

LIGHT and EYE DAMAGE

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1. WHAT SPECIFIC PORTIONS OF THE ENVIRONMENTAL ELECTROMAGNETIC SPECTRUM CAUSE EYE DAMAGE?

With sufficient magnitude almost all portions of the electromagnetic spectrum can cause damage to the eye.

For example: Lasers of a wide variety of wavelengths from the short wavelength UV (Excimer laser for LASIK) through the visible spectrum (Argon laser for diabetic retinopathy) to short wavelength IR (YAG laser for iridotomy and capsulectomy) are used to “damage” eye tissue in the treatment of various eye conditions.

However, in our “natural” environments with natural and man-made lights, the most offending portions of the EM spectrum are the UV-A (315 nm to 400 nm), UV-B (280 nm to 315 nm), and “blue-light” portion of the visible spectrum (380 nm to 500 nm). Our atmosphere generally protects us from UV radiation below 280 nm.

Additionally, as the cornea and crystalline lens absorbs almost all natural UV radiation, UV radiation is thought to cause damage to the anterior eye, while short visible light (“blue-light”) can cause damage to retinal structures. Also, as the damaging processes are thought to be at least partially photochemical in nature, the damaging effects can be cumulative in nature, which may compound across one’s lifetime.

2. IS THERE ANY EVIDENCE TO SUGGEST THAT BLUE LIGHT/UV RADIATION CAUSES SIGNIFICANT DAMAGE TO THE EYE?

There is evidence that UV-B radiation “causes” cortical cataracts. This is shown both in studies of high intensity (laser) short-term exposure to animal eyes in the laboratory and in epidemiological chronic exposure studies in humans.

While the cause of cataracts is certainly multifactorial with associations shown, for example, with smoking, diabetes, and corticosteroid use (Robman and Taylor. *Eye* 2005; 19:1074-1082), numerous studies have shown the relation between various types of cataract and cumulative ambient ultraviolet exposure. A positive association between UV exposure and cataracts has been found for several population based studies to include: 1) Chesapeake Watermen Study (Taylor et al. *New Engl J Med.* 1988; 391:1429-33.), 2) Beaver Dam Eye Study (Cruickshanks et al. *Am J Public Health* 1992; 82:1658-62), 3) Salisbury Eye Evaluation (West et al. *J Am Med Assoc.* 1998; 280:714-8), 4) Blue Mountains Eye Study (Mitchell et al. *Ophthalmology* 1997; 104:581-8).

Blue light damage to the retina has research support from studies with both acute and

chronic exposure. Ham et al. (Nature 1976; 260:153-5) first showed that the retina was most sensitive to light at the shorter wavelengths (maximum sensitivity shown at 441 nm) and that retinal damage at the shorter visible wavelengths (up to 500 nm) was primarily photochemical in nature (versus purely thermal effects).

This research helped explain the retinal damage seen for those viewing a solar eclipse without proper protection. More recent research has linked long term exposure to sunlight to retinal changes seen in age related macular degeneration. In the Beaver Dam Eye Study, early signs of age related macular degeneration were positively correlated with excessive exposure to sunlight (> 5 hours per day) during the teenage years and beyond (Tomany et al. Arch Ophthalmol 2004;122:246-50).

Similarly, in the Chesapeake Bay Watermen Study, late ARMD was positively correlated to cumulative sunlight exposure (Taylor et al. Arch Ophthalmol 1992; 110:99-104). Concerning sunlight and retinal damage, ultraviolet radiation does not appear to be the causative agent as UV is almost totally absorbed by the crystalline lens. Shorter wavelengths of the visible spectrum (i.e. blue-light, 400 to 480 nm), however, show the greatest effects possibly due to photochemical or photooxidative damage in the retinal pigment epithelium ((Taylor et al. Arch Ophthalmol 1992;110:99-104, Roberts. J Photochem Photobiol B. 2001; 64:136-143, and Arnault et al. Plos One 2013; 8:71398).

Additionally, in a recent study, porcine retinal pigment epithelial cells were exposed to visible light in narrow bands between 380 and 520 nm. Loss of cell viability was correlated with exposure was maximal for wavelengths between 415 and 455 nm. The chronic exposure research support comes from the study of age-related maculopathy within the Beaver Dam Study. Their results showed that persons who reported more than five hours a day of summer sun exposure in their teens, in their 30s, and at the baseline examination, had a higher risk of developing retinal changes indicative of early age-related maculopathy than those exposed for less than two hours per day. Additionally, for those showing the high outdoor exposures, using a hat or sunglasses decreased the risk of early ARM changes by nearly 50 percent.

3. AT WHAT AGE SHOULD AN OPTOMETRIST RECOMMEND PROTECTIVE EYEWEAR COATINGS AND CONTACT LENSES WITH UV RADIATION AND VISIBLE LIGHT PROTECTION?

While the risks for cataracts and early ARM changes are shown to increase only after long-term and substantial sun exposure, it is important to realize that there are no perceived benefits to UV exposure for the eyes. Also, the lens of the eye “yellows” with age, which helps protect the retina from short wavelength radiation. In fact, a young child’s lens can even transmit a small percentage of ultraviolet radiation around 320 nm to the retina. The structures of the eye have antioxidant mechanisms that efficiently defend the eye from ambient radiation; however, most antioxidants and protective enzymes begin to decrease around the age of 40 (Roberts, 2001). Thus, the very young and those past middle age can benefit the most.

The use of hats, sunglasses, and/or clear glasses with UV protection are advisable for all individuals regardless of age. Wide brimmed hats will block most UV from the sun and sky, and, most surface structures do not have a high UV reflectance. White sand and especially fresh snow are the two primary exceptions. Providing clear spectacle lenses with UV protection is also advisable (at any age).

Also, most of the short wavelength light hazard (blue and violet light) outdoors is from direct sun and sky exposure. Natural outdoor surfaces (grasses, dirt, green vegetation) do not have high short wavelength reflectance. The use of a wide brim hat will decrease outdoor blue light exposure significantly. Sunglass wear will decrease exposure even further while blue-blocking sunglasses (amber in color) can reduce short wavelength light substantially.

While age is a factor to the need for UV and light protection, the length of exposure is even more important. Individuals who are routinely outdoors for long periods are most in need of protection. Whether the exposure is from an outdoor occupation (farmer, police officer, construction worker, etc.) or an outdoor avocation (hiker, golfer, bicyclist), the use of a hat or sunglasses while decrease the risk of future eye problems.

4. WHAT ARE THE OPHTHALMIC MATERIALS THAT PROTECT EYES FROM CERTAIN LIGHT SOURCES?

Everyday spectacle lenses, regardless of material type, appear clear because they transmit nearly 100 percent of visible light. Concerning ultraviolet radiation, however, the different lens materials provide varying levels of protection. Polycarbonate and trivex lenses both naturally block nearly 100 percent of UV-A and UV-B radiation. Also, importantly, both of these materials are highly impact resistant. Polycarbonate's short wavelength cutoff is 380 nm while that for Trivex is 394.

CR-39 blocks all of UV-B radiation but allows a substantial portion of UV-A to pass. The short wavelength cutoff is 350 nm. Crown glass blocks very little atmospheric UV radiation as its short wavelength cutoff is 300 nm.

To reduce retinal exposure to visible light, a tinted lens is required. A gray lens reduces light exposure approximately equally across the visible spectrum. A gray lens alters color perception the least of any tinted lens.

To protect the retina more fully from the "blue light hazard," a yellow, amber, orange or red lens is required. An orange or red lens is not recommended for general wear, however, as these tints can block recognition of traffic signal lights and will greatly alter general color perception. Sunglasses for general wear should state that they meet the ANSI Z80.3 standard, which ensures the lens tint will not significantly alter traffic signal light perception. An amber or orange tint is recommended for protective wear in a dental office to protect patients and dental office

personnel from the strong blue light outputs of instruments used to cure adhesives or used with bleaching agents.

5. WHAT DO THE LABELS “SPF” OR “UV” MEAN ON OTC SUNGLASSES BEING SOLD?

The Eye-Sun Protection Factor (E-SPF) is a new international objective rating index that specifies the overall UV protection provided by a lens. It has been developed by Essilor International and rates daily eyewear as well as sunglasses. Overall, the higher the E-SPF, the greater the UV protection. Specifically, a lens with an E-SPF of 25 means that the eye is 25 times better protected than without a lens. (Note: The E-SPF measure is based upon UV blockage by the lens and does not take into account eye exposure from UV radiation passing around the lens.)

6. WHAT GUIDELINES, IF ANY, SHOULD BE INCLUDED IN INFANTSEE® MATERIALS REGARDING PROTECTIVE EYEWEAR FOR CHILDREN (SOMETHING TO PROVIDE TO PARENTS WHEN THEY LEAVE THE OFFICE)?

The eyes of infants and young children are especially sensitive to solar ultraviolet and visible radiation. The cornea and lens of eyes of young children transmit more radiation back to the retina than for older children and adults. Young children should wear wide-brimmed hats and sunglasses when exposed to bright sunlight. This is especially true when on bright reflective surfaces such as when at the beach or on the cement of swimming pools, playgrounds, or neighborhood sidewalks.

It is recommended that sun wear lenses for children be made of polycarbonate or trivex, both of which have good impact resistance in addition to their natural absorption of ultraviolet radiation.

7. CONTACT LENSES AND UV PROTECTION

Soft contact lenses with UV protection have added benefit over spectacles in that the entire cornea and pupil area is protected regardless of the direction of incident UV radiation. Spectacles lenses do not provide total protection as radiation can reach the eyes from above, below, and to the sides of lenses. This is important as it has been postulated that UV radiation striking the peripheral cornea from the temporal side is “focused” to the nasal equatorial lens area. This exposes developing lens fibers to ultraviolet radiation, which may be a factor in the association of UV-B radiation and cortical cataracts.

It is important to remember, however, that UV absorption does not protect the retina from the effects of blue-light. Sunglass wear is recommended outdoors over the contact lenses to provide the best overall protection. Also, sunglasses will help provide UV protection for the conjunctiva and lid structures, which are not covered by the contact lenses. UV radiation is associated with pinguecula and pterygia development.

8. WHAT IS THE BEST LIGHT SOURCE FOR READING, WATCHING TV, COMPUTER AND TABLET USE, ETC.?

For many decades, incandescent light sources have dominated use in the home while offices have been predominantly using fluorescent sources. Also, the overall quality of light sources have been generally “graded” using three indices:

- Lighting efficiency (lumens/watt),
- Color rendering index (color fidelity), and
- Visual comfort index

Incandescent sources generally provide for high color fidelity and visual comfort but grade low on energy efficiency. Incandescent sources are now being phased out of production due to their poor energy efficiency. Fluorescent (to include CFLs – compact fluorescents) and LED sources are now being manufactured for more general use to include use in the home. While improvements are being made, these newer sources do not provide for the same “comfort level” in the home we previously enjoyed with incandescent sources, although there appears to be a wide variation in the acceptance of these new sources.

When making recommendations for lighting for paper or visual display tasks, however, overall light level (illumination) and light source positioning are the variables that are generally manipulated to maximize visual performance and comfort.

Working on paper copy (reading or writing) requires external illumination to see task detail. Generally speaking, the smaller the task detail and the lower the task contrast, the more light is required. Additionally, age is an important factor as we need more light due to pupil constriction and neural factors as we age, especially in ages over 60 years. As patients don’t possess a light meter for precise illumination measuring, it is rarely useful to provide an exact value of illumination; however, having direct illumination onto the task from a nearby light source can increase illumination when required.

Almost all of us use visual displays (televisions, computers, cell phones, electronic tablets) daily in our lives. These devices produce their own light images and do not require external illumination. In fact, ambient light (especially outdoors) can greatly reduce the visibility of detail on the display screens.

When making recommendations concerning lighting to patients, there are general rules that can be used. For paper copy, try to position the light source to the side of the task or behind the viewer. This is to reduce the chance of a specular reflection off the paper back to the eyes of the viewer, which can reduce task contrast. Similarly, for visual display use, bright sources or windows should not be positioned behind the viewer where specular reflections are seen on the display. Also, any extremely bright sources in the field of view around the paper or display should be eliminated.

For long term viewing comfort, the brightness (or luminance) of sources adjacent to the paper or display should be no brighter than three times that of the object of regard. A bright source in

the viewing field (such as a lamp or window) can cause both discomfort and disability glare. Additionally, viewing of a visual display with a dark surround can also cause discomfort over the long term. Having at least a low background illumination is recommended.

9. WHAT ARE THE EFFECTS OF BLUE LIGHT ON SLEEP PATTERNS AND MELATONIN?

Short wavelength light (blue light) has been shown to have substantial effect upon alertness, vigilance, and general wakefulness.

The effects appear to be mediated through the intrinsically photosensitive retinal ganglion cells (iprgc). These cells appear to be important components of the circadian pacemaker. Stimulation of the iprgc's can suppress melatonin levels in the circulation. The iprgc's have a peak wavelength sensitivity around 480 nm and have a fairly wide spectral sensitivity around the peak wavelength similar to other retinal photoreceptors (rods and cones). Stimulation of these cells by blue colored light (or from strong white light with a substantial blue component) can inhibit sleep and keep one alert. This can be beneficial to keep one alert during tedious activities, but can be detrimental if one is stimulated right before bedtime.

Most electronic displays and our newer residential light sources (CFLs and LEDs) have substantially greater blue light production than traditional incandescent sources. Also, a Harvard researcher (Lockley 2007) has recommended that blue-blocking sunglasses should not be recommended for night shift workers driving home from work as the early morning blue light from the sun would be advantageous to increase alertness. The same argument would apply to anyone driving with less than desired alertness.

10. WHAT ARE THE EYE HEALTH RELATED CONCERNS FOR PATIENTS EXPOSED TO LIGHT FROM OPHTHALMIC EQUIPMENT, SUCH AS: BIO, SLIT LAMPS, DO, ETC.?

While the human eye is specifically "designed" to sense a small portion of the electromagnetic (EM) spectrum (i.e. visible light), it is also susceptible to damage when exposed to high energy levels across the EM spectrum. The focusing properties of the eyes also make the retina susceptible to EM damage by concentrating into a small optical image EM energy from the visible and infrared portions of the EM spectrum.

Light within the blue portion of the visible spectrum has the lowest threshold (approximately 440 nm). This led to the so-called "Blue Light Effect" as an important element when assessing possible retinal damage from EMR. Ham et al.⁶ discuss the thermal vs. photochemical mechanisms independently, but report the two as related. They state, in fact, that the two mechanisms work in synergy, meaning that a small rise in temperature (too small to cause thermal damage) can lower the threshold for photochemical damage.

In terms of ophthalmic instrumentation, this is an important concept. Infrared radiation represents a substantial portion of emission spectra of incandescent light sources (regular tungsten and tungsten halogen sources). The infrared radiation can increase the temperature across the retina but serves no purpose in the visualization of retinal structures. Mainster et al. 7 suggested that ophthalmic instruments be manufactured with filters that eliminate 100 percent of the infrared and ultraviolet radiation. These wavelengths do nothing to enhance the visualization of the retina but can damage retinal tissue with prolonged exposure.

New technology has allowed the substitution of Light Emitting Diodes light sources (LEDs) for incandescent sources for many different applications. LED sources are more efficient and last much longer than their incandescent counterparts. LEDs produce light only of a single wavelength. In order to produce “white” light using LEDs, several LED types must be joined. Blue, green and red single wavelength LEDs can be joined in the proper mixture into a single source to produce a neutral color.

Newer LEDs can produce a “continuous spectrum” by using phosphors to absorb short wavelength monochromatic energy and re-emit longer wavelength continuous spectrum light through fluorescence. While the incandescent lamp yields a total radiant power emission 13 percent higher than the total LED emission, the LED source is reported to yield 20 percent more light. Also, because of the strong emission peak near 440 nm, the Blue Light Hazard output for the LED source is nearly 200 percent greater (i.e. three times the blue light hazard) than that for the incandescent lamp.

- Unfiltered BIOs and SLs can have safe viewing times (on maximum settings) of only approximately 60 seconds or less.
- Elimination of the UV and IR components of the BIO and SL spectra would substantially reduce retinal irradiation during retinal visualization. Clinicians should investigate the presence of UV and IR filters when purchasing new instruments for their offices.
- A yellow filter substantially reduces the blue-light hazard of retinal imaging instruments while reducing visible light level only by a small amount.
- A yellow filter increases safe viewing time for BIO and SL instruments at least 10 fold.
- Clinicians should take steps to eliminate unnecessary retinal exposure to high intensity light from office instrumentation, especially for patients who will require extensive and/or multiple sessions for evaluation and treatment.
- When replacing lamps for ophthalmic equipment, clinicians should follow the exact recommendations of the manufacturer to help ensure that eye/retinal exposures do not exceed limits set by ANSI and other safety organizations.

11. WHAT LIGHTING IS RECOMMENDED FOR SAD OR DEPRESSION THAT DOES NOT HAVE ADVERSE EFFECTS TO THE EYE?

Seasonal Affective Disorder is often treated with the use of a light box during the fall and winter months. Full spectrum lamps are recommended, which can mimic the visible solar spectrum. Care should be exercised, however, to ensure that lamps filter out ultraviolet radiation to protect the skin and eyes. (Lamps are made to treat skin conditions where exposure to ultraviolet-A radiation is desired. These lamps should not be used to treat SAD.)

Lamps are designed to provide up to approximately 10,000 lux illumination. This is about 1/10th the solar illumination from a clear summer day. Thirty minute exposure to this illumination should be safe; however, to provide protection from the emitted blue light, patients can wear yellow or lightly tinted amber glasses to block the shorter visible wavelengths without significantly decreasing overall illumination.

12. WHAT ARE THE EYE HEALTH CONCERNS FOR DENTAL STAFF AND PATIENTS EXPOSED TO LIGHT FROM DENTAL EQUIPMENT, E.G. LASER WHITENING?

High intensity light sources are used in dentistry to cure adhesives and for tooth whitening (bleaching) using primarily the short visible wavelengths (“blue-light”) but also long ultraviolet wavelengths (down to 370 nm). Various type sources are used, for example, halogen, LED, metal halide, plasma arc, and diode laser.

Dental Curing. Curing of dental adhesives is typically done using a high intensity light probe. The probe is held very close to the tooth for one to two minutes. While there is little risk to operator or patient when the procedure is done correctly, high intensity blue light can reflect off dental structures and instruments, and the light can be inadvertently directed to one’s eye.

In a recent study using 11 different light curing instruments, the irradiance was measured for seven different exposure distances from 2 cm to 60 cm. Using these values, the “safe viewing times” were calculated using ICNIRP guidelines (International Commission on Non-Ionizing Radiation Protection). The most powerful instrument had a safe viewing time of only 12 seconds if viewed directly by the eye at 2 cm (patient or operator staring into the probe held right at the eye). The safe viewing time increased to approximately 90 seconds if viewed from 60 cm (specular reflection off dental instrument flashed back toward operator). To cause damage, the same retinal location would have to be irradiated for longer than the safe viewing time. This testing simulated the worst case situations.

The authors concluded that the short term risks associated with dental curing lights appear to be very low; however, they felt there was potential for prolonged exposure risk. This increased risk would apply to dental office personnel who may be exposed on a daily basis and who did not wear protective eyewear.

Bleaching. Lights used to assist bleaching of the teeth are also of high intensity for short wavelength light and may be used for up to one hour. Although the light source is used very close to the patient's mouth, the eyes of the patient can be exposed especially to reflected radiation.

Summary. For both types of these dental processes, patients and dental personnel may be exposed to direct or reflected high intensity blue-light. Although the expected exposures from this reflected radiation may be of low intensity, the photochemical effects of short wavelength light may have compound effects on vision especially for dentists and assistants that may be exposed numerous times a day throughout their careers. During these procedures patients and office personnel should wear protective eyewear that blocks short wavelength light. Orange or amber tinted, blue-blocking glasses should substantially reduce exposure to radiation of wavelengths shorter than 500 nm.