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Violet and Blue Light: Impact of High-Energy Light on Vision and Health

Daniel Chang[1], Tawnya Pastuck[2]*, Robert Rosen[2], Sarah Hollmann[3], Tanja Babic[3] and Andris Stapars[2]

[1]Empire Eye & Laser Center, CA, USA
[2]Johnson and Johnson Surgical Vision, Andrew Place, Santa Ana, CA, USA
[3]EVERSANA Life Sciences, CA, USA

***Corresponding author:** Tawnya Pastuck, Johnson and Johnson Surgical Vision, Andrew Place, Santa Ana, CA, USA, Tel: 360.600.3489; E-mail: tpastuck@its.jnj.com

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Abstract

Violet and blue light are frequently grouped together and referred to as high-energy light despite having different clinically relevant properties. This paper reviewsthe visual and health benefits and concerns of these discernable high-energy light wavelengths. An overview of light spectra categorization, environmental sources and how it interacts with the eye for vision and health is provided. The differential impact of violet light and blue light on visual quality and function, phototoxicity and circadian rhythms is explored. Clinical evidence shows blue light is important for scotopic vision and entrainment of the circadian rhythm, while violet light is associated with chromatic aberration, increased light scattering and increased phototoxicity. The literature surrounding light filtration by intraocular lenses (IOLs) shows that a chromophore should maximize the filtering of known harmful wavelengths while minimizing the filtering of potentially beneficial wavelengths. Possible photoreception improvements were also identified by the use of high-energy light filtering chromophores coupledwith high-index, high-dispersion IOL materials. The authors recommend consistent, accurate differentiation of violet light and blue light when referring to high-energy wavelengths of light. Further studies separating violet light and blue light are warranted.

Keywords: Blue light; Violet light; Intraocular lenses; Chromophore filters

Introduction

Visible light is part of the continuous electromagnetic spectrum, with no natural breaks to necessitate a division into individual colors. However, in order to understand and to study its component nature, visible light has been divided into wavelength ranges corresponding to the spectral colors. These visible light spectral categories have been defined by the International Organization for Standardization (ISO) (Table 1) and provide logical divisions based on measured spectral characteristics [1-3]. In spite of these definitions, review of the ophthalmic literature reveals many differing wavelength values and general definitions for the terms "blue light" and "blue light hazard." While the terms frequently refer to both blue light and violet light, they are not often acknowledged as such. Moreover, studies have reported conflicting results on the health benefits and concerns of light encompassed within these terms. A few studies have identified the need more specifically to differentiate between violet light and blue light to resolve the conflicting outcomes. There are a vast range of ophthalmic exposure studies to violet light and blue light,ranging from advanced *in vitro* human retinal pigmented epithelium (RPE) cell culture evaluations to large *in vivo* longitudinal designs with validated subjective endpoints. In this paper we review the pertinent evidence found for violet light and blue light filtering relative to their effect on vision quality and visual function, phototoxicity, as well as circadian rhythm and cognition from Pubmed, Scopus and manual searches performed until June 2020.

Additionally, this paper will explore the evidence supporting the concepts behind wavelength selection of light filtering for IOLs.

Light and the Retina

The literature acknowledges that there is no consensus cutoff to the visible spectrum [4], with slight differences between competing definitions by organizations such as the ISO and the International Commission of Illumination (CIE). Due to relevance of ISO ophthalmic standards, this review adopts the ranges set by ISO. The visible light spectrum begins with violet light at 380 nm and ends with red light at 780 nm [2]. Based on ISO 20473 and 20772, blue light is defined between 460 nm to 500 nm, and violet light is defined between 380 nm and 460 nm wavelengths [2,3]. Since energy is inversely proportional to wavelength, blue light is only second to violet light in high-energy, short-wavelength value ranges. Thus, while blue light has been grouped with violet light in some studies with respect to its effect on the eye, they are in fact distinct visible spectral categories with discernibly different positive and negative effects.

Natural light originates from the sun, which has a fairly even irradiance spectrum in the visible range [4]. Artificial light sources

Table 1: Visible spectral categories [1-3].

Wavelength range (nm)	Color
380 nm ≤ λ< 460 nm	Purple (Violet)
460 nm ≤ λ< 500 nm	Blue
500 nm ≤ λ< 570 nm	Green
570 nm ≤ λ< 591 nm	Yellow
591 nm ≤ λ< 610 nm	Orange
610 nm ≤ λ< 780 nm	Red

Abbreviations: λ=Wavelength; nm=Nanometers.

through the years have included incandescent, halogen, fluorescent, and light emitting diodes (LEDs), each with its own characteristic irradiance spectrum. LEDs have emerged as the preferred artificial lighting source used both in electronic devices as well as general lighting [5,6]. Although most LEDs used in electronic devices appears white, they have a dominant wavelength in the blue-light range (450 nm to 470 nm) near the peak sensitivity for the melanopsin system, an important contributor to circadian rhythm [5,6]. Consequently, LED exposure at different times of day has elevated the awareness of differing light wavelengths and the possible implications those wavelengths have on ocular tissue and general health.

When visible light reaches the retina, it stimulates three types of retinal cells; cones, rods, and intrinsically photosensitive retinal ganglion cells (ipRGCs), with each cell type being stimulated by a specific wavelength and intensity of light. Cones are stimulated in photopic (i.e., brightly lit) conditions and can be subdivided into three types based on their sensitivity to various wavelengths. Long wavelength cones (L-cones) have a peak sensitivity range of approximately 556 nm to 563 nm, medium wavelength cones (M-cones) of approximately 526 nm to 534 nm, and short wavelength cones (S-cones) have a peak sensitivity range of approximately 418 nm to 420 nm [7,8]. Full absorption curves and wavelength stimulation is seen in Figure 1 [9,10]. L and M cones are densely packed in the fovea accounting for the ability of high visual acuity [11], whereas the S-cones are peripheral to the fovea and constitute 5 -10% of the total cone population [12]. The relative low density of S-cones in the visual system may have two potential benefits. First, less dependence on high energy wavelengths minimizes image quality compromises due to the refractive properties of the vitreous [11]. Second, less absorption of high energy wavelengths mitigates the risk of potential retinal damage. Rods out number cones by more than 20:1 and are stimulated in scotopic (i.e., low light) conditions, with their sensitivity peaking at approximately 498 nm [7,11]. Although rods are specialized for sensitivity, they have a low spatial resolution [11]. Finally, the ipRGCs, which do not transmit images but are responsible for circadian rhythms and contribute to pupillary response to light, have a peak sensitivity range of 460 nm to 480 nm [10,13,14]. Further studies have reported maximum response for circadian entrainment range from 460 to 500 nm and pupil response peak sensitivity at 482 nm for ipRGCs [10,13]. As such, retinal cell stimulation for functions such as photopic and scotopic vision, regulation of circadian rhythms and pupil size have a greater dependency on blue light versus violet light (Figure 2, Table 2).

Table 2: Retinal cells, wavelength ranges and ocular relevance [7,8,10,11].

Retinal Cells	Approximate Peak Sensitivity Range (nm)	Ocular Relevance
Cones L-cones M-cones S-cones	 556 nm-563 nm 526 nm-534 nm 418 nm-420 nm	• Plays role in photopic vision • Mediate daylight vision and critical for color discrimination • Specialized for visual acuity at the expense of light sensitivity • S-cones peak within violet light spectrum (380 nm-460 nm)
Rods	498 nm	• Plays role in scotopic vision • Extremely sensitive to light at the expense of resolution • Peak within blue light spectrum (460 nm-500 nm)
ipRGCs	460 nm-480 nm	• Plays a role in pupil response to light • Provide primary light input for circadian rhythms • Peak within blue light spectrum (460 nm-500 nm)

Abbreviations: L=long; M=Medium; S=short; ipRGCs=Intrinsically photosensitive retinal ganglion cells; nm=Nanometers.

Visual Quality and Function

Scotopic vision

The human eye has a dynamic range of over 12 orders of magnitude, allowing vision from luminance levels ranging from 3 × 10-6cd/m^2 (faint starlight) to 3 × 106 cd/m^2 (tungsten filament) [15]. While cones primarily mediate photopic (>101/2 cd/m^2) vision, rods are important in both mesopic (10-3 to 101/2 cd/m^2) and scotopic (<10-3 cd/m^2) vision [15]. Since rods have a peak sensitivity in the 498 nm blue-green range [10] (Figure 1), lower levels of illumination increase the importance of short wavelength blue light to vision and contrast.

Transmission of blue light to the retina is affected by both the natural aging process and the development of cataracts. As the eye ages, changes in the retina and lens reduce the number of rods and decrease the transmission of short-wavelength violet and blue (380 nm to 500 nm) light, leading to reduced scotopic and mesopic vision [16]. Consequently, age-related reduction in scotopic and mesopic vision has a negative impact on patient functionality and safety [17]. Further, age-related loss of scotopic sensitivity is more significant for blue light than for light of higher wavelengths (e.g., green or red), since the transmission of blue light is responsible for 35% of scotopic vision compared with 7% of photopic vision [18,19]. This is important because the processing of light during dark adaptation causes a shift of peak luminance sensitivity from red light towards the blue light end of the spectrum [19].

Several industries, including the military and aviation, have leveraged the importance of blue light for vision in low-light conditions. For example, since blue-green lights appear brighter and red lights appear dimmer in low-light conditions, airports use blue lights to illuminate taxiways and holding areas to make them clearly visible to pilots at night [20,21]. This allows for good visibility of blue-green light while allowing pilots to remain dark adapted while taxiing to the runway or terminal.

Chromatic aberration

Chromatic aberration affects all optical systems and is caused by the dispersion of a lens material, which is the change of refractive index with differing wavelengths of light [22]. For example, the Duochrome Test is based on the principle of longitudinal chromatic aberration

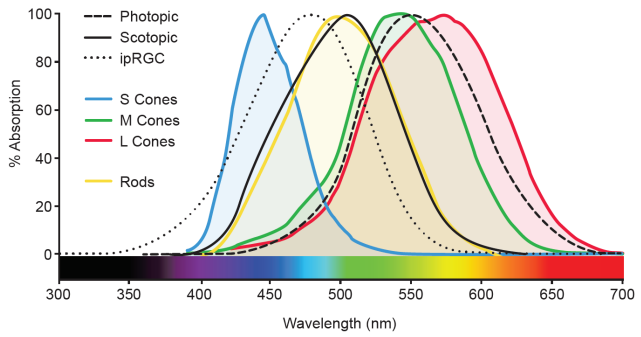

Figure 1: Wavelength of light mediating photopic and scotopic vision, and circadian rhythms coupled with L-cone, M-cone and S-cone and Rods action spectra [7,8,10].

Abbreviations: nm=Nanometers; ipRGC=Intrinsically photosensitive retinal ganglion cells

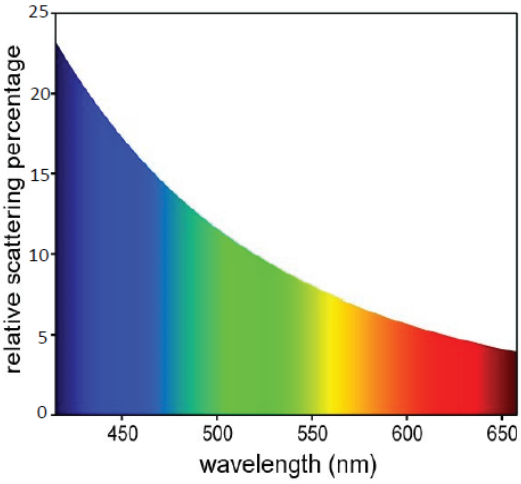

Figure 2: Rayleigh scattering of light by wavelength [28].

Greater proportion of violet light scatter is shown relative to red light.

Abbreviations: nm=Nanometers

(LCA); which states that the shorter wavelengths of light (green light) are refracted more by the human eye than longer wavelengths of light (red light) when looking through a lens [23]. Both green wavelengths and red wavelengths are dioptrically equidistant from yellow wavelengths (approximately 0.25 diopters). Emmetropia is therefore determined when the yellow wavelength is at the plane of the retina, and patients view the black letters on both the green and red backgrounds with equal clarity.

The rate of refractive index change is a function of wavelength, with the greatest LCA observed for high-energy violet light and blue light [24]. This is evidenced by the color named and commonality of the term "purple fringe." Most commonly, the term is used in photography, but it dates back to at least 1845, when it was used to describe a remaining chromatic aberration during the development of an otherwise "perfect" achromatic lens [25]. Furthermore, in the visual system the chromatic difference of refraction for violet light is roughly double that of blue light [26]. Therefore, violet light has the greatest potential negative impact on visual quality, particularly in materials with higher dispersive qualities.

Effects of light scatter including contrast sensitivity

Retinal straylight is wavelength dependent and results from entoptic light scattering [27]. It has been shown that high-energy short-wavelength light is more prone to scatter, thus violet light is the color with the highest percentage of scatter (Figure 2) [28]. Light scatter degrades image quality, manifesting clinically as starbursts, halos, and glare [29,30]. For example, the phenomenon of disabling glare can be caused by light scatter from opposing headlights while driving at night [27,31]. Additionally, retinal straylight has been reported to reduce vision in low-light conditions and reduce contrast sensitivity [32,29,31]. Studies that evaluated the impact of various wavelengths of light on image contrast reported that optimum contrast is achieved by blocking wavelengths shorter than 450 nm (i.e., in the violet light spectrum) but not those longer than 480 nm, indicating that violet (not blue) light degrades image contrast [33,34]. A supporting study concluded that the ability to block 100% of ultraviolet A and violet light, while transmitting blue light to preserve scotopic sensitivity, is ideal for sunglasses and indoor clear lens spectacles [14]. Elderly individuals frequently experience reduced visual quality, specifically contrast sensitivity, which can compromise safety, functionality, and quality of life. For example, reduced contrast sensitivity is associated with an increased risk of falls in elderly individuals due to a reduced ability to see uneven surfaces (e.g., curbs) when walking [35,36]and an increased risk of being involved in a traffic accident [37]. In patients with cataracts, reduced contrast sensitivity can lead to self-regulation of driving behavior (i.e., patients limit the amount of driving due to perceived risks) and depressive symptoms, further indicating that contrast sensitivity is an important consideration for patient safety and functionality. Accordingly, researchers in the United Kingdom have proposed that contrast sensitivity testing should be implemented along with visual acuity when determining the ability of older individuals to drive [37]. Additionally, a study demonstrated that lenses filtering wavelengths of light up to 430 nm (i.e., violet light) were associated with greater improvements in visual functioning than traditional blue light-filtering lenses in a patient population with retinal diseases including diabetic retinopathy, glaucoma and age-related macular degeneration (AMD) [38].

Phototoxicity

Exposure to short-wavelength high-energy light can contribute to oxidative stress by producing reactive oxygen species (ROS) which may in turn lead to ocular damage and contribute to conditions such as AMD [10,39-42]. The risk of retinal phototoxicity correlates with the energy of the light, thus violet light presents the greatest risk [42]. Therefore, despite the common label of "blue light hazard," it is indeed violet light and ultraviolet light, not blue light, that primarily contributes to phototoxicity. In fact, it has been proposed that blue light may not pose a substantial risk at all [16]. Most studies that investigated the effect of light on ocular damage used either white light or broad bands of "blue" light, ranging from 390 nm to 550 nm [42]. However, Godley and colleagues showed that visible light with peak absorptions at 370 nm, 440 nm and 450 nm caused cell dysfunction in confluent cultures of human RPEs through the action of ROS on DNA, thus possibly leading to age-related pathologies [43]. Moreover, a study conducted by Marie and colleagues using narrow (10 nm) bands

of light irradianceshowed that violet light in the 415 nm to 455 nm range, with a peak at 420 nm, causes the greatest amount of hydrogen peroxide formation, a ROS associated with cell damage [42].

Circadian Rhythm and Physiological Functions

The circadian rhythm is dynamic over a lifespan and impacts nearly all physiological functions including cognition, sleep, metabolism, cardiovascular health, and immunity [44]. Blue light is essential for entrainment of the circadian rhythm [14,,44-46,]. While morning and even daytime exposure to blue light is important, excessive exposure to blue light at night, such as with evening electronic device use, can have deleterious effects [47]. When stimulated by blue light, ipRGCs release melanopsin, which suppresses the release of melatonin, a key hormone that regulates the circadian rhythm [48,49]. Chronic impairment of the circadian rhythm has a negative impact on health and is associated with an increased risk for psychiatric disorders, gastrointestinal problems, sleep and cognitive impairment [47]. Treatment options include modification of indoor lighting for beneficial effects on sleep, blue light therapy for modulation of circadian sleep disorders, and blue light filters for evening use with digital devices [50,45,51].

In many cases, the circadian rhythm becomes increasingly fragmented with advancing age, and elderly individuals often experience symptoms such as poor sleep quality and cognitive impairment [44]. A longitudinal study of 2,754 adult males over the age of 65 years demonstrated that decreased overall circadian rhythm robustness (or increased fragmentation) was associated with a greater decline in the Modified Mini-Mental State examination ($p<0.001$), with increased odds of clinically significant cognitive decline (≥ 5 point decrease) (odds ratio [OR] 1.4; 95% confidence interval [CI] 1.0 to 1.9) [52]. Additionally, a global study of 42,116 subjects aged 50 years and older showed that individuals who experienced sleep disturbances were more likely to suffer from chronic conditions such as angina, arthritis, asthma, chronic lung disease, depression, diabetes, and stroke [53].

Patients with cataracts experience an even higher reduction in blue light transmission than elderly individuals without cataracts [48]. Clinical studies show that cataract removal and the replacement of an opacified crystalline lens with a colorless IOL improves circadian rhythm, cognitive function, and sleep function [54,55]. Subjective sleep quality was evaluated using the Pittsburgh Sleep Quality Index before and at 2 and 7 months after colorless IOL implantation for 71 consecutive patients [54]. Significant improvements for poor sleepers ($p<0.05$) was reported, suggesting that colorless IOLs have the potential for improving circadian rhythm. Whether or not blue light filtering IOLs show a disadvantage to colorless IOLs in regard to compromising circadian rhythm has been raised in the literature for over 25 years with inconsistent effects being reported [56,57]. A recent cross-sectional study shows the debate continues by (N=29) reporting that colorless IOLs improved cognitive function by approximately 70% and sleep function by approximately 50% compared with blue blocking IOLs [55].

Light Filtering and IOLs

The purpose of an IOL is to provide visual rehabilitation to an eye following removal of the natural crystalline lens. With a primary function of focusing light, IOLs also provide a platform to filter the incoming light. Traditional IOLs are clear, colorless, and filter UV light, while generally allowing transmission of wavelengths in the visible light spectrum. Purportedly, concerns about chromatic aberration, color perception, and the possible increased risk for AMD from high-energy absorption led to the development of IOLs that filter blue light [55,58]. In the sections that follow, studies are presented to highlight the principles surrounding visual quality and function, phototoxicity, and circadian rhythm and physiologic functions. Since the absorption spectra of various IOLs and chromophores have different slopes, inflections, and cut-offs, and since IOLs are made of optical materials of differing properties, direct comparisons between IOLs must be carefully interpreted.

Visual quality and function

As people age, more light is required to overcome age-related pupillary miosis, age-related decreases in the retinal photoreceptor population, and decreased environmental illumination [59]. Light transmission has been shown to be significantly lower with an IOL containing a blue light filtering chromophore (74.41%) as compared to a colorless IOL of the same material (92.14%) [60]. Additionally, as noted before, scotopic (rod mediated) vision is more blue-light dependent than photopic vision (35% *vs* 7%). However, scotopic vision is not as highly dependent on violet light (only 10%) [16]. These factors support the reports suggesting detrimental effects of blue light-filtering IOLs on scotopic sensitivity [10]. Therefore, full blue-light transmission is warranted for best scotopic vision in older adults. Chromatic aberration is important to consider in all refractive IOLs because it can adversely affect contrast sensitivity [19]. Optically, chromatic aberration is the failure of a lens to focus all component colors of incoming light to the same focal point. Abbe numbers are used to characterize IOL materials in terms of their chromatic aberration and is an approximate measure of the material's dispersion or change of refractive index versus wavelength (Table 3) [26,61-63]. The higher the Abbe number, the lower the chromatic aberration and therefore the better the optical performance [26,64]. The refractive index of an IOL is defined for yellow light with a wavelength of 589 nm, and while red and green light are slightly out of focus, blue and violet light are the most defocused, particularly in high-dispersion materials [26]. The use of a blue- and violet-light filtering chromophore with high-index, high-dispersion, high chromatic aberration IOL materials may reduce the negative impact of chromatic aberration on contrast sensitivity.

Studies comparing blue light-filtering and colorless IOLs failed to show a benefit of the chromophore on visual acuity, contrast sensitivity, color discrimination, ocular straylight or lighting condition comfort [19,65-71]. A recent review of blue light-filtering and colorless IOLs defined and reported findings of glare discomfort, but the glare discomfort reported was for a squint response without IOL use identified [72]. Furthermore, clinical evidence generally shows that blue light-filtering IOLs do not provide clinical benefits over their colorless counterparts in terms of visual quality. In fact, a meta-analysis of 4 studies reported that blue light-filtering IOLs significantly reduced color vision under mesopic conditions in the blue light spectrum ($p=0.001$), indicating that transmission of blue light is important for vision under dimly lit conditions [66]. A study comparing blue light-filtering IOLs and violet light-filtering IOLs (n=110 eyes) reported better contrast sensitivity with the violet light-filtering IOLs under photopic and mesopic conditions ($p<0.05$) [73]. Of note, a chromatic dispersion difference was reported between the two IOLs, which likely contributed to the improved visual performance of the violet light-filtering IOLs.

In a study of 240 patients, a directed questionnaire on visual function showed that patients with a violet light-filtering IOL had significantly less difficulty with driving, during both daytime ($p=0.033$)

and nighttime (p=0.017), compared to the colorless control IOL [74]. These results confirmpreviously reported visual comfort improvement with short-wavelength filtering lenses [75].

Furthermore, the subjective findings were strengthened through a scotopic computer simulation of LED headlights, commonly used in newer vehicles, showing a 29% reduction in halo intensity by a violet light-filtering lens compared to the colorless control lens [74].

Phototoxicity

Violet light-filtering IOLs have been introduced in an attempt to limit the disadvantages inherent in depriving the non-central retina of blue light while addressing the risk of retinal phototoxicity and subsequent potential for ocular damage [19,42]. Investigations comparing blue light-filtering IOLs with colorless IOLs have been conducted showing reduced spread of retinal damage [76,77]. However, these studies were limited to one and two year follow-up respectively, which is not sufficient for a definitive conclusion [70]. A recent systematic review reported that using blue light filtering IOLs to impart benefits to the macula is not currently supported [78]. Furthermore, it has been reported that no studies comparing violet light filtering IOLs with blue light filtering IOLs in terms of vision-forming or non-vision-forming outcomes, including photoprotection, have been conducted [19]. As noted before, differences in absorption spectra of various IOL chromophores are complex and multidimensional, thus directly comparing protection against harmful high-energy light can be challenging. One approach is to consider the protection effectiveness of an IOL, or the ultraviolet cutoff wavelength at which a maximum transmission of only 10% is allowed [63]. Manufacturer reported spectral transmission values for three blue light-filtering IOLs and one violet light-filtering IOL are seen in table 3 [79-82]. Based on the reported values, the IOL with the greatest protection effectiveness coverage is the violet light-filtering IOL.Interestingly, this is aligned with Artigas and colleagues, who report that the ideal IOL filter should reach close to 100% transmission of the visible band spectrum, while eliminating all the UV, but not the blue area of the spectrum [83].

Circadian rhythm and physiologic functions

A meta-analysis of 6 studies evaluating the impact of blue light-filtering and colorless IOLs on sleep quality reported that cataract surgery significantly improved sleep quality irrespective of the IOL type implanted [77]. While previousreports confirm this finding [84], the reported limitations encompass non-randomized trial designs, variable participant tolerance for sleep disorders and follow-up data collected from differing time points or modelled expectations without clinical data [48,69,85,86]. Conversely, a recent stringently controlled in-laboratory cross-sectional study recently elevated the impact of blue light-filtering IOLs on circadian rhythm, sleep, and cognitive function as compared to that of colorless UV light-filtering IOLs and healthy controls [55]. Both blue light-filtering and colorless IOLs normalized the response of melatonin to light, indicating a similar impact on the circadian rhythm. However, patients with blue light-filtering IOLs had significantly longer reaction times and shorter duration of non-rapid-eye movement sleep than those with colorless IOLs, indicating that blue light-filtering IOLs may have a negative impact on sleep and cognitive performance. Additionally, patients with blue light-filtering IOLs had significantly worse sleep structure, as assessed through electroencephalographic [EEG] activity, than those with colorless UV light-filtering IOLs [55].

Color Filtering Concepts

The goal of light filtering with IOL chromophores is to balance photoprotection and photoreception in a permanent static fashion. After IOL implantation, light filtering can easily be increased through reversible means like sunglasses, but it cannot be easily reduced. While there may not be a chromophore that is perfectly suited for all environments and lighting conditions, the ideal chromophore should maximize the filtering of known harmful wavelengths while minimizing the filtering of potentially beneficial wavelengths [39].

Chromophores are typically referred to with respect to the color range that they filter. This can lead to ambiguity and confusion in nomenclature and function if the bandwidth range over which light filtering occurs is not considered. For example, a chromophore with variable filtering over a broad bandwidth range may inadvertently give the impression of greater filtering than actually provided. Augustin and colleagues reported blue light-filtering IOLs transmit approximately 10% at 400 nm to 80% at 500 nm [87]. Although the report claimed protective filtering in the violet light range and noninterfering filtering in the blue light range, the broad band of

Table 3: Spectral Transmittance of Violet light-filtering and Blue light-filtering IOLs [26,60-,62,78-80].

Feature	Alcon	Hoya	Zeiss	Johnson & Johnson Surgical Vision
IOL name	AcrySof® IQ	251 iSert™	CT Lucia 601PY	OptiBlue™
Light filtration (lens color)	UV/blue (yellow)	UV/blue (yellow)	UV/blue (yellow)	UV/violet (yellow)
Spectral transmittance: UV cut-off at 10%	Not reported	20 D IOLs = 392 nm	20 D IOLs = 400 nm	5 D IOLs = 422.6 nm 34 D IOLs = 427.4 nm
	Spectral transmittance: cut-off percentage by wavelength for 20 D IOLs = 8% at 400 nm 34% at 425 nm 49% at 450 nm			
Abbe Value	37	43	50	55

Abbreviations: nm=Nanometers; UV=Ultraviolet

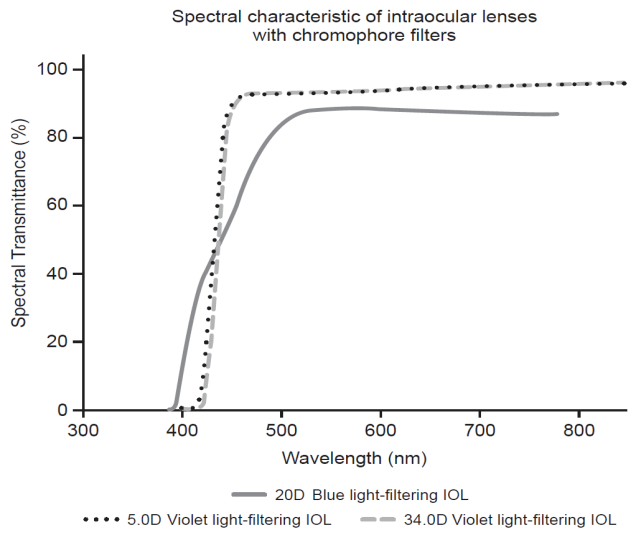

Figure 3: Spectral charateristic of intraocular lenses with violet and blue light-filtering chromophore filters [79].

Three IOL are depicted: one 20D blue light-filtering IOL example from AcrySof (R) Natural Sn60AT Alcon Lab and two violet light-filtering IOL 5.0D and 34.0D examples from Opti Blue (R) Johnson & Johnson Surgical Vision.

Abbreviations: nm=nanometers; D=diopter, IOL=intraocular lense

filtration makes the relevant conclusion difficult to interpret [87]. The lack of specification regarding the bandwidth of filtration may be a contributing factor to the varyingoutcomes reported for blue light-filtering IOLs [88-93]. Conversely, when greaterspecificity of the filtration bandwidth is shared, a more informative comparison can be conducted. For example, the violet light-filtering IOL seen in Figure 3 has a steep cutoff wavelength compared to the blue light-filtering IOL, which has a broader sloping cutoff spanning a wider wavelength range [60,80]. This shows a greater transmission of violet light with a decreased transmission of blue light spectrum by the blue light-filtering IOL. These characteristic differences may in part account for the improved visual performance found with the violet light-filtering IOL when compared to blue light-filtering IOLs [73]. Differences in IOL material and design as well as limited studies directly comparing violet light-filtering IOLs and blue light-filtering IOLs indicate that more research is warranted regarding these chromophores.

Conclusion

Due to the importance of consistency in nomenclature, this review recommends adoption of the ISO definitions of blue light and violet light when describing high energy light. This improved specificity would allow for more accurate differentiation and characterization of each wavelength range within the visible light spectrum. Full transmission of blue light is important to vision and to contrast, particularly at lower levels of illumination. Conversely, filtration of violet light has benefits in areas of visual quality, visual comfort, and low-light dysphotopsias. Investigations with narrow bands of high energy light show no evidence that the additionalfiltration of blue lightwas beneficial for reducing ROS formation, over violet light filtration alone. Blue light is associated with the entrainment of the circadian rhythm, while violet light has no reported effect.

Considering the evidence and usage in the literature, the broad term “blue light hazard” can be confusingly nonspecific. When considering the evidence for IOLs, violet light and blue light filtering chromophores can have very different impacts toward vision quality, visual function, ocular health, and overall systemic health. Moreover, it is important to accuratelycharacterize the bandwidth of filtration for a given chromophore when considering its relevant clinical impact. Therefore, consistent and accurate differentiation of violet light and blue light should be made when referring to high-energy light. Additional research with this specific differentiation is warranted.

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