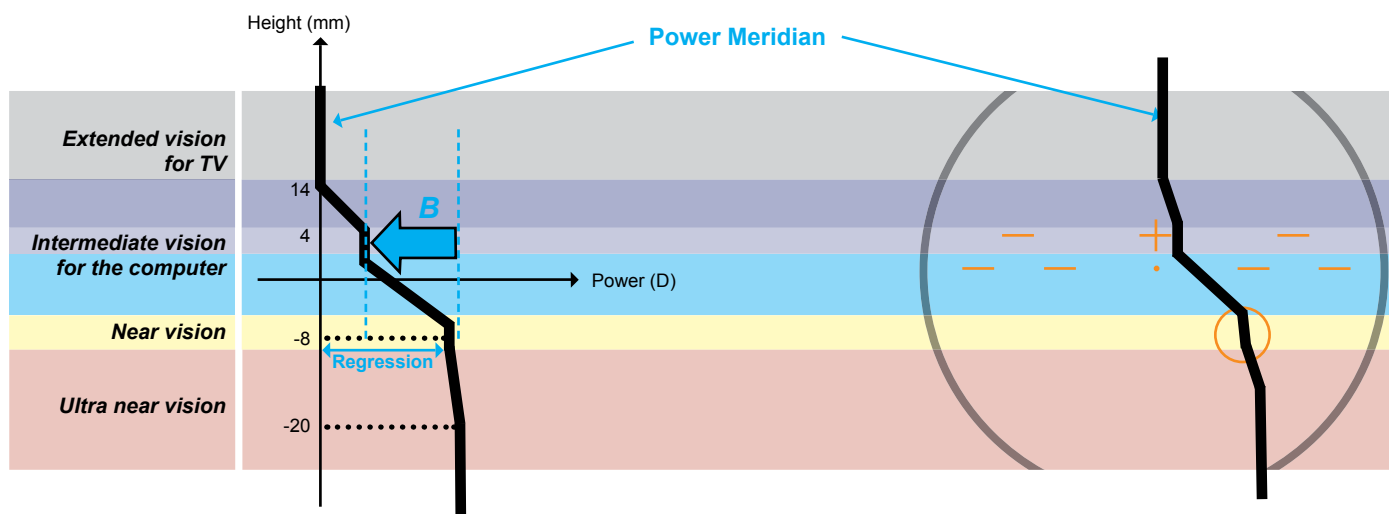
**Customization of intermediate vision on Varilux® Digitime™ mid-distance lenses**

The average distance of use for a computer is 63 cm, but a wide variation has been observed: 95% of people use a computer at distances between 38 and 88 cm. It is therefore recommended to customize intermediate vision for each individual.

To customize intermediate vision, Essilor has taken into account a new parameter known as “**Screen Distance**”, which corresponds to the distance between the eye and the computer screen. When calculating the lens, this



Customization for a MAX distance to screen



Customization for a MIN distance to screen

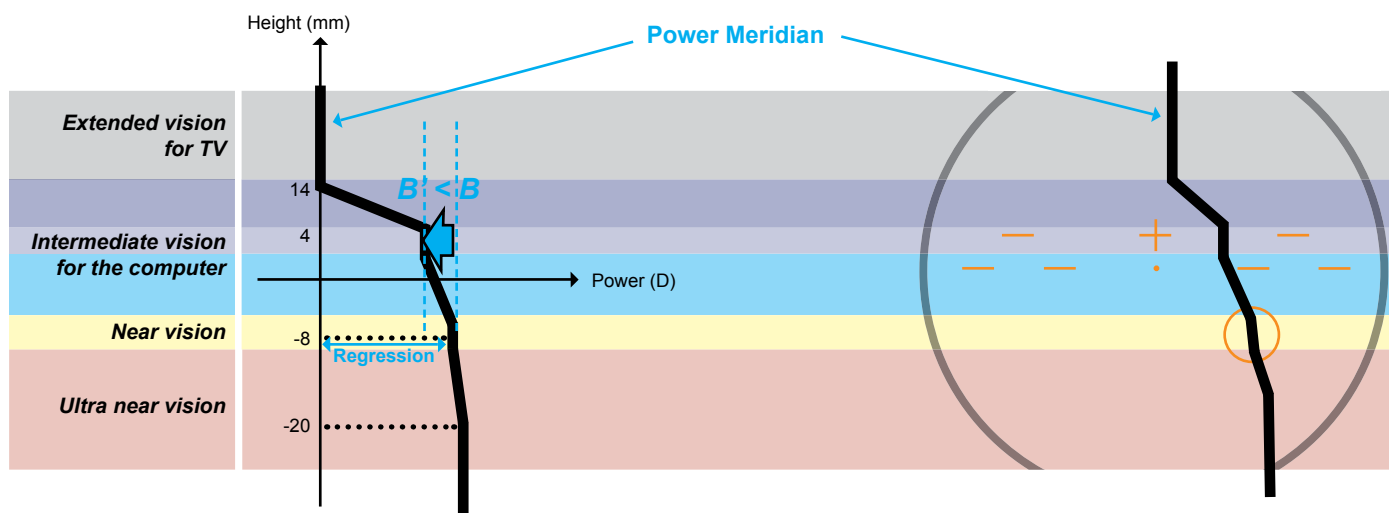


FIG. 8] Principle of degression of the intermediate vision field customized relatively to the “Screen Distance” parameter for Varilux® Digitime™ Room mid-distance lenses and a given fixed degression. The left-hand image represents the power variation along the meridian sectional view, and the right-hand image the location of the meridian on the lens seen from the front. For the same prescription and two different “Screen Distance”, the lateral position of the near vision zone remains unchanged, but the lateral position of the intermediate vision zone for the computer is customized.

parameter is used to customize the degression and the horizontal positioning of the intermediate vision zone relatively to the near vision zone.

Taking the “Screen Distance” into account does not change the vertical position of the intermediate vision zone in the lens. The length of the degression is therefore fixed. A general illustration of customized degression as a function of “Screen Distance” is given in Fig. 8 for Varilux® Digitime™ Room mid-distance lenses.

The default “Screen Distance” value is set to 63 cm which is the average distance of use for a computer (in the event that the optician do not indicate this parameter when the order is placed). It may range between 35 and 99 cm (as a reminder, 95% of people use their computer at a distance ranging between 38 and 88 cm).

**The benefits** provided by this parameter are a natural posture in front of the computer and maximum comfort for intermediate vision use.

**New light environment**

In addition to the optical design of lenses, it is essential to define an appropriate treatment for new light environments and for the spectral characteristics of the light emitted by screens.

**The role of light is essential, but can also be harmful at times**

Visible light plays a crucial role in our everyday lives. It is essential, in particular, for the perception of colours,

contrast and for visual acuity. Besides vision, certain frequencies of the visible light spectrum are even more important for our health. For example, blue-turquoise light, around 480 nm (465-495 nm) is known as “good blue” light because it is responsible for synchronizing our circadian rhythms (our biological clock) in charge of regulating our waking and sleep cycles, as well as our body temperature and mood<sup>4</sup>, among other things.

Chronic exposure to light also presents some risks for our visual health. Blue light is the highest energetic light to reach the retina, since ultraviolet radiation (UV), which is even higher in frequency, is blocked by the anterior ocular media. There is a rich literature on the harmful effects of blue light on the retina, the first articles dating back over forty years. But it was only recently that the precise spectrum of toxic action of this light on a cellular model of AMD was demonstrated.

**Identification by Essilor and the Paris Vision Institute of the toxicity of blue light on the retina**

Joint research conducted by the Paris Vision Institute (see inset) and Essilor International led to the identification of the most dangerous part of the blue light spectrum for retinal cells involved in the development of AMD<sup>5</sup>. The light inducing the highest mortality rate in retinal cells corresponds to a narrow band of 40 nm centred on 435 nm<sup>5</sup>. These wavelengths correspond to the blue-violet light bordering on the blue-turquoise light that is essential to our health (Fig. 9). The research was conducted on retinal pigment epithelium (RPE) cells, the first cells to degenerate in AMD. These cells were photosensitized, to form a model of aging and AMD, and exposed to narrow 10-nm bands of illumination in the blue-green spectral range, between 390 nm and 520 nm, under physiological conditions of solar radiation on the retina (with a control band centred on red at 630 nm).

**Protection provided by Crizal® Previncia®**

Photobiological studies demonstrated an average 25% reduction in cell death by apoptosis comparatively between Crizal® Previncia® lenses and exposure without a filter over the spectral range [400 nm ; 450 nm]. Fig. 10 illustrates the comparative levels of apoptosis between the naked eye (grey) and a Crizal® Previncia® lens for each blue light bandwidth. This level of protection over the long term would mitigate the risk related to harmful blue light, and therefore the onset of AMD.

**Blue-violet light is everywhere**

Today, our eyes are confronted with potential new dangers, both at home and at work. Several independent studies conducted by health agencies are now taking an interest in risks related to new sources of artificial light, such as light emitting diodes (LEDs)<sup>6</sup>, since the latter, particularly cool white LEDs, present an emission peak in the harmful blue-violet band (Fig. 11) and have a more elevated luminance/brightness than traditional sources. Yet, LEDs are now present in most modern lighting systems and in a large number of screens, especially computer, tablet and smartphone screens.

**A unique light filtering technology and wearer benefits**

Concerned about the amount of time we spend in front of screens, Essilor has made protection one of its priorities for its new range of lenses designed for a connected life. To protect our eyes, Crizal® Previncia® coating, the product of a unique light filtering technology, was therefore integrated into the entire range.

This technology **selectively filters out harmful blue-violet light**, emitted especially by screens, while allowing beneficial light (including blue-turquoise light necessary to the proper regulation of circadian rhythms) to pass through. This technology also provides the best protection against reflected light, smudges, scratches, dust and water for optimal vision and lasting transparency.

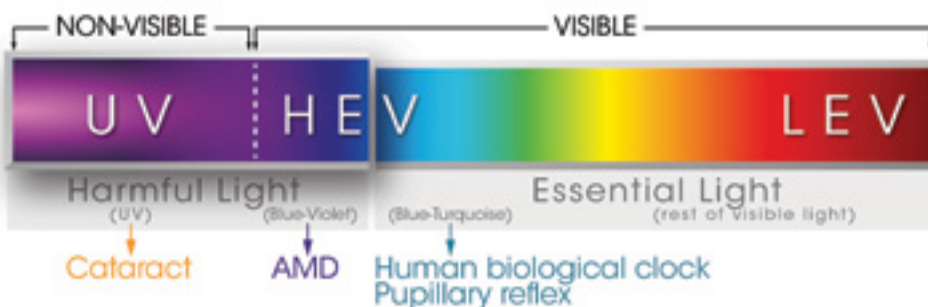


FIG. 9| Visible and ultraviolet light spectrum

**“For the prescriber, the new lens range stands out for its simplicity of implementation”**

The benefits of Eyezen™ lenses and mid-distance lenses combined with Crizal® Previncia® coating have been confirmed by numerous tests. When evaluated under actual conditions of use, 89% of wearers reported that they experienced **reduced glare and better contrast during screen use**. In addition, *in vitro* tests have shown that blocking 20% of blue-violet light would reduce the rate of retinal cell (RPE) death by apoptosis by **25%**<sup>7</sup>. This should contribute to longer-term health benefits, and particularly to the **prevention of premature aging of the eyes**.

**Recommendations concerning the mode of prescription**

For the prescriber, the new lens range stands out for its simplicity of implementation. We have made no changes to the prescriber’s usual practices. He or she conducts the eye exam to obtain the prescription in the usual manner.

- For **Eyezen 0.4, 0.6, 0.85** lenses, the only prescription required is for distance vision: the prescriber does not need to worry about selecting additional power.

- For **Varilux® Digitime™ Near, Mid and Room** mid-distance lenses, the distance vision prescription and addition is required: the prescriber does not need to worry about selecting the design.

As for the optician, Essilor can provide a “Screen Distance” measurement tool for in-store use so that the customer can also enjoy the benefits of a customized version of mid-distance lenses. All that the optician need do, when placing the order, is indicating the “Screen Distance” value obtained via this measurement tool in addition to the customer’s prescription.

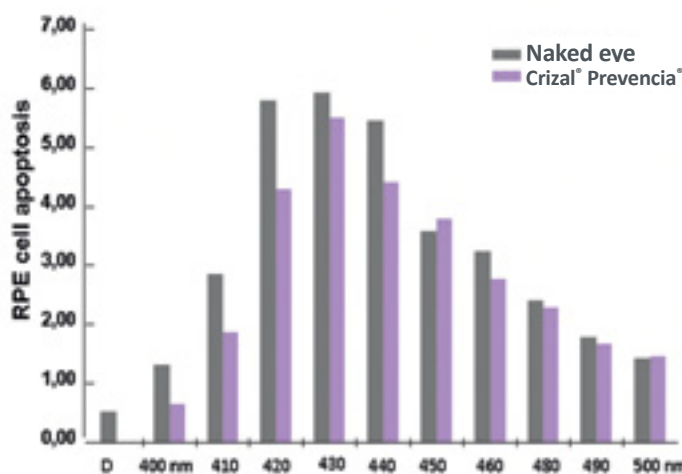


FIG. 10| Comparative results between a lens with Crizal® Previncia® coating and the naked eye on cell death by apoptosis of photosensitized RPE cells, exposed for 18 hours *in vitro* to sunlight normalized for a 40-year-old human eye.

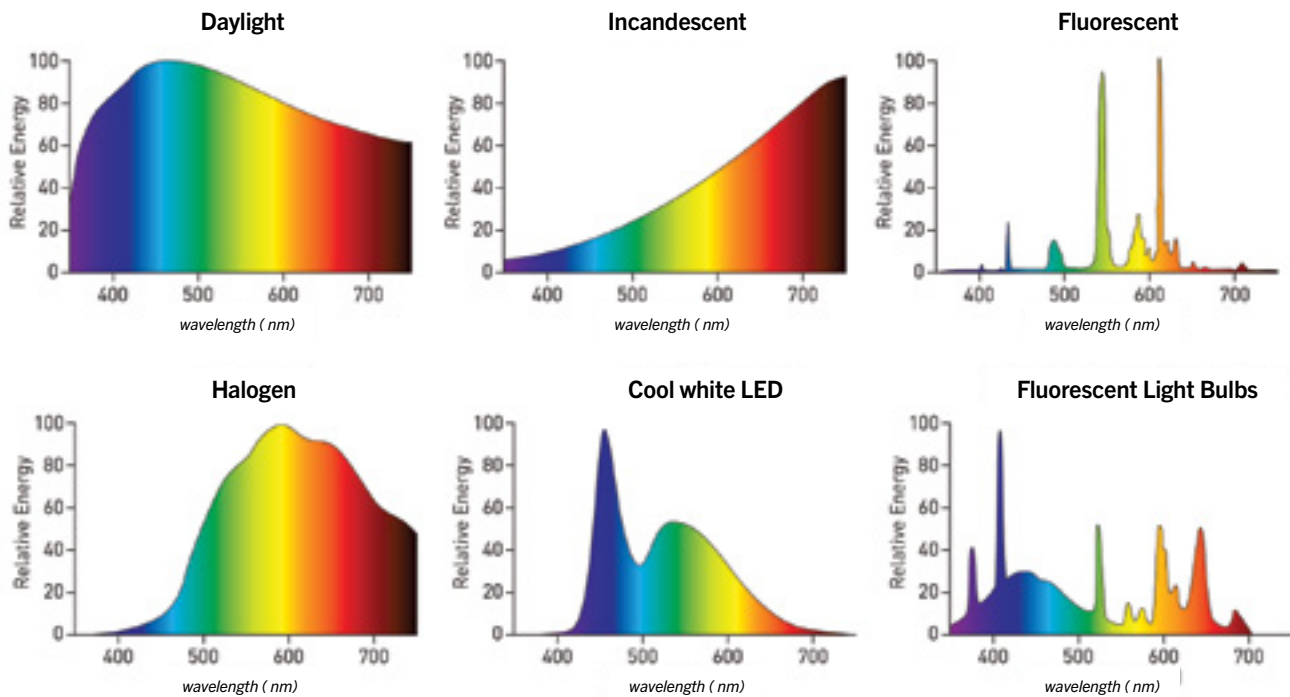


FIG. 11| Emission spectrum of various light sources including LEDs

**Conclusion**

By continually placing end users at the heart of its innovation process, Essilor closely studied how new digital devices and their use are impacting vision and posture, thus making it possible to identify and characterize new visual needs.

This in-depth understanding of the users of digital devices led to a combination of two cutting-edge technologies of power distribution and light filtering. This patented technology alliance (several patent applications have been filed and are currently under consideration), the basis of both Eyezen™ lenses for ametropes and emmetropes and of Varilux® Digitime™ mid-distance lenses for presbyopes, is a perfect fit with our new connected lifestyles.

These new lenses underwent performance testing under actual conditions of use and prescription before they were placed on the market. This approach was adopted to confirm their benefits and measure wearer satisfaction. •



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[www.institut-vision.org](http://www.institut-vision.org)



**YOUR PATIENTS SPEND A LOT OF TIME LOOKING AT SCREENS.**

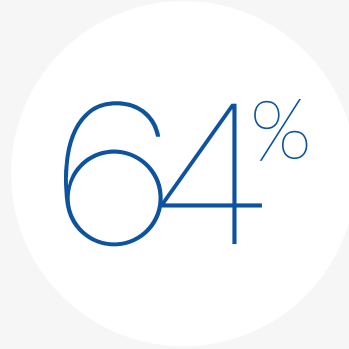
Smartphones, tablets, computers and TV are now an indispensable part of their lives, to socialize, inform, learn, educate, work, play, relax and see the world.



**4 DIFFERENT DIGITAL DEVICES ARE USED ON AVERAGE FOR WORK, EDUCATION AND LEISURE\*.**



**2 OUT OF 3 PEOPLE DAILY USE A SMARTPHONE.**



**64% OF PEOPLE SPEND 4 HOURS OR MORE ON A COMPUTER PER DAY.**

\* Consumer quantitative study conducted in 2014 among 4000 individuals in France, Brazil, China and the US by Ipsos for Essilor.



**KEY TAKEAWAYS**

- Connected life has changed our light environment and visual and postural behaviours.
- Essilor internal and external research centers have achieved a detailed comprehension of these needs.
- The new range of lenses for a connected life is the result of this research and was designed to respond to these new needs.
- It is available in several products to specifically meet each user's needs.
- They are suitable for all users starting at age 20.
- The range was tested and approved by wearers before it was placed on the market.

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# THE NEW RANGE OF EYEZEN™ LENSES: WHAT ARE THE BENEFITS PERCEIVED BY WEARERS DURING SCREEN USE?

With recent technological advances, ophthalmic lenses can now offer more than just good everyday vision. They are also aiming to meet emerging needs arising from connected life. Innovations are put to the test by specialized research institutes to measure user satisfaction and the effects of lenses on postural and visual fatigue during screen use.

The new Essilor® Eyezen™ lenses were tested in an independent study before they were placed on the market. This article describes the results obtained with a population of ametropic patients wearing single vision lenses.



 **Briec de Larrard**  
Consumer & Sensory research Director  
– Eurosyn, France

As a product testing specialist, Briec de Larrard is contributing in large measure to the development of Eurosyn's Research department and to the introduction of sensory testing in numerous business sectors. Today, he actively participates in the development and validation of innovative product testing methodologies on a national and international scale.

Essilor® Eyezen™ lenses were defined according to Essilor's R&D programme: LiveOptics. This programme includes four major steps for the introduction of a new design. Tests conducted with consumers known as "wearer testing" constitute the fourth part of this programme.

Because the best evidence is provided by the wearer, it was essential that this new class of Eyezen™ lenses be tested and approved by the final consumer.

To ensure the impartiality of this type of test and lend credibility to the key role assigned to the wearer in the quality process, testing protocols are validated by independent research institutes. The latter, which hold large consumer databases, are in charge of implementing questionnaires for the purpose of evaluating the objective and subjective performance of Essilor® products.



## KEYWORDS

Eyestrain, postural fatigue, glare, headaches, dry eye, contrast perception, adaptation, comfort, posture, digital screens, ergonomics, e-reading, digital devices, connected life, computer, smartphone, tablet, Essilor® Eyezen™, Crizal® Previncia®, ophthalmic lenses, wearer test, protocol.

**“To ensure the impartiality of this type of test  
and lend credibility to the key role assigned to the wearer  
in the quality process, testing protocols are validated  
by independent research institutes.”**

## INTRODUCTION

To focus attention on the consumer benefits of the new class of Eyezen™ ophthalmic lenses, Essilor contacted Eurosyn, a French market research institute specializing in sensorial analysis. In cooperation with this institute, Essilor established a test protocol for the purpose of validating the performance of Essilor® Eyezen™ lenses with a target group of ametropic subjects.

The purpose of this study was to verify whether or not an effortless transition from standard single-vision lenses to Essilor® Eyezen™ lenses was possible for persons with refractive error. More specifically, the goal was to determine the perceived benefits of this new range of lenses during digital device use.

## METHODOLOGY

The Essilor® Eyezen™ range comprises three new products: Essilor® Eyezen™ 0.4, Essilor® Eyezen™ 0.6 and Essilor® Eyezen™ 0.85. These three additional refractive powers were all tested during this study.

Thin lenses (n = 1.67) equipped with Crizal® Previncia® coating were chosen for this study. The lenses were optically centred on the height of the pupil, taking into account the measurement of the pupillary distance for far vision. Before beginning the wear period, each of the testers answered a quantitative questionnaire to assess their general satisfaction and the level of visual fatigue experienced (if any) with their usual eyeglasses (standard single-vision lenses). Each tester was asked to wear Essilor® Eyezen™ lenses instead of their main pair of usual eyeglasses for four weeks. These tests were performed “blind”, i.e. the subjects were given no information on the type of lenses being tested, and the prescription for these lenses was exactly the same as the prescription

for their previous pair of glasses, to avoid any bias related to the new refraction.

At the end of the wear period, the consumers evaluated the performance of the Essilor® Eyezen™ lenses by completing an online questionnaire. This questionnaire was used to quantify wearers' satisfaction in terms of visual comfort during the performance of everyday tasks, and more specifically, during tasks related to the use of digital devices.

## POPULATION

Inclusion criteria were: 1/ Be between 20 and 55 years of age. 2/ Be a user of digital devices (for at least 6 hours a day), 3/ Alternate between different screens. 4/ Present symptoms of visual fatigue and/or postural discomfort. 5/ Be ametropic and wear standard single vision lenses to correct distance vision (DV) with or without anti-reflective coating. 6/ Have a prescription less than 1 year old. 7/ Have a correction of:  $-4 < \text{Sphere} < +4$   $-2 < \text{Cylinder} < 2$ . 8/ Not be a wearer of progressive lenses. Exclusion criteria were: 1/ Associated strabismus and amblyopia. 2/ Anisometropia greater than 1.5 dioptre. 3/ Diabetes, glaucoma or other eye diseases. Wearers were recruited online by Eurosyn. The institute then contacted each subject to discuss their availability for appointments: the first to select the test frame and take all necessary measurements; and the second, to be fitted with the eyeglasses to be tested. During this appointment, visual acuity testing for distance vision (Monoyer scale) and near vision (Parinaud) was performed. For this wearer test, the sample population was divided into three groups, depending on the wearer's age: The first group of 25 wearers, aged 20 to 34, were equipped with Essilor®

Figure 1 shows that ametropia distribution is representative of non-presbyopic wearers of single-vision lenses

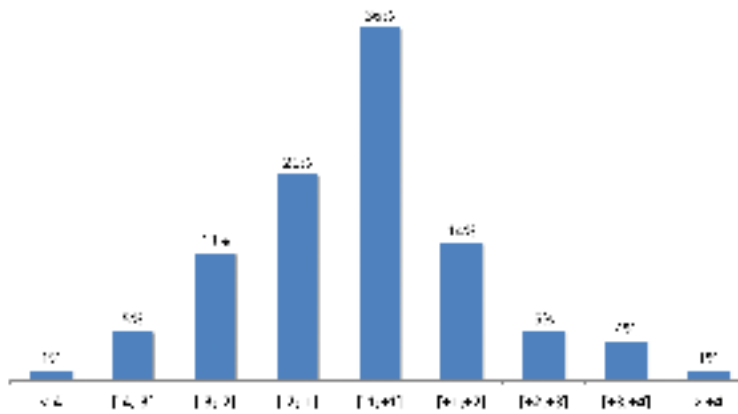


FIG. 1| Ametropia distribution (right mean sphere)

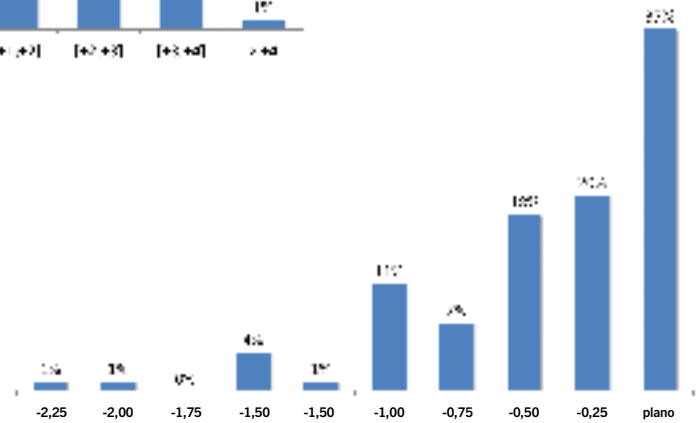


FIG. 2| Cylinder distribution (right eye cylinder)

Eyezen™ 0.4 lenses; the second group of 31 wearers, aged 35 to 44, were equipped with Essilor® Eyezen™ 0.6 lenses; and the last group of 20 wearers, aged 45 to 55, were equipped with Essilor® Eyezen™ 0.85 lenses. (Figure 1).

Cylinder distribution is shown in Figure 2. It indicates a high percentage of low astigmatism values with 75% of the sample having a cylinder of less than 0.5 dioptre.

**RESULTS**

The results concern the entire Essilor® Eyezen™ range, including all three additional refractive powers (0.4, 0.6 and 0.85). They are consolidated over the complete sample. **Seventy-six wearers tested the Essilor® Eyezen™ ophthalmic lenses for four weeks.**

In this type of test, the first criterion to be verified is adaptation. The wearers reported that adaptation to these new Essilor® Eyezen™ lenses was easy (“fairly easy” to “very easy”), and 83% were satisfied, all additional refractive powers combined. As regards rapidity of adaptation, 79% rated it as rapid (“fairly rapid” to “very rapid”).

The testers wore the Essilor® Eyezen™ lenses on a continuous basis throughout their activities (including during their use of digital devices). In fact, 94% of them wore the

Q. On average, how long did you wear these new lenses each day?

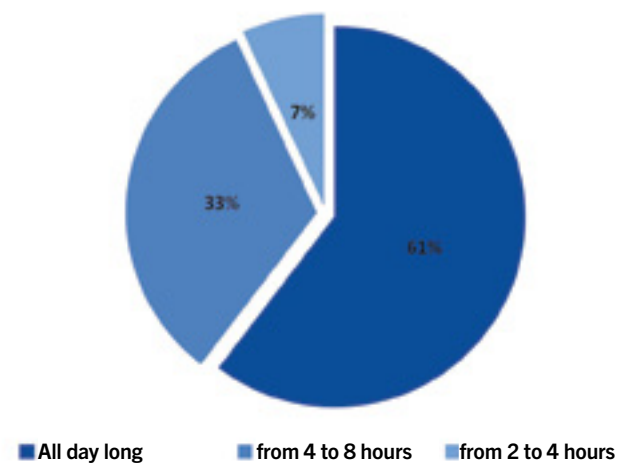


FIG. 3| Daily wear time



**Q. With these new glasses, what grade would you put to qualify the following visual discomfort**

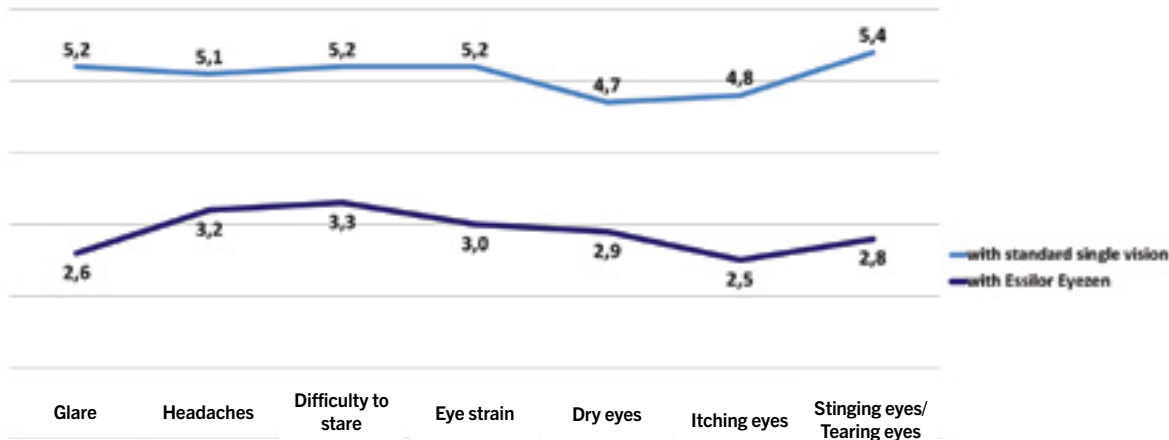


FIG. 4| Reduction of visual fatigue symptoms

Essilor® Eyezen™ lenses more than four hours a day and over one out of two testers wore Essilor® Eyezen™ all day long (see Figure 3).

A first observation was made on visual fatigue symptoms and postural pain felt by subjects. All wearers recruited for the test previously experienced ocular or postural discomfort during screen use.

At the end of the wear period, all wearers reported that they felt less visual and postural discomfort while using their digital devices. They stated that this discomfort was less frequent and less intense with the test lenses (Figure 4 and 5).

The remainder of the analysis was aimed at identifying the benefits perceived by the subjects while wearing Essilor® Eyezen™ lenses.

Due to the additional refractive power provided at the bottom of the lens, they are perfectly suited to wearers who make demands on their near vision throughout the day, particularly while using digital devices. Figures 6 and 7 highlight the performance of Eyezen™ lenses:

At the end of the day, 90% of wearers state that their eyes are less tired ('somewhat less tired' to 'much less tired'), in comparison with how they felt with their old eyeglasses (standard single-vision lenses).

**Q. With these new glasses, please grade postural discomfort**

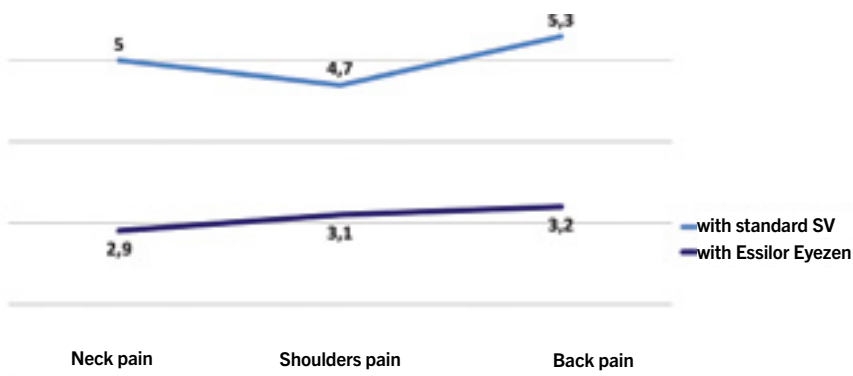


FIG. 5| Reduction of postural symptoms

**Q. With these new lenses, are your eyes...**

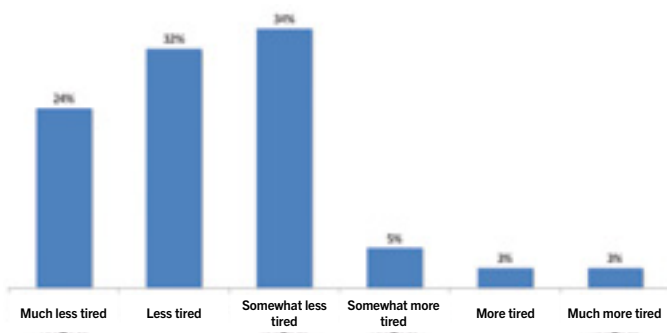


FIG. 6| Reduction in feelings of eye fatigue

**Q. With these new lenses, does your ability to read small characters seem to be...**

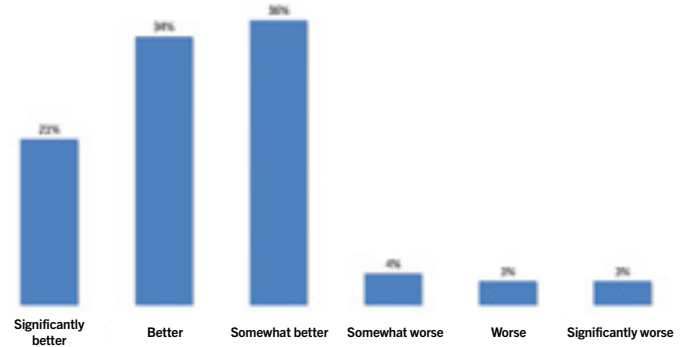


FIG. 7| Readability of small characters

**Q: With this new pair of glasses, the glare sensation facing screens is:**

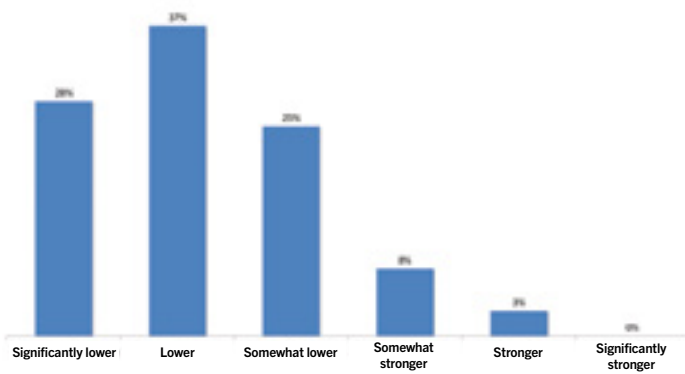


FIG. 8| Glare during digital screen use

**Q: With this new pair of glasses, contrast perception is:**

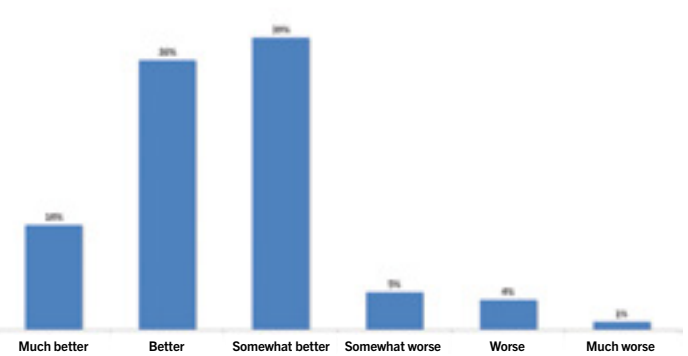


FIG. 9| Improved contrast perception

In addition, 91% of wearers who tested Essilor® Eyezen™ lenses felt that they had less difficulty reading small characters, particularly during smartphone use (see Figure 7: “somewhat better” to ‘significantly better’)

Moreover, 90% of wearers reported that light from screens caused less glare, as indicated in Figure 8.

It is also noteworthy that 89% of wearers had improved perception of contrasts with Essilor® Eyezen™ Crizal® Prevencia®, in comparison with their previous eyeglasses (see Figure 9).

Visual comfort = outcome of benefits

In addition, the study evaluated visual comfort during the use of digital devices, as well as the general satisfaction level.

Indeed, 91% of wearers reported having comfortable vision during screen use with Essilor® Eyezen™ lenses

(see Figure 10). 83% of wearers were very satisfied with the level of on-screen comfort provided by these new lenses. On average, 72% of wearers were satisfied with their visual comfort using a computer compared to their previous eyeglasses.

The final result, at the end of four weeks of testing, indicates that 91% of ametropic wearers were satisfied with Essilor® Eyezen™ (see Figure 11), with a satisfaction level ranging from 7-10 on a scale of 10. It is also noteworthy that 78% of wearers reported being very satisfied with the new Essilor® Eyezen™ lenses (with a score of 8-10 on a scale of 10).

This demonstration of performance over the entire Essilor® Eyezen™ range was verified for each of the additional refractive powers (0.4, 0.6 and 0.85). All three ophthalmic lenses provided an equivalent level of satisfaction for the individual testers, as indicated in Figure 12.

**Visual comfort before and after using Essilor Eyezen lenses  
(1= Highly uncomfortable to 10= Highly comfortable)**

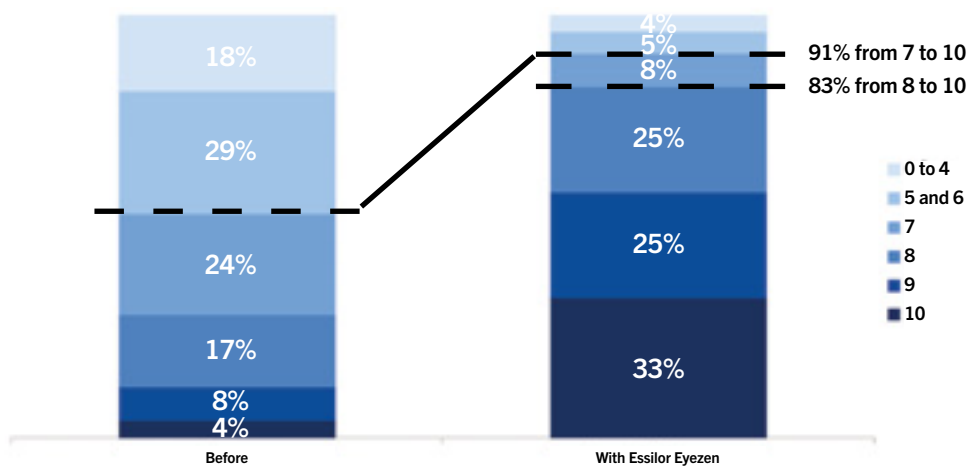


FIG. 10| Visual comfort while using digital devices

**Q: What was your general level of satisfaction with this new pair of lenses?  
(1= Highly unsatisfactory to 10= Highly satisfactory)**

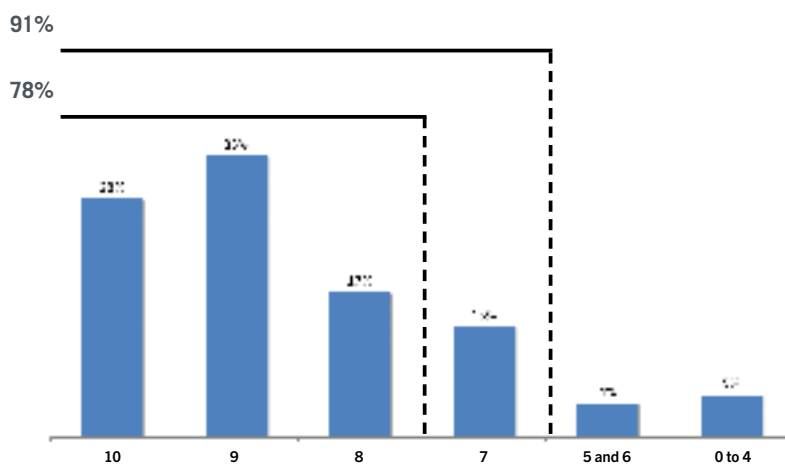


FIG. 11| General satisfaction

**Q: What was your general level of satisfaction with this new pair of lenses?  
(1= Highly unsatisfactory to 10= Highly satisfactory)**

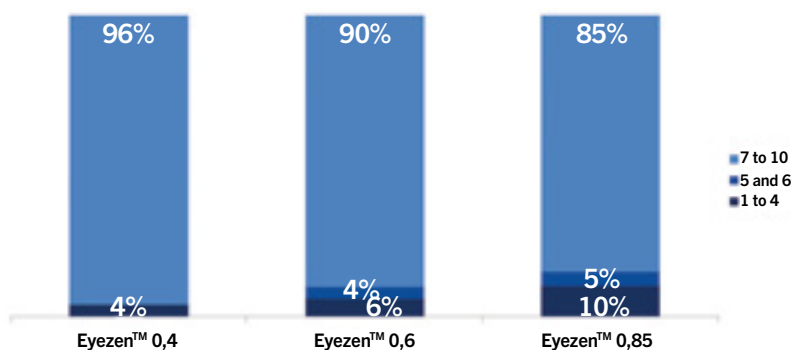


FIG. 12| General satisfaction relative to additional refractive power

**CONCLUSION**

Essilor® Eyezen™ lenses were tested and approved by ametropic wearers, who previously wore standard single-vision lenses, with very good results. Indeed, 91% of them were satisfied with the new Essilor® Eyezen™ lenses, regardless of their additional refractive power.

Throughout the testing, we observed that wearers preferred Essilor® Eyezen™ lenses to their previous eyeglasses by a wide margin. They reported that their eyes were less tired and that they had less difficulty reading small characters. Finally, during on-screen use, their impression of glare also seemed to have decreased while their perception of contrast increased.

In addition, this new type of lens can completely replace a standard single-vision lens, throughout the day for all types of activity. In fact, 94% of wearers, all prescriptions combined, wore these new ophthalmic lenses for a minimum of four hours a day.

In conclusion, Essilor® Eyezen™ lenses, combined with Crizal® Previa® coating, were truly appreciated by wearers. Today, 93% of them continue to wear their new eyeglasses, and 88% would recommend this new type of ophthalmic lens to their families and friends. •



**KEYTAKEAWAYS**

- Essilor® Eyezen™ ophthalmic lenses combined with Crizal® Previa® coating were approved during a wearer test conducted by an independent institute.
- The results showed a reduction in all symptoms of visual and postural fatigue.
- A reduction in glare and improved contrast were demonstrated during the use of digital devices.
- 91% of wearers reported having comfortable vision during screen use, and 91% expressed satisfaction with Essilor® Eyezen™.
- Essilor® Eyezen™ lenses are proving to be an appropriate solution for the emerging constraints arising from connected life. They are a suitable replacement for standard single vision lenses.

## **3. CONSUMER TRENDS**

# THE WELL-BEING OF 'WELL-SEEING' - WHY ARE WOMEN AND THE OVER-50s MORE ENGAGED WITH THE HEALTH OF THEIR EYES?

Prevention has become a focus of health strategies in many countries, especially those with growing ageing populations. Changes are also happening in the attitudes and perceptions of individuals. Two consumer groups in particular emerge as being more engaged in the health of their eyes: women and those over the age of 50.



**Philippe Zagouri**  
Managing Director at  
Zed Marketing 'Research', Paris, France

Philippe Zagouri is the founder of Zed Marketing Research and has a background in social sciences (Philosophy, Political Sciences). He has developed a true understanding of consumers' needs and behaviours based on intuition, rigour and through the use of non-standardised methodologies. For the last five years he has been strongly involved in fuelling Essilor with insights from wearers and ECPs worldwide.



**Joëlle Green**  
International Research Manager at  
Zed Marketing 'Research', Paris, France

Joëlle Green is a Research Manager at Zed Marketing Research, with a focus on international qualitative research. She has a background in social sciences (Durham University) and six years' experience of working in the field of global healthcare marketing, in both advertising and market research agencies.

#### KEYWORDS

Prevention, protection, eye health, vision health, sun protection, seniors, women, UV, blue, light

Over the period 2012-2014, Zed Marketing conducted multiple qualitative research projects with Eye Care Professionals (ECPs: i.e. opticians, ophthalmologists and optometrists) and consumers (glasses wearers) in France, Spain, Germany, Switzerland, China, the U.S. and Canada. From these, Zed Marketing was able to gain an understanding of consumer awareness and ECP management of preventive eye care to feed into impactful and *relevant* communication recommendations.

**We live in a visual society, but the eye is not number one**

*“Good vision is a part of good health, being safe and avoiding danger”* (U.S., 27, female).<sup>1</sup>

The eye is a highly complex organ that allows us to see and understand the world around us. Vision has always been important and is becoming increasingly so in today’s society, where even our mobile telephones have become more visual than audio.<sup>2</sup> Consequently, the loss of sight is the number one health fear in the U.S., higher even than HIV/AIDS or cancer.<sup>3</sup> Despite this importance placed on being able to see, the eye is often overlooked as a part of the body that cannot be protected or get ill in the same way as other organs.

*“Honestly, the health of the eye is something I just don’t think about, it’s not as important as my heart or my circulation”* (France, 51, male).<sup>4</sup>

When things go wrong with our sight under the age of 40 it is thought to be due to ‘bad genes’. Everyone is then aware that from the age of 45 or so, our eyesight starts to worsen. Presbyopia is accepted as inevitable and there is often little thought or question as to what could potentially be done to prevent, slow down the onset or the rate of deterioration.

**“To prevent an issue from happening is the best way to look at health; I do whatever I can to implement preventive measures.”**

**Challenging perceptions of how the environment affects our sight**

In more developed countries, consumers are only just beginning to consider additional exogenous factors and the impact it can have on the health of their eyes.

Ultra violet (UV) is the main offender, and is widely known already due to its noxious effect on skin.<sup>5</sup> However, the dangers associated with UV and its exact impact on eyes are often not clear and are underestimated. As a consequence, prevention against UV is currently often limited to wearing sunglasses on sunny days. The idea that UV can also affect the eyes on a day-to-day basis is often ignored.

Asia leads the way against Europe in terms of awareness and understanding about UV issues and related eye damage (a subject matter which has been widely reported about in Asian media).

*“UV protection is very simple, therefore no excessive description is needed. This is because everybody knows the damage that UV does to eyes”* (Optometrist, Taiwan).<sup>5</sup>

Globally, a dependence on technology and an increase in the number of hours spent looking at screens have raised concerns about ‘visual fatigue’ and the short term symptoms. Glasses-wearers are also beginning to notice that use of certain electronic devices for extended periods may be negatively affecting their visual performance in the long term.<sup>6</sup>

*“Before we used to read only books, now we are using all sorts of vision that never existed before”* (Canada, 30, female).<sup>7</sup>

Consumers in Asia are generally more anxious about ‘waves’ (radiations) in general, living in countries that rely heavily on technology and that have seen a drastic increase in the number of myopic children.<sup>8</sup>

Coupled with bad pollution in cities, this health-threatening environment has encouraged people to find strategies to try and avoid blue light (BL) damage with many anti-BL products available on the market.<sup>5</sup>

*"It's all those screens: too much TV, computer and playing on iPad"* (China, parent of a myopic child).<sup>9</sup>

Increased awareness about UV, BL, and the rise in the use of technology have started making people question the fragility of the eye and its health, before its unavoidable ageing.

Nonetheless, other than regular visits to an eye doctor, there would appear to be a general lack of awareness as to what should or can be done to keep the eye 'healthy'.

*"I see my doctor and use eye drops for dry eyes. What else is there left to do?"* (France, 46, female).<sup>4</sup>

**ECPs: currently control and correct**

Even if it may contribute to 'healthier' eyes, the act of going to see an ECP is often more reactionary than proactive. People currently do not think of going to see an eye doctor unless they require corrective glasses/contact lenses or have a problem with their eyes. For this reason, all eye care professionals are perceived by people as helping to correct vision and solve eye issues, rather than offering any preventive benefits.

**"The earlier preventive measures are taken, the more beneficial and impactful the effect can be."**



This belief is further underpinned by the ECPs themselves (especially opticians and optometrists), as even though in Europe and USA they are fully versed in UV damage, some are not always able to pinpoint the exact damage that can occur.<sup>10</sup> As a result, talking about the more abstract long-term benefits of protecting against UVs to their customers can prove to be challenging. At the time of our studies (2012, early 2013), only ECPs in Asia felt comfortable talking about BL to consumers to warn them of the dangers.<sup>5</sup>

**Focus on prevention**

Prevention has become a focus of health strategies in many countries, especially those with growing ageing populations. Changes are also happening in the attitudes and perceptions of individuals, all encouraging signs that eye health may soon be taken more seriously.

Two consumers groups in particular emerge as being more engaged in the health of their eyes: women and those over the age of 50.

**Over 50: prepared to help prevent**

With age, many people start to suffer from their first health issues, with certain diseases known to become more common. 50 is often used as a milestone for someone to take stock of their health and, where necessary, consider some healthy changes.

This can include a change in diet, increasing exercise and other preventive measures such as taking vitamins or getting regular health checks. Those over 50 are often proactively looking as to how they can stay healthy and avoid serious illnesses, and this too would seem to extend out to their eye health.

*"To prevent an issue from happening is the best way to look at health; I do whatever I can to implement preventive measures"* (France, 62, female).<sup>4</sup>



### Over 50: more aware of what can go wrong

The over-50s have a better general awareness of eye-related diseases (especially Age-Related Macular Degeneration (AMD), glaucoma and cataracts).

*“AMD is like Alzheimer’s of the eye, you lose your vision little by little, and it must be awful!”* (France, 55, male).<sup>4</sup>

This is thanks firstly to national disease awareness campaigns (which are sometimes directed specifically at this age group) inviting them to take self-diagnosis tests or to visit a doctor; and secondly, people over 50 have more experience of peers who have already been directly affected.

AMD is also becoming a much talked about topic, its incidence rate increasing with ageing populations.<sup>11</sup>

### Over 50: more aware of what is going wrong

For many, the onset of presbyopia is the first time in their lives that will require them to wear corrective glasses. As they become aware of something happening to their eyesight, they are, by association, more concerned about the overall health of their eyes.

### Women: avoid ageing at all costs

Women are more readily open to the idea of prevention as they have already integrated it for another organ: their skin. They are aware of and are often taking specific measures to slow down and prevent premature signs of ageing on their skin. The negative impact of UV on skin in this respect is well known, so the need to also protect eyes against UV light damage is more intrinsic for women. Inclusion of an AR or anti-UV coating can be an important criterion of lens choice for women.<sup>10</sup>

**“AMD is like Alzheimer’s of the eye, you lose your vision little by little, and it must be awful!”**

### Women: the importance of being seen (by an ECP)

Women visit health care professionals more often than men<sup>12</sup> and are more likely to seek out preventive care.<sup>13</sup> This may be due to women being more likely to report poorer health<sup>14</sup> or because, as women are often responsible for their family’s health, it is in their best interest to stay healthy. This means that preventive health care measures are generally more top of mind.

*“My grandma has AMD, I want to be sure that I have my eyes checked as often as possible”* (Canada, 44, female).<sup>6</sup>

Men, on the other hand, seem to have lower awareness about health problems and are more reluctant to go to the doctor.<sup>15</sup>

### ECPs: moving towards prevent and protect

ECPs, too, are thinking more preventively, as they now have better options that they can propose to consumers. Whilst prevention has always been considered more within the remit of ophthalmologists, opticians are also keen to get involved.<sup>16</sup>

*“The optician proposed the [anti-reflective] treatment because I work on the computer a lot and spend considerable time outside as well.”* (U.S., 46, male)<sup>1</sup>

However, going further than offering a preventive solution – and explaining how the use of optical products can help the prevention of premature eye ageing and eye disease – can be a difficult and abstract idea for consumers to accept.<sup>10</sup>

*“Mentioning that the lenses help to prevent eye diseases is not convincing enough. The customers cannot feel the benefit directly.”* (Taiwan, optometrist).<sup>5</sup>

**“Good vision is a part of good health, being safe and avoiding danger.”**

*“Glasses only correct vision, I’m not aware of how they could work as prevention” (France, 58, female).<sup>4</sup>*

**Looking to the future**

As positive as it may be that certain groups of society and ECPs are increasingly concerned about preventive eye health, some key questions remain.

Firstly, how to engage men, non-corrective eye-glasses wearers and most importantly younger generations on eye health matters that are not necessarily top of mind?

The earlier preventive measures are taken, the more beneficial and impactful the effect can be. This is going to be significant in Asia, with

their ever-growing number of children with myopia.

Secondly, how to further educate on risks associated with cumulative exposure to harmful light, a non-tangible subject for many consumers, as it is not something that can necessarily be seen? Europe and the U.S. should perhaps look to Asia for guidance and examples on how best to communicate and raise awareness about UV and BL. These questions may become even more important in the global context of today’s screen-society – young people currently spend on average six hours 50 minutes per day looking at a screen<sup>17</sup> – and this looks set only to increase. •

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**KEY TAKEAWAYS**

- Despite the increasing importance of vision in today’s society, the eye is not thought about in the same way as other organs and little is done preventively.
- Consumers (especially in Asia) are beginning to understand that there may be exogenous factors that can have an impact on the eye’s health such as UV and visual fatigue from screen overuse.
- There is a general lack of awareness of what can be done to keep the eye healthy: ECPs (eye care professionals) are currently perceived as being only a measure to correct eye issues rather than prevent anything.
- However, there is a move towards thinking about ‘prevention’ at both governmental and individual level for all things health, especially amongst women and those over 50 years old.
- Over-50s are more engaged in their eye health as suffering from presbyopia and potentially other health issues (or at least aware of them) makes them more open to the notion of prevention.

- Women are more engaged in their eye health as already preventing ageing of another organ, skin, and are more aware of health issues so more likely to see an ECP than men.

# PROTECTION OF EYE HEALTH: WHAT PRACTICES THROUGHOUT THE WORLD AND WHAT LOCAL SPECIFICITIES?

In 2014, the protection of eye health is a widespread practice worldwide. Yet there are behaviours specific to each country. A major international survey of 7,000 people conducted on four continents – Europe (France, Germany), North America (United States), South America (Brazil) and Asia (China, Japan, India) – revealed the similarities and differences of the various practices.



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#### KEYWORDS

Prevention, protection, eye health, vision health, sun protection, seniors, women, trends

While eyes have always been seen as a precious asset, they are difficult to preserve throughout a lifetime. With the spectacular advances in ophthalmology in recent decades, it has become easier to improve and maintain one's eyesight. In fact, far more information about eye health and safety is available than ever before. And in many countries, access to eye care specialists has greatly improved.

Yet there are still areas for improvement worldwide because the question remains: at a time when we are bombarded with information, have we all become accustomed to protecting our eyes? What are the most widespread practices in today's world? And are they evenly spread across all segments of the population?

To answer these questions, Ipsos conducted a major international survey on the following four continents in 2014<sup>1</sup>: Europe (France, Germany), North America (United States), South America (Brazil) and Asia (China,

Japan, India). In each country, a sample of 1,000 people representative of the national population was surveyed (urban populations in China, India and Brazil). Overall, 7,000 interviews were conducted. In each country, the same indicators were measured, enabling researchers to compare perceptions and habits across different countries.

In the end, it appears that protecting eye health is a widespread practice worldwide, but that public education on the issue differs from one country to another. The research supports the need for different communication and targeting strategies to continue improving the public's well-being and eye health.

**On a global scale, two-thirds of individuals take preventive measures to protect their eye health.**

Interviewed about what they do to protect their eyesight, 68% of respondents said they take at least one preventive measure (see Fig. 1). Notable fact: this figure is comparable across countries. In countries such as China and Brazil, the health habits of the urban middle classes are increasingly dovetailing with those of populations in developed countries. There is only one noteworthy exception: in Japan, only 36% of respondents report taking one preventive measure.

**The two pillars of prevention: sun protection and visiting a vision care specialist**

How do people take care of their eyes? Two preventive measures particularly stand out worldwide. The wearing of sunglasses is the first measure. This is a well-established habit among 32% of respondents. Protecting the eyes from sun exposure is viewed as a very important health habit. Populations in France and the United States are most likely to be concerned about this issue. In these two countries, nearly one in two individuals reports wearing sunglasses to protect their eyes – 45% in France and 47% in the United States.

**“The ubiquitous presence of screens is encouraging the most exposed individuals to protect their eyes”**

The second most widespread preventive measure worldwide is visiting a vision care specialist. From this perspective, 30% of respondents believe there is nothing better than regular eye checks. It should be noted that people living in Western countries are much more likely to regularly visit a

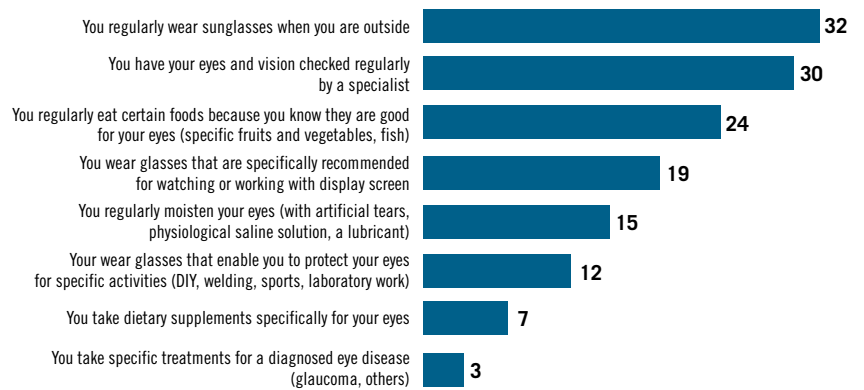
vision specialist: 48% in France, 41% in the United States and 31% in Germany. In Asia, regular check-ups are much less common (11% in China and 7% in Japan). Respondents reported other practices as well, but they are much less widespread and their intensity varies greatly from one country to another. It should be noted, however, that the ubiquitous presence of screens is encouraging the most exposed individuals to protect their eyes. This reflects the fact that computers and tablets are now an integral part of the workplace for a large number of people, with the proportion of those using lenses for protection from touch screens numbering on average one in ten individuals among the surveyed population. Lastly, certain measures are specific to certain cultures. For example, in

Asia (mainly India and China), a significant percentage of the population reports regularly eating certain foods that supposedly have a positive effect on eyesight (47% in India and 41% in China). This type of prevention measure is much less common in Western countries, where food is more likely to be associated with health benefits unrelated to vision health.

**Seniors and women are most concerned about protecting their eyesight**

The survey confirms that certain segments are more concerned about protecting their eyes than the rest of the population. Not surprisingly, the older you get, the more likely you are to take steps to preserve your eyesight (see Fig. 2). Seventy-three percent (73%) of people over 50 report taking preventive measures compared to 66% of those under 35. Visiting an eye care professional is the factor that

FIG 1 | Specific things people do for their eyes (in %)



“Seniors and women are most concerned about protecting their eyes”

most differentiates the older population. While all generations have adopted the habit of wearing sunglasses, the practice of regularly visiting a vision specialist increases with age. Forty-one percent (41%) of people over 50 report doing so compared to only 25% of those under 35. Another segment being proactive about caring for their eyes is women. For one thing, more women do something to protect their eyesight: 70% versus 65% of men (see Fig. 3). Secondly, they are significantly more proactive than men when it comes to most preventive measures. Far more women than men, for example, report wearing sunglasses when they are outside (37% vs. 28%). Women are also more likely to regularly see a vision specialist (33% vs. 27%). Similarly, they are more likely than men to report taking into account the ability of certain foods to protect their eyesight (26% vs. 22%). Last but not least, more women than men lubricate their eyes (17% vs. 12%). In short, women are currently more aware than men and act accordingly. This is a tuned-in population, which means that women are also seeking information on long-term protection.

**Eye care professionals: an intermediary role among healthcare providers**

A more detailed breakdown of the figures concerning visits to eye care professionals shows that 37% of respondents reported seeing an ophthalmologist (optometrist in English-speaking countries) at least once a year and 29%, an optician. These figures are significant: on aver-

age, one-third of the population has contact with a vision specialist at least once a year. Yet when these figures are compared with those involving other specialists, it becomes clear that visits to other professionals are far more common. (Fig 4) This especially holds true when it comes to general practitioners, whom 63% of respondents report seeing at least once a year. And respondents report visiting dentists far more often than they do ophthalmologists. Fifty-nine percent report visiting an ophthalmologist at least once a year.

Overall, eye care professionals rank behind dentists and, for women, gynaecologists. On the other hand, they rank ahead of dermatologists, osteopaths, cardiologists and nutritionists. Vision specialists play an important albeit intermediary role. In all of the survey’s countries, patients are much less likely to visit an eye care professional than a general practitioner, which is to be expected, but also far less likely than a dentist even though vision is a precious asset, as demonstrated by numerous surveys. For example, a survey conducted by Ipsos in 2013<sup>2</sup> among young people aged

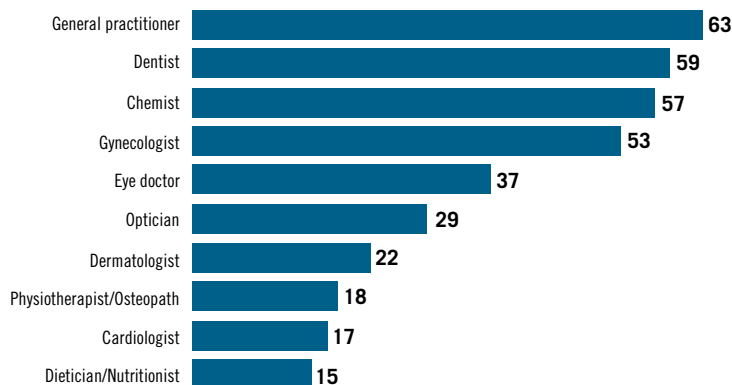
FIG. 2 | Differences between age groups.

	TOTAL	16-34 y. o.	35-49 y. o.	50-64 y. o.
% DO AT LEAST ONE ACTION FOR THEIR EYES	68	66	65	73

FIG. 3 | Differences between men and women.

	TOTAL	Men	Women
AT LEAST ONCE	68	65	70
You regularly wear sunglasses when you are outside	32	28	37
You have your eyes and vision checked regularly by a specialist	30	27	33
You regularly eat certain foods because you know they are good for your eyes (specific fruits and vegetables, fish)	24	22	26
You wear glasses that are specifically recommended for watching or working with display screens	19	19	19
You regularly moisten your eyes (with artificial tears, physiological saline solution, a lubricant)	15	12	17
You wear glasses that enable you to protect your eyes for specific activities (DIY, welding, sports, laboratory work)	12	16	8
You take dietary supplements specifically for your eyes	7	6	7
You take specific treatments for a diagnosed eye disease (glaucoma, others)	3	4	3

FIG. 4 | The healthcare professionals they have visited.



15-30 showed that the eyes, after the teeth, were the part of the body considered most important to take excellent care of as early as possible. This opinion was consistent across Europe, the United States and China. Europe ranks number one for the frequency of visits to general practitioners, while the number of visits to eye care professionals is relatively uniform among the other regions covered by the survey. Americans are most likely to get regular eye checkups and to see an ophthalmologist than any other nationality. In emerging countries, the urban and online population has greater access to vision professionals.

Lastly, while seniors are more likely than young people to visit specialists, a significant percentage of young people get regular checkups. This fact can undoubtedly be explained, in part, by the role played by parents and schools.

**Women and seniors: populations more concerned about protecting their eyesight**

In conclusion, it seems that while populations in most of the countries surveyed are aware of measures to protect their eyesight, certain seg-

ments are more committed. In particular, women and seniors are more likely to see vision specialists and on a more regular basis. As a result, they are priority targets for any prevention campaign. These results should also encourage eye care professionals to also target less committed populations, i.e. young people and men. This is a public health issue that requires more targeted information. •

**“Protecting eye health is a widespread practice worldwide”**



**KEY TAKEAWAYS**

The two pillars of prevention worldwide: sun protection and visiting a vision care specialist

- 32% of people worldwide wear sunglasses (45% in France, 47% in the USA)
- 30% of people see a specialist (48% in France)
- 41% in the US, 31% in Germany, 11% in China, 7% in Japan.

On average, one-third of the population has contact with a specialist at least once a year.

- 37% of respondents see a doctor-prescriber at least once a year, and 29% an optician.

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