EXPANDED 2ND EDITION

How to Save Your Eyes in the Digital Age

The Handbook on Blue Light, Screen Time, Health, and Electronics

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KEY TAKEAWAYS:

Digital devices emit a low-wavelength, high-energy blue light with potential short- and long-term health risks.

SEE CHAPTER 2, CHAPTER 16

Screen time and blue light may contribute to digital eye strain and affect sleep.

SEE CHAPTER 3, CHAPTER 4

Chidren may be at increased risk from overexposure to blue light.

SEE CHAPTER 6, CHAPTER 8, CHAPTER 10

Healthcare providers and policy-makers are advocating for solutions, especially since the onset of COVID-19.

SEE CHAPTER 13, CHAPTER 19

Educators and employers are concerned about impacts on learning and productivity with increased screen use.

SEE SECTION 5

The electronics industry is responding with solutions from integrated technology to screen accessories.

SEE SECTION 4

New technologies to mitigate high-energy blue light enable digital displays to be designed for health.

SEE SECTION 3

FOREWORD

As Screen Time Skyrockets, the Time to Address Blue Light is Now

The COVID-19 pandemic dramatically changed how many of us work, how our children learn, and how we spend time with family and friends. Amazingly, in many cases, it was technology that brought people closer together than ever – albeit virtually. However, with the significant surge in the use of technology spurred by the pandemic, eye care professionals have raised concerns around the potential short- and long-term implications of excessive use of screen time and exposure to high-energy blue light emitted from these devices.

In response, UnitedHealthcare and Eyesafe began collaborating on a variety of fronts to provide information and educational resources about screen time and blue light to support the well-being of the various stakeholders we serve, including employers, members and their families, care providers, and the public. I took a personal interest in blue light because of the feedback I was receiving from some of the more than 23 million vision members we serve, as well as the over 31,806 eye care professionals in our national network.

This handbook represents contributions and collaboration from globally recognized eye care professionals, researchers, and industry experts with decades of experience in optometry, ophthalmology, consumer electronics, research, and engineering. It covers the potential health concerns of excessive digital device use and exposure to blue light, with guidance from leaders in the health care and the consumer electronics industries.

UnitedHealthcare is committed to helping inform the public discussion about blue light, while supporting industry wide efforts through focused research, better standards, and advanced solutions to reduce the potential impacts of technology on our health. We hope you find this book useful and informative.

Yours in good health,

John Ryan
CEO, UnitedHealthcare Vision

Preface

How to Save Your Eyes in the Digital Age now in its Second Edition, is the go-to source for the latest information on blue light effects, health considerations, display industry perspectives, standards, requirements and solutions. This handbook provides electronics manufacturers, healthcare providers and consumers important information about eye and health protection from blue light. Contributors to the handbook have been carefully selected among the eye and health care community, and each represent thought and market leadership.

Purpose of This Book

This book is our collective effort to shine a light, so to speak, on the subject of blue light from digital displays.

- What is the relative risk of eye problems from blue light emitted by the screens of digital devices compared with blue light emitted by the sun?
- Will current and future generations experience more health problems than their parents and grandparents from disruption of circadian rhythm caused by using digital devices in the evening?
- Are the current and future generations of computer users at greater risk of macular degeneration or other eye problems than their non-computer-using parents and grandparents?
- How much blue light exposure from digital devices is too much?
- What eye protection solutions, if any, are on the market that truly address the issue of excessive blue light from displays?

Let's admit that smartphones have become our inseparable companions. Speaking ill of what is so near (and dear) to us is just wrong, isn't it? Most people would say that smartphones and consumer electronics have elevated humanity by giving us greater access to each other plus sources of information and entertainment that enrich our lives. If there was any basis to a public health issue associated with digital displays, wouldn't the tech industry have already taken care of it?

In and of itself, the subject invites a high degree of skepticism. There are some things we know, and there are many things we do not know. There is no consensus on the effects of blue light emissions. There are gaps in the research. There are differing opinions within the health community and certainly within the technology community.

We invite your critical reading. Noted up front, the collective authors of this book have a vested interest. We want everyone to be better educated on the subject of blue light. We also want progress toward more research, better standards and clear health guidelines. We are promoting specific solutions. And, we hope that out of an abundance of caution, you might consider taking steps to protect your and your children's eyes.

How This Book is Organized

The beginning chapters of this book cover the health issues associated with toxic exposure to blue light. The second part of the book provides guidance from the health care community. The last section covers emerging standards and technical remedies.

It is not necessary to read each chapter in sequence. Topics are cross referenced – you can jump to the appropriate chapter to find more detail – and explore the diversity of research and opinion.

We hope that these points and other information in this book will provide a context for future research findings, health advisories and public policy.

– Justin Barrett, CEO Eyesafe

About Eyesafe

Eyesafe Inc. is the worldwide supplier of advanced blue light mitigating technology, solutions, and standards. With pioneering products and services, in collaboration with healthcare, Eyesafe is shaping the future of consumer electronics designed for human health. Eyesafe® Requirements, Eyesafe® Technology, and the associated intellectual property portfolio is developed by a world-class team of eye doctors, engineers, and scientists with decades of experience in electronics, display materials, light management, optometry and ophthalmology. The Eyesafe brand is trusted by consumers and integrated in millions of digital devices from Dell, HP, Lenovo, ZAGG and others. Eyesafe was ranked #5 in the computer hardware category in the Inc. 5000 Fastest-Growing Private Companies in America. Learn more at eyesafe.com

Eyesafe Vision Health Advisory Board

The Eyesafe Vision Health Advisory Board is made up of leading eye care professionals across ophthalmology and optometry. They help define and shape the future of eye health and vision care delivery through innovation, continuous education, and collaboration. The Eyesafe Vision Health Advisory Board reviews and establishes clinical research, develops industry standards for eye and human health, and collaborates with leading manufacturers.

How Does Blue Light From Electronic Devices Affect Our Health?

MELATONIN
Cumulative exposure to device blue light at night time may lead to suppressed melatonin levels

SLEEP
Night time use of devices has been shown to impair the ability to get a good night's sleep

VISUAL ACUITY & DRY EYE
Researchers are investigating connections to visual acuity, dry eye and other eye health issues

ABILITY TO CONCENTRATE
A poor night's sleep can make it difficult to concentrate and over the long term not enough sleep leads to a build up of neurotoxin

DEVELOPING EYES
Eyes are not fully developed until teenage years, meaning more blue light enters the eye

EYES & HEALTH
Overexposure to intense blue light may have both short-term and long-term negative effects including visual fatigue and vision problems

Contents

SECTION 1

How Blue Light Affects the Eye and Body

In this section we define blue light and the potential health impact of overexposure from digital devices.

A Close Look at Our Eyes

About the Authors:

Chad Dockter, OD attended the University of Minnesota from 1985-1989 to study Biology. He then attended Illinois College of Optometry in Chicago in 1989 and graduated in 1993. At Illinois College of Optometry he completed an externship at Low Vision Resources in Minneapolis. Specialty areas include family eye care, refractive surgery and pediatrics.

Chris Freed, OD graduated from Michigan State University in 1993 with a major in biology and a minor in ecology. Dr. Freed graduated from Illinois College of Optometry in 1997.

Our eyes are our dominant sensory organs.

More than most other animals, we rely on sight to gain information about our surroundings. Other animals are wired to their sense of smell. As such, human eyes have a different complexity than the eyes of other animals, with the eyes collecting the information and the brain interpreting them.

The eye is a ball separated into two chambers by the iris and crystalline lens (Figure 1-1). The outer surface, the sclera is white except for its anterior clear part, the cornea, delimiting, with the iris and crystalline lens, the anterior chamber filled with a clear fluid called the aqueous humor. The posterior chamber is filled with a more viscous substance called the vitreous humor which helps to regulate the eye pressure and its shape. Lining the inside of the sclera, in the posterior chamber, is the choroid, a vascular layer, containing connective tissues. And inside of the posterior chamber, against the choroid is the retina, formed during the fetal development of the brain, which contains the eye's sensory cells and photoreceptors.[1]

The photoreceptors of the retina are rods and cones. There are about 120 million rods in an eye, responsible for the scotopic vision, or vision in low levels of light. Rods are sensitive to shape and movements, but are not sensitive to colors. Cones, located in the macula, are the photoreceptors sensitive to colors. There are about 6 million of three different types of cones with sensitivity to blue, green, and red, and of different abundance. There are more red cones than green and blue cones. The distribution of cones in the macula and fovea also differ as a function of the wavelengths they absorb.

Along with rods and cones, a third type of photoreceptors

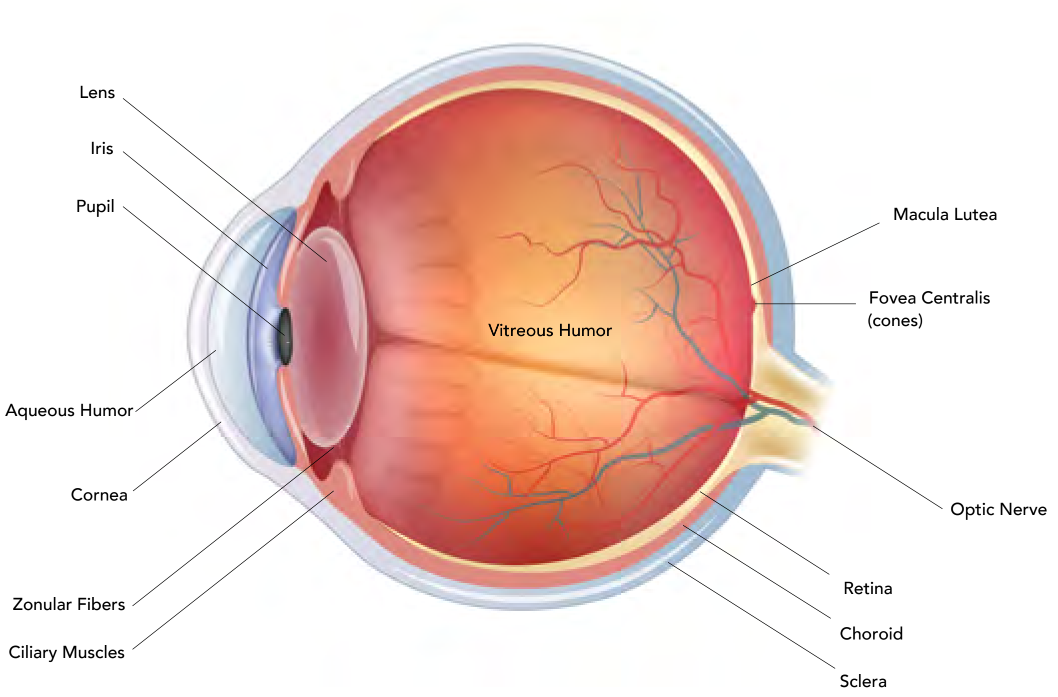


Figure 1-1. Cross-section of a human eye. It is marvelously complex in how it senses color and interacts with our brain and body.

are present within the retina. They are the intrinsically photosensitive retinal ganglion cells (ipRGCs). Photosensitive because of the melanopsin they contain, a light sensitive protein, ipRGCs are involved in non-image forming signal transmissions to the brain. They help regulate circadian rhythm, pupil constriction, mood, alertness and more body functions.

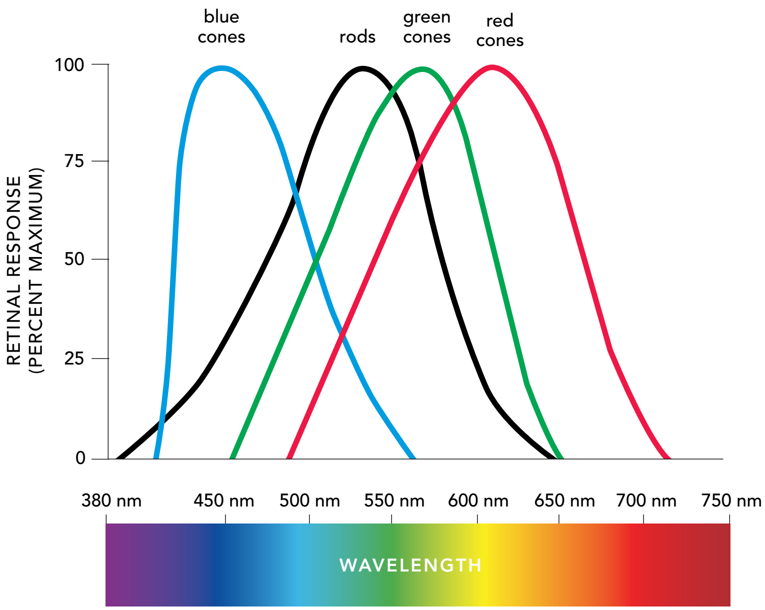
Color Sensing

Color sensing and visual perception occurs when light in the 380–780 nm range hits the retina. Ultraviolet and infrared wavelengths are not absorbed by the retina, but by the outer layers of your eyes, the cornea and lens. In a normal eye, light enters the eyes through the cornea, and passes through the pupil. The iris around the pupil regulates the amount of light entering the eye by getting bigger or smaller. As the light hits the lens, the zonular fibers and ciliary muscles change the shape of the lens in order to focus and maintain the light on the retina where the photoreceptors are located. Cones and rods convert the light into electrical impulses transferred by the optic nerve to the brain, which interprets the signals as an image.

Colors are defined by their wavelength and frequency. Different wavelengths are perceived by the eye as different colors. Rods and cones contain photopigments made up of a protein component (opsin) and a chromophore (retinal). The opsins of the rods and cones are different and make rods and the three types of cones sensitive to different ranges of light wavelengths. See Figure 1-2. Upon photoexcitation, the retinal contained in the photoreceptors changes, triggering a cascade of reactions as part of the visual signal.

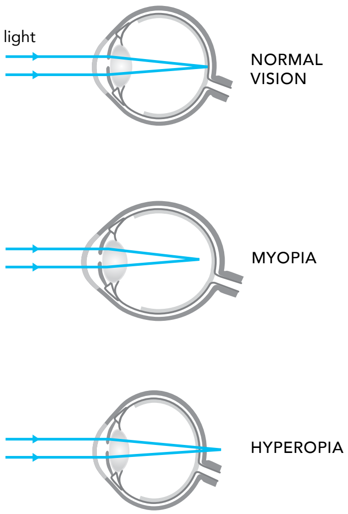
With the cones centered on the wavelengths corresponding to blue, green and red, the brain interprets the signals sent by the overlap of different cones into various colors, with white being interpreted from the stimulation of the three cones and yellow for example, from the stimulation of green and red cones. Conditions such as color blindness are due to genetic mutations causing abnormalities of the cone pigments.

Figure 1-2. The rods and cones in our eyes are sensitive to different wavelengths of light.



20/20 Vision

20/20 vision is a term used to express normal visual acuity (the clarity or sharpness of vision) measured at a distance of 20 feet. If you have 20/20 vision, you can see clearly at 20 feet what should normally be seen at that distance.



The cornea facilitates the focusing of an image on the retina. Adjustments for distance are realized through a change in the lens shape, which is called accommodation. The process of accommodation is carried out by the contraction of the ciliary muscles and the zonular fibers connecting this muscle to the lens.

See Page 38

See Chapter 5 on Accommodation

The shape of the eyeball, along with the focusing power of the crystallin lens and the cornea, plays a role in projecting a crisp image on the retina. An eyeball too long or too short will change the place where the image focuses, before or after the retina, hence causing refractive errors such as nearsightedness (myopia) or farsightedness (hyperopia). Other vision defects such as astigmatism can occur when either the lens or the cornea does not have an optimal spherical surface.

Vision Problems

With aging the lens stiffens and leads to a loss of accommodation manifested by presbyopia. Presbyopia is a condition where it is increasingly difficult to focus on near objects, despite corrective lenses. Aging can also lead to an opacity of the crystalline lens, a common eye disorder called cataract.

Other deteriorations of the eye include glaucoma, a group of eye diseases characterized by an increase of pressure within the eyeball.[2-3] The buildup of pressure converges on the optic nerve, the weakest point of the sclera where the nerve leaves the eye. This can lead to the death of the retinal cells and degeneration of the nerve fibers, finally resulting in permanent vision loss.

1.3 billion

PEOPLE WORLDWIDE HAVE VISION PROBLEMS

80%

OF ALL VISION PROBLEMS ARE PREVENTABLE[5]

Another cause of vision loss is macular degeneration.[4] It is caused by the damage of cells and photoreceptors located on the macula, where the vision is focused and characterized by the presence of large drusen (extracellular material) and pigmentary abnormalities in the macula. There are two types of macular degeneration, wet and dry, and several stages of development of the disease. The specific factors of macular degeneration are still to be completely understood even though genetics, race, age and a long-term exposure to sunlight and in particular the action of the blue component of the light have been evidenced as causative factors.

According to the World Health Organization (WHO), upwards of 1.3 billion people worldwide have some sort of vision problem.[5] The WHO report indicates that 80% of all vision problems are preventable.

The leading causes of vision problems globally include:

- Accidents and Injury
- Uncorrected refractive errors
- Cataracts
- Age-related macular degeneration
- Glaucoma
- Diabetic retinopathy
- Corneal opacity
- Trachoma

A National Institute of Health study estimates that ninety million adults over forty years of age in the United States experience vision problems. Almost everyone has some degree of presbyopia by this age.[6]

The NIH summarized some findings from eye care professions, and projects some alarming trends, as seen in Table 1-1. Some of this is due to aging populations, but others appear to be caused by external factors.

Blue Light and Eyes

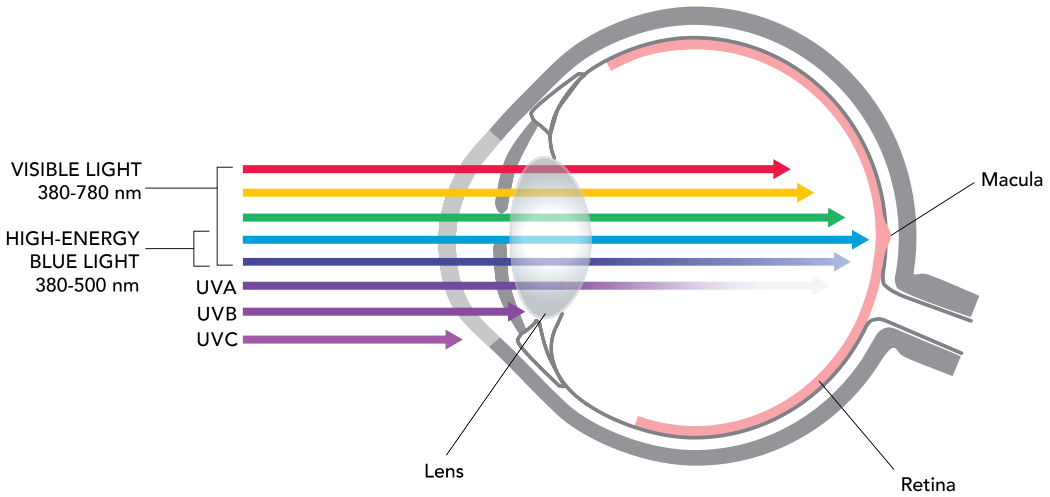
A close look at our eyes helps us appreciate how they react to light and sense color, see Figure 1-3. The nature of various vision-related problems is also important as we begin a discussion of blue light and its potentially hazardous effects.

One effect, how much blue light penetrates the eye, can vary by age. As we age, our eyes transmit various bands of visible light differently, as shown in Figure 1-4. Young children do not filter as much blue light, for example, as older children. Older adults transmit less.

Table 1-1. Projected prevalence of eye problems in US population by year 2050. All are the subject of ongoing research on blue light.[6]

Problem	Part of Eye Effected	2010 Prevalence in US Population	2050 Projected US Population Prevalence	Subject of Research on Blue Light Hazard
Cataract	Lens	24.4 million 31%	50 million 63%	Yes
Age-Related Macular degeneration	Retina	2.1 million 3%	5.4 million 7%	Yes
Glaucoma	Optic nerve	2.7 million 3%	6.3 million 8%	Yes

Figure 1-3. Visible light is transmitted to the retina from natural and artificial light sources, between the range of 400-780 nm. The cornea and lens of the adult human eye are effective at blocking UV rays from reaching the light-sensitive retina. HEV blue light is different, passing through the cornea and lens to the retina and macula.



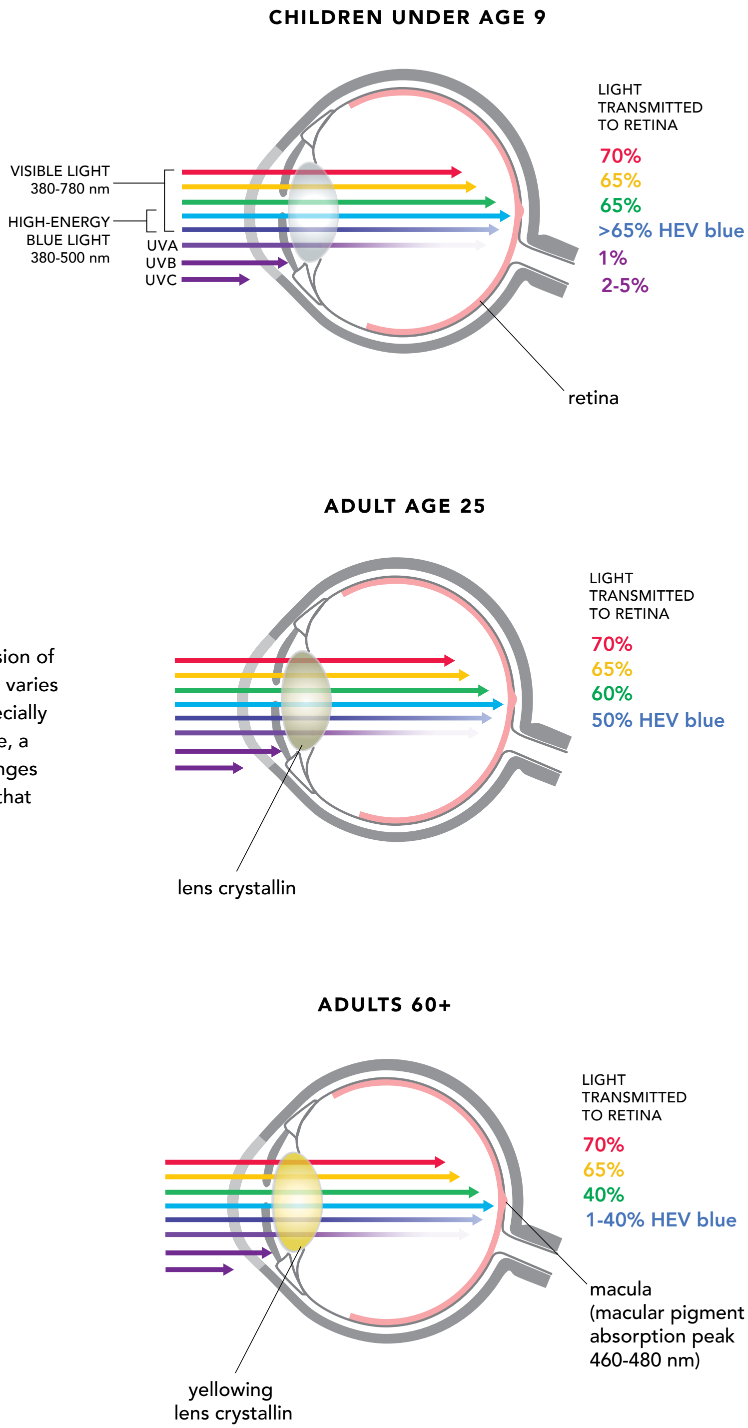


Figure 1-4. The transmission of various light wavelengths varies by age. Children are especially vulnerable. As people age, a yellowing of the lens changes the amount of blue light that penetrates the eye.[7-10]

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▶ eyesafe.com/research

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Blue Light and Displays

About the Author:

Derek Harris, PhD and VP R&D at Eyesafe received his PhD in Chemical Engineering from Georgia Institute of Technology. He has over 30 years spanning experience in liquid and vacuum deposited coating processes and formulation with the early parts of his career focused on electrochemistry.

Although the dangers of UV rays from the sun have been known for years, we are only now recognizing that visible blue light from digital screens (and sunlight) also may pose risks to the health of our eyes.

What is Light?

Throughout the day, our eyes are nearly constantly exposed to light. Yet most of us would struggle explaining exactly what "light" is. Visible light is a very limited portion of the spectrum of natural and artificial electromagnetic radiation that includes gamma rays, X-rays, ultraviolet (UV) radiation, infrared rays, microwaves and radio waves.

Visible light is the only type of electromagnetic radiation that can be perceived by the human eye. All other types of electromagnetic rays are invisible.

Light and all other forms of electromagnetic radiation travel in waves. The length of these waves ("wavelength") is inversely proportional to the energy of the radiation.

In other words, electromagnetic radiation that has very short wavelengths has very high energy, and rays with longer wavelengths have less energy.

The energy in light and other forms of electromagnetic radiation is contained within *photons*, which are a type of elementary particle. Photons carry a discrete quantity of energy (that's proportional to the frequency of the waves) but have no mass.

Visible light has wavelengths ranging from 380 to 780 nanometers (nm). Portions of the electromagnetic spectrum are shown in Figure 2-1, in order from highest energy (shortest wavelengths) to lowest energy (longest wavelengths).

Each wavelength of visible light has a specific color.

Sunlight comprises a wide array of colors, whose intensities vary throughout the day. Blue light rays are stronger in the morning and at midday, promoting alertness. Later in the day and at dusk, blue light is less prominent, promoting relaxation.

Sunlight is the basis of life on earth, but too much exposure can cause damage to our skin and eyes. You can irreparably damage your eyes if you stare directly at the midday sun for even less than a minute. You can also prematurely age your eyes and skin through prolonged exposure.

Nonetheless, our physiology is better adapted to natural light than to blue-enriched artificial lighting. Health problems from overexposure to natural light are well understood. We are just beginning to understand the potential harmful effects of artificial blue light.

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See Chapter 8 on Intensity

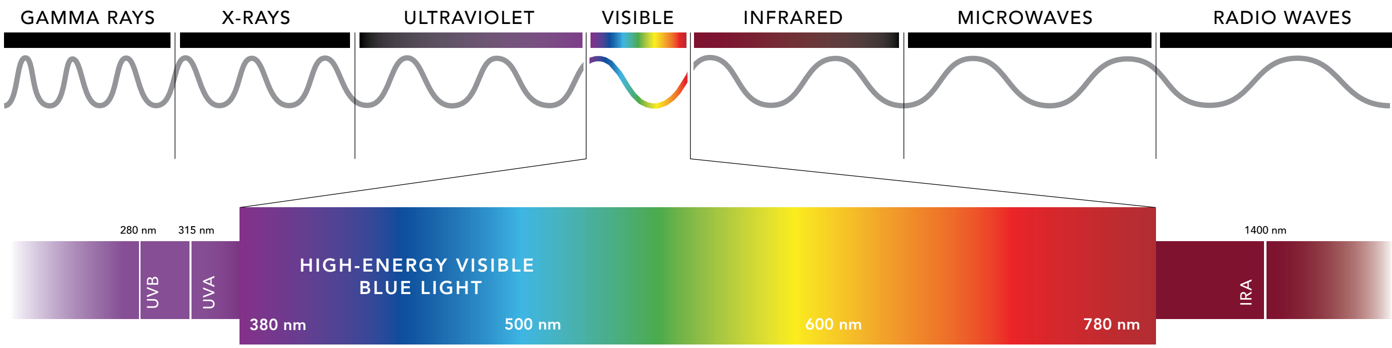

Figure 2-1. High-energy visible (HEV) blue light ranges from 380 to 500 nm. The blue light rays that border UV (at 380 nm) have the highest energy.

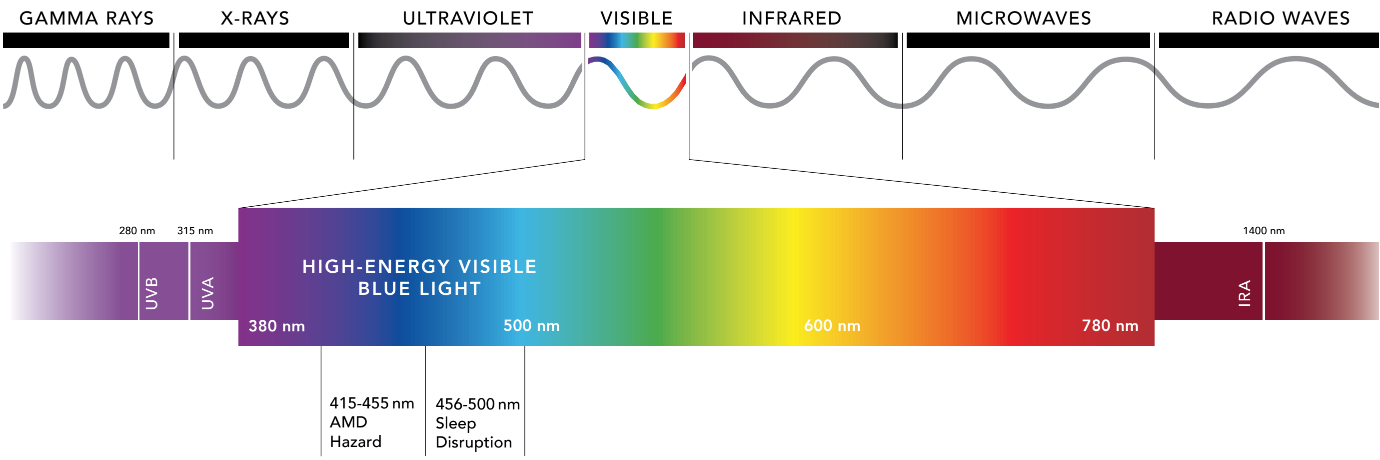

Figure 2-2. The entire spectrum of visible light is important, but certain bands of blue light have been linked to potential health concerns.

Blue Light

Blue light is a component of the visible light spectrum (Figure 2-2). In general, about 25% of sunlight is blue light. But the actual amount of blue light depends on many factors — including time of day, the season, and the latitude of your location.

What is blue light?

When sunlight approaches the Earth, its rays are scattered by molecules and particles in the atmosphere. Because blue light travels in shorter waves than other visible light, it is scattered more easily in the atmosphere. This scattering is why the sky usually appears blue.

The blue-colored bands of visible light range in wavelength from 380 to 500 nm. Blue light also is known as high-energy visible (HEV) light because it has the shortest wavelengths — and therefore the highest energy — of all visible light.

Because too much HEV light can have negative effects, we have evolved ways to limit how much visible light enters our eyes. These adaptations include pupil constriction, reflexively looking away from the sun, and squinting in bright sunlight.

But these evolutionary adaptations don't do us much good when we're staring at the screens of our computers, tablets and phones for hours at a time and most of our day.

Researchers have found that high-energy blue light – particularly in the shorter wavelength range – produces oxidative and phototoxic damage to cells in the cornea and retina of the eye.[1]

Researchers have found that high-energy blue light – particularly in the 415 to 455 nm wavelength range – produces oxidative and phototoxic damage to cells in the cornea and retina of the eye.[1]

Longer-wavelength blue light, on the other hand, has been shown to have some beneficial effects. At wavelengths of 455nm and greater it helps regulate our wake/sleep cycle (circadian rhythm) and appears to contribute to physical and emotional health.

Just below the blue light band are ultraviolet (UV) rays, which have higher energy than visible light. Lower-energy UVA rays (315 to 380 nm) account for approximately 95% of the ultraviolet radiation our bodies are exposed to. Then below are higher-energy UVB rays (280 to 315 nm) that have been associated with causing skin cancer.[2]

UVA penetrates into the deeper layers of the skin. In addition to producing a suntan, it causes premature aging of the skin and wrinkles. In moderation, UV exposure is beneficial. It helps the body produce vitamin D.

All UV rays are invisible and penetrate clouds. For this reason, sunglasses that block 100% of UV radiation should be worn outdoors in daylight – even on overcast days.

UV rays have been associated with eye conditions, including growths on the surface of the eye (pingueculae and pterygia), photokeratitis (snow blindness), cancers of the eye and eyelids, and cataracts.

Evolution of Artificial Light

The human eye evolved to harness sunlight. Fire and candlelight might seem quaint and romantic now, but for our ancestors these were the only source of light after sunset.

Incandescent lamps were invented in 1879, but they weren't widely used until after World War I. With the establishment of electrical utilities, power standards and grids, millions of people could finally snuff out candles and switch on a light.

Fluorescent lighting became available in 1937. It was widely adopted in commercial and industrial settings because of its ability to provide near-daylight illumination.

Over the last 25 years, we have seen regulations and market forces favoring light sources that consume less energy. When compared with the common household incandescent bulb, compact fluorescent lamps (CFLs) provide better energy savings, longer life and are designed to fit existing appliances. Up until very recently, they were the most common source of commercial and household light.

LED (Light Emitting Diode) lights were first developed in 1962 at General Electric. As LED designs became better and better, they found use as low-power alternatives to incandescent and fluorescent lights. They have many advantages, including compact size, higher switching rates, better lighting efficiency (less heat as a byproduct) for wattage consumed, and can be designed into arrays for display screens.

TIMELINE OF ARTIFICIAL LIGHT[3]

Late 1800s
Incandescent Bulb and Cathode Ray Tube

1907
Electroluminescence

1937
Fluorescent Bulb

1962
Red LED

1964
Plasma Flat Panel

You could say that LED lights have nearly eclipsed the sun in their usefulness in modern life. LEDs can effectively mimic virtually all colors of natural light, and they can be used 24 hours a day at relatively low cost compared with other sources of artificial light.

And, with new OLEDs (organic LEDs) finding commercial applications, we will be soon be seeing flexible displays that can be folded or even rolled up.

Computer, Cell Phone and TV Displays

Since the early days of television and computing, monitors and displays were powered by the cathode ray tube (CRT). A CRT display contains an electron gun (or 3 guns for color) and an electromagnet that directs an electron beam in a pattern to excite a phosphor field on the back side of the display glass.

CRTs worked fine for rendering the black and white and color images of the day, but they had size and form-factor limitations, high voltage requirements, relatively short lifecycles, and included toxic components.

In less than 20 years, LEDs and liquid crystal displays (LCDs) replaced CRTs in commercial display technologies. The last known manufacturer of CRTs stopped making them in 2015. You have to pay someone to dispose of a CRT tube nowadays. They are considered hazardous waste. And LCD displays, including handheld readers, are now most often illuminated with LED backlighting.

1973
Sharp LCD

1980
Compact Fluorescent Bulb

1992
Blue LED

1994
Cell Phone

2000s
Smartphone

2010
LED Lighting

2014
Nobel Prize in Physics awarded to inventors of blue LED

It's been estimated that 90% of all artificial light will be produced by LED or OLED technology in the very near future.[3] LEDs have advanced to meet the requirements of displays in smart devices, computers and wall-sized TV sets, and they serve the needs of an interconnected, always-on global society. If all light sources were the same, this would be a wonderful and amazing story of advancement for society. But light sources are not the same.

The Blue Light Spike

If you compare the spectral emissions of light from sunlight and incandescent, fluorescent and LED sources, you will notice some clear differences. See Figure 2-3.

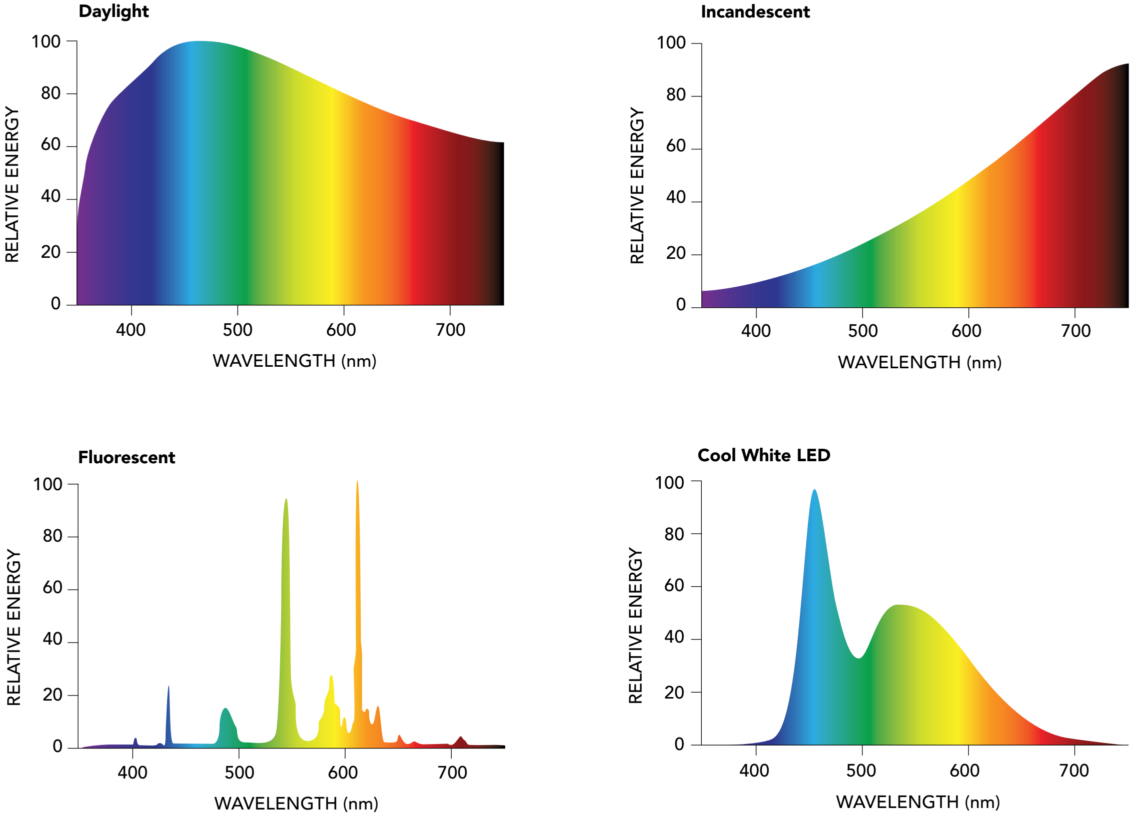

Figure 2-3. Spectral distribution of typical daylight, incandescent, fluorescent and LED. Note the distinct blue spike characteristic of LED.

A blue LED has a spike of light emission in the blue light range. In order to produce color, it excites yellow phosphor, shifting some of its energy into other color bands. Similarly, OLEDs emit energy in the blue, green and red areas of the spectrum. See Figure 2-4.

LEDs have a more intense illumination than most other forms of commercial lighting. Their negative effects were first noticed when white LED lights began to replace fluorescent and other lighting technologies in commercial settings.

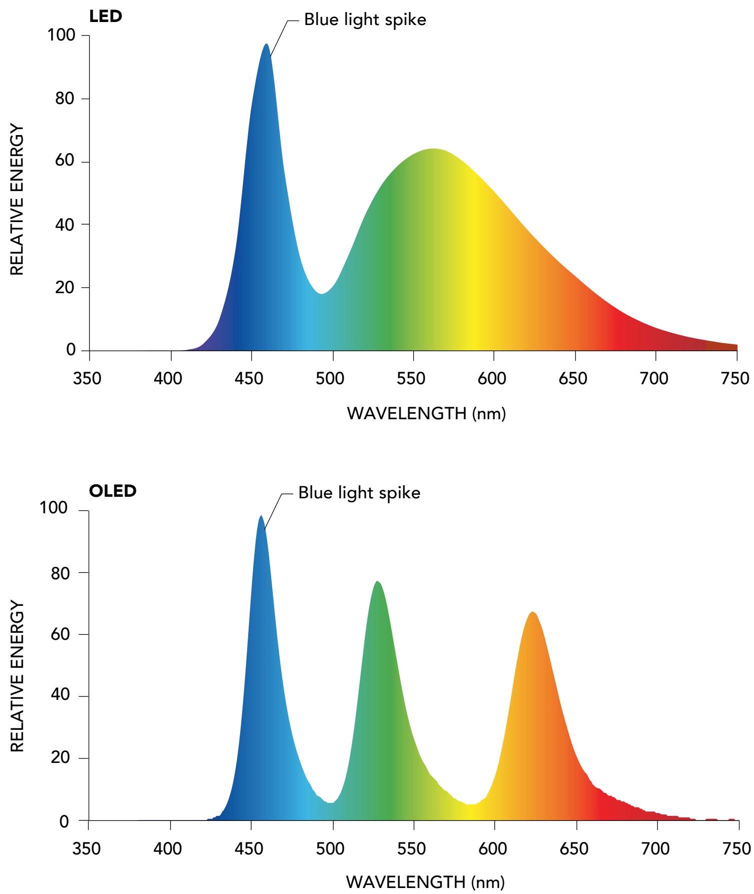

Figure 2-4. Wavelength plots typical of both LED and OLED light sources show a high-energy blue light spike.

RISK GROUPS:

The French agency ANSES[5] and other regulatory bodies are trying to raise the awareness that LEDs may be harmful to:

- Infants and young children
- Post-cataract surgery patients
- Pregnant women
- Elderly people
- Night workers exposed to LED lighting
- People with sleep disorders
- Migraine sufferers

The International Dark Sky association reported concerns that LED lighting was disturbing the routines of nocturnal animals. A museum implicated LED lighting in the yellowing of pigments of precious oil portraits by Van Gogh and Cézanne.[4]

In May 2019, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) updated its 2010 assessment of the health effects of LEDs.[5] After analyzing more than 600 recent research papers on the topic, ANSES confirmed its previous conclusion that blue light can have a toxic effect on the retina of the eye. The agency recommended measures to reduce blue light exposure, including:

- When choosing LED lighting for home use, select bulbs with a "warm white" tone (color temperature below 3000K). These LED lights emit less harmful blue light than "daylight" or "cool white" bulbs that have higher color temperatures.
- People (especially children) should reduce their exposure to the blue-rich light of LED screens (tablets, computers and smartphones) at nighttime to avoid disrupting biological rhythms and causing sleep problems that have been associated with multiple health conditions.

ANSES also called for the establishment of standards and performance criteria for devices and equipment designed to protect eyes from harmful blue light.

ANSES and other regulatory bodies are trying to raise the awareness that LEDs may be particularly harmful to certain risk groups that include infants and young children, people who lack a crystalline lens or have an artificial intraocular lens (IOL) following cataract surgery, pregnant women (due to possible dangers of disruption of the mother's circadian rhythm to her unborn child), elderly people (glare effects), night workers exposed to LED lighting, people with sleep disorders, and anyone who suffers from migraine headaches.

Although agencies such as ANSES follow the research and publish assessments, they typically cannot keep pace with the rapid adoption and spread of LEDs and similar technologies.

Device makers are now introducing OLEDs and AMOLEDs (a similar technology) in smartphones, tablets and other types of displays. OLEDs, when compared to LEDs, have application advantages of higher density, lower power and the ability to directly illuminate a display. Although somewhat less toxic to the eyes, OLEDs do have a blue spike.[6]

One way to compare LEDs and OLEDs with other light sources is by color temperature, measured in degrees Kelvin (K). Normal daylight temperature averages 6500 K. White light bulbs range in color temperature from 2700 K for a warm hue to 7500 K for a bright cool hue. (See Figure 2-5.)

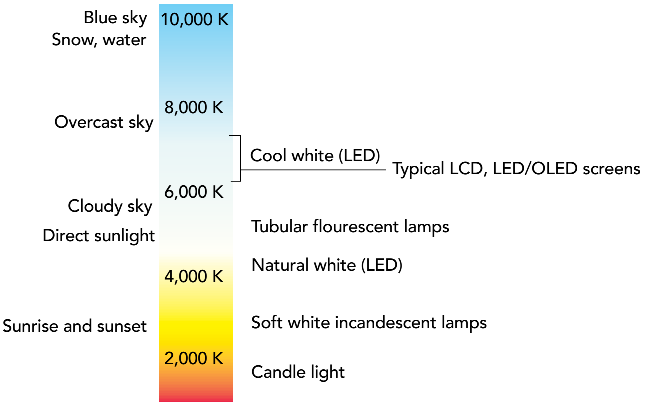

Figure 2-5. Wavelength compared LED to color temperature. Both LED and OLED technologies have a spike in the wavelength range of harmful blue light, and absolute energy, as measured by color temperature, can be 7500 K and higher.

Two key development trends should be noted:

1. LED light bulbs today are steadily increasing in luminance per watt, and therefore creating intense bright light from very small sources.
2. Electronic displays (computers, cell phones, etc.) also are increasing in luminance, with high performance displays now operating at color temperatures of 7500 K and higher.

The blue light spike represents a challenge for display makers. Display makers mine the energy from the HEV band to power phosphors in other color bands so that a matrix of pixels can emulate practically any hue in the visible light band.

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See Chapter 16 on display emissions

Figure 2-6. Example of Eyesafe® Display, where blue light is selectively reduced.

Very sophisticated methods are used today for creating artificial white light or enhancing color to make it pleasing to the eye. Display makers create LED and OLED displays that can render full color by altering phosphors that can precisely blend red, green and blue to very accurate levels.

The fact remains, however, that the blue light spike is a characteristic of displays, resulting in greater blue light exposure.

There are remedies to minimizing the blue light spike. Most of these solutions, however, either do not address it at the source, or they filter out too much blue light, making images appear dull and yellowish.

One remedy, as shown in Figure 2-6, is to use an Eyesafe® Certified display or to apply an Eyesafe® Blue Light Screen Filter. Eyesafe® technology selectively filters the characteristic blue light spike. This has minimal effect on color rendition and luminescence, enhancing eye comfort and retaining the integrity of the display experience.

Key Points on Blue Light

In summary, here are a few key points about blue light:

- Blue light has the shortest wavelengths and highest energy of all visible light.
- Like UV radiation, HEV blue light has beneficial and harmful effects.
- Blue light is everywhere – it is present in both natural and artificial light.
- The impact of blue light is not all bad. Longer-wavelength blue light in the morning or at midday (but not in the evening) helps regulate our sleep cycle.
- LEDs and OLEDs have a characteristic blue light spike.
- Displays can have a color temperature greater than sunlight.
- The lens of a child's eye does not filter blue light as effectively as the lens of an adult eye, putting children at higher risk of eye damage from blue light exposure.

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Digital Eye Strain

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At its simplest, digital eye strain is eye and vision-related, caused by spending extended periods of time on computers, tablets, smartphones, or gaming consoles.

There is a good correlation between the number of digital devices someone owns and the amount of time spent using them. In some cases, extensive daily use is common (spending 8+ hours on a computer at work, then another few on a tablet or smartphone or gaming consoles during “off” time).[1]

In the midst of the COVID-19 epidemic, when remote work and study increased dramatically, average daily screen time rose to 13 hours, exceeding the time spent on all other activities combined including sleep.[2] Further, digital device use has broken all age barriers—grandparents use their devices to communicate with grandchildren, and younger people use tablets to read or play games. Even preschool children regularly use digital devices.

While the device of choice may differ (older people tend to prefer laptops and desktop computers for surfing the Internet, while younger people tend to prefer smartphones), social media use and multitasking on multiple devices simultaneously is commonplace among people under thirty.

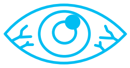
With this increasing reliance upon digital devices comes an increasing percentage of people with vision complaints directly related to their digital device use. Complaints typically fall into two categories: vision problems (where the screen becomes more difficult to focus on), and abnormal sensations (i.e., dry eye). For some, these symptoms will be transient in nature but for others, symptoms will be frequent and persistent to the point of seeking medical attention.

Digital Eye Strain

The above phenomenon has been a recognized health issue for the past twenty years. Originally called "computer vision syndrome," the introduction and rapid acceptance of digital devices has broadened the overall category to be renamed "digital eye strain."[1]

At its simplest, digital eye strain is eye and vision-related, caused by spending extended periods of time on computers, tablets, smartphones, or gaming consoles. In more technical terminology, digital eye strain "is a condition characterized by visual disturbance and/or ocular discomfort related to the use of digital devices and resulting from a range of stresses on the ocular system, including glare, defocus, accommodation dysfunction, fixation disparity, dryness, fatigue and discomfort."[3]

One key point, however, is that signs and symptoms do not always correlate. For instance, external symptoms (such as a burning sensation, or irritation and tearing, or dryness) are



Symptoms of digital eye strain may include the following:

- Dry, irritated eyes
- Trouble sleeping
- Blurred vision
- Reduced attention span
- Irritability and difficulty concentrating

all closely related to dry eye, but vision/internal symptoms (such as eye strain, or headaches behind the eyes) are linked more to vision stress.[1]

Digital eye strain is now being considered an emerging public health issue, and its effect on vision cannot be overlooked.[3] Although most symptoms are temporary, they are risk factors for visual health problems that can occur from prolonged constant use of digital devices.[4]

Anatomy of the Eye

To understand how digital eye strain affects vision, a basic understanding of the anatomy of the eye is warranted. The eye is responsible for the detection of visible light; for humans that range is about 400 to 700 nm. This organ must be able to address all the optical requirements of imaging, while concurrently being able to readjust and optimize the parameters across the entire range of visible light and ideally at any distance.[5] And it does so with only about one-sixth exposed and easily seen (the remainder is protected by orbital sockets in the skull).

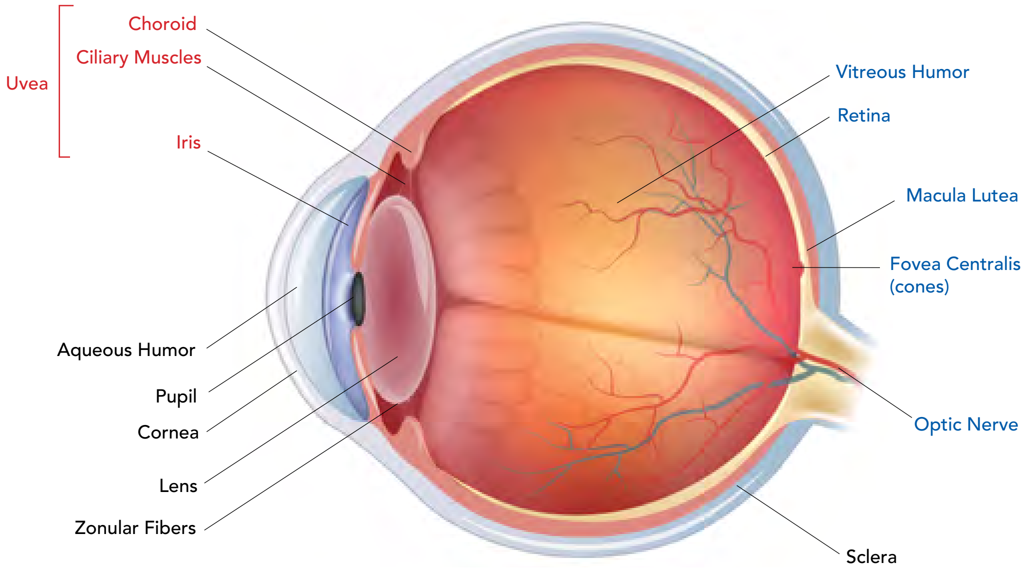


Figure 3-1. Basic anatomy of the eye. Fovea is the area of highest visual acuity. The parts of the eye labeled in black are considered the front of the eye (anterior segment), those labeled in red are the middle of the eye (uvea), and those in blue are in the back of the eye (posterior segment). The retina (in the posterior segment) is responsible for vision.

As shown in Figure 3-1, the retina is the innermost layer of the eye, and lines three quarters of the back of the eye. It is where the visual pathway originates, and is often compared to a camera. The retina is considered the "photographic film of the eye that converts light into electrical energy for transmission to the brain."[6] There are two key components within the retina that are directly responsible for vision: the macula and the fovea. The macula is in the exact center of the retina, and is the center of all human vision. The fovea is a small depression in the center of the macula that contains highly sensitive photoreceptors (rods and cones). The fovea is the area of highest visual acuity or resolution and is responsible for the sharpness of vision.[5]

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See Chapter 14 on blue light hazard

Triggering Digital Eye Strain

In 2016, The Vision Council released its *Eyes Overexposed: The Digital Device Dilemma* report on the digital habits of more than 10,000 U.S. adults.[7] Among the findings:

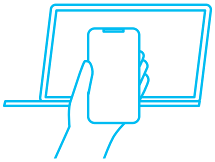
- 65% self-reported symptoms of digital eye strain.
- Women are more affected than men (69% vs. 60%).
- Digital eye strain complaints are more common in those using two or more devices simultaneously (and in that group, 75% complain about digital eye strain).

65%

REPORTED SYMPTOMS OF DIGITAL EYE STRAIN IN SURVEY OF 10,000 U.S. ADULTS[7]

75%

OF INDIVIDUALS WHO USE TWO OR MORE DEVICES SIMULTANEOUSLY SUFFER FROM DIGITAL EYE STRAIN[7]



Slower blink rates are associated with dry eyes, a common symptom of digital eye strain. Children that use a smartphone are twice as likely to be diagnosed with dry eye disease, according to one study.[8] Another study found the incidence of dry eye disease 13 times higher in children who use smartphones.[9]

Symptoms of digital eye strain can include any of the following: headaches, blurred vision, dry eyes, "tired eyes," and pain in the neck and shoulders. People who often squint while looking at a digital device (most often, a computer screen) also tend to complain of digital eye strain. While squinting helps facilitate concentration and makes it easier to see the screen clearly (possibly also minimizing the glare associated with these screens), it also reduces the blink rate.

To date, the best strategy to treat digital eye strain is to prevent its occurrence altogether.[3]

"When patients come to me complaining about certain symptoms, dry and irritated eyes, sleep disruption, or blurred vision, they are complaining about digital eye strain."

– Dr. Sheri Rowen

Digital Eye Strain and the Role of Digital Displays

Numerous activities that used to be done at a distance are now being done on digital devices, including watching movies, playing games, finding recipes, checking weather, getting directions, online shopping, setting timers (alarm clocks), etc. Although the general rule of thumb is that the healthiest distance for digital devices is about 20-40 inches away from your eyes (about an arms' length), oftentimes the distance is much, much closer.

See Page 96

See Chapter 13 for more on blue light and its potential hazards.

Most people in their 40s and 50s will already have a visual condition called presbyopia that affects intermediate vision (as the need for reading glasses becomes more prevalent, documents on a computer need to be larger in order to be read, etc.). People with presbyopia have additional visual stress when looking at digital devices, as they often do not attempt to correct this intermediate vision, or they undercorrect by using readers that do not offer the proper magnification.[10]

Limiting the amount of time spent with digital devices can also reduce digital eye strain, yet The Vision Council found one-third of Americans do not attempt to limit their exposure, and more than 90% do not discuss their device use with an eye care practitioner.[11]

We still do not know what, if any, effect digital devices have on accommodation (the ability to quickly focus on something nearby and then quickly focus on something across a room). Poor accommodation, however, was the most common diagnosis among patients in a recent digital eye strain study.[1]

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Circadian Rhythm

Today's digital generation is sleeping less than previous generations, and blue light in excess of normal daytime dosages may be a cause.

Over the past few decades we have found important links between blue light and the human sleep cycle, otherwise known as circadian rhythm. Even though visible light can reset our biological clock, blue light is the most effective at it with the highest efficiency. A growing body of evidence shows that the disruption of the circadian rhythm is linked to various diseases such as obesity, depression and possibly cancer.

Non-Image Forming Brain Pathways

Blue light penetrates our eyes and signals a specific set of photoreceptors present in the retinal epithelium, called ipRGCs (intrinsically photosensitive Retinal Ganglion Cells). They are one of three types of photoreceptors in the retina, along with rods and cones. See Figure 4-1. Rods and cones are the main image forming receptors.

The ipRGCs are primarily responsible for non-image forming signal transmission to the brain. They regulate pupil dilation and are actors on the circadian system, by transmitting to the suprachiasmatic nucleus SCN (a small group of hypothalamic nerve cells), which is our central clock. This clock synchronizes other clocks for the metabolism including those of liver, heart and kidney functions. It controls the circadian physiology by signaling to the pineal gland the secretion or suppression of melatonin, the so-called sleep hormone that controls our sleeping and waking phases (Figure 4-2).[1]

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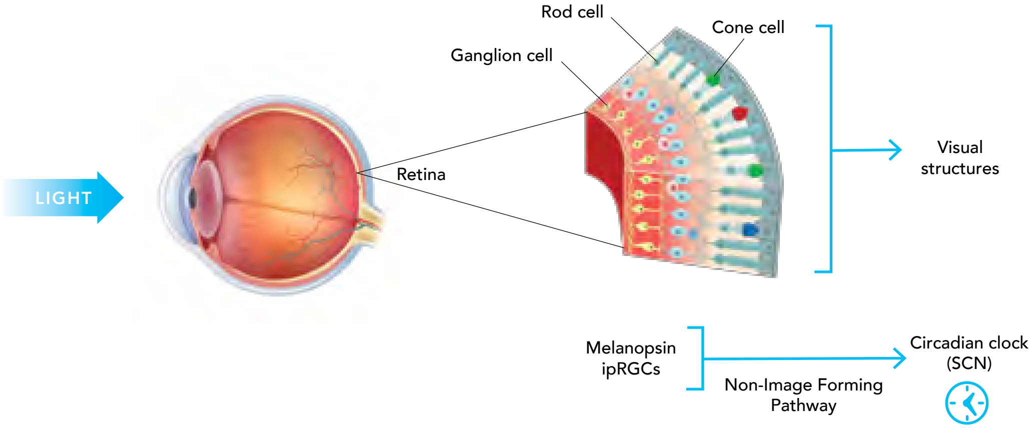


Figure 4-1. Photoreceptors and the non-image forming pathway. See Chapter 7 Page 50 for more detail.

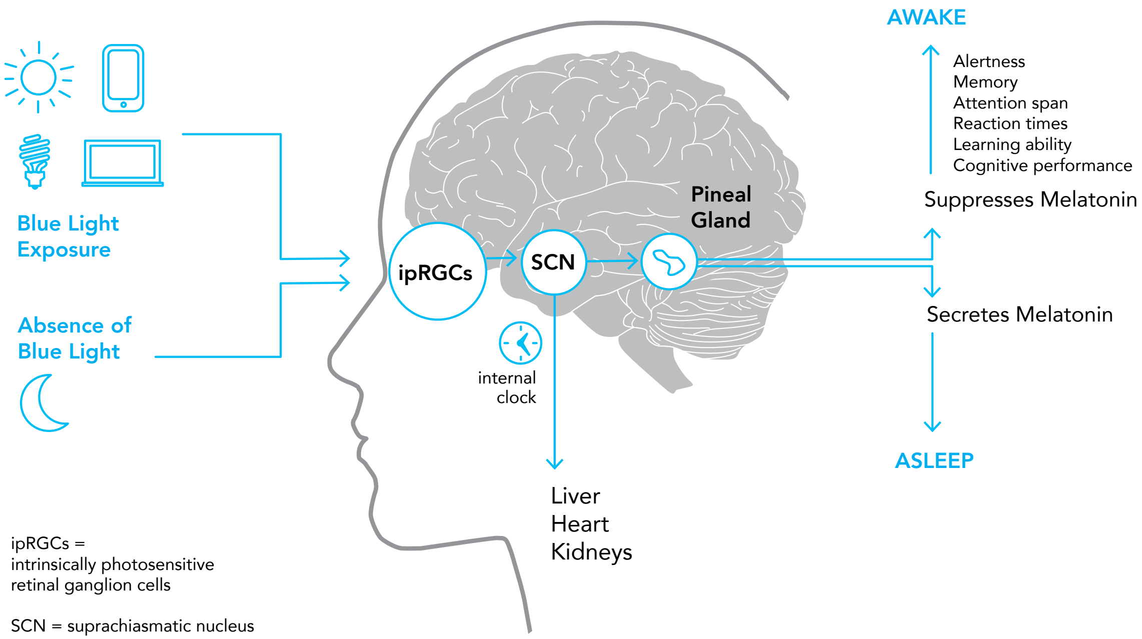


Figure 4-2. Blue light, through ipRGC pathways, affects sleep cycles by the secretion or suppression of melatonin. Ordinarily the progression of daylight from sunrise to sunset maintains the normal awake to sleep cycle through non-image brain pathways.

Melatonin

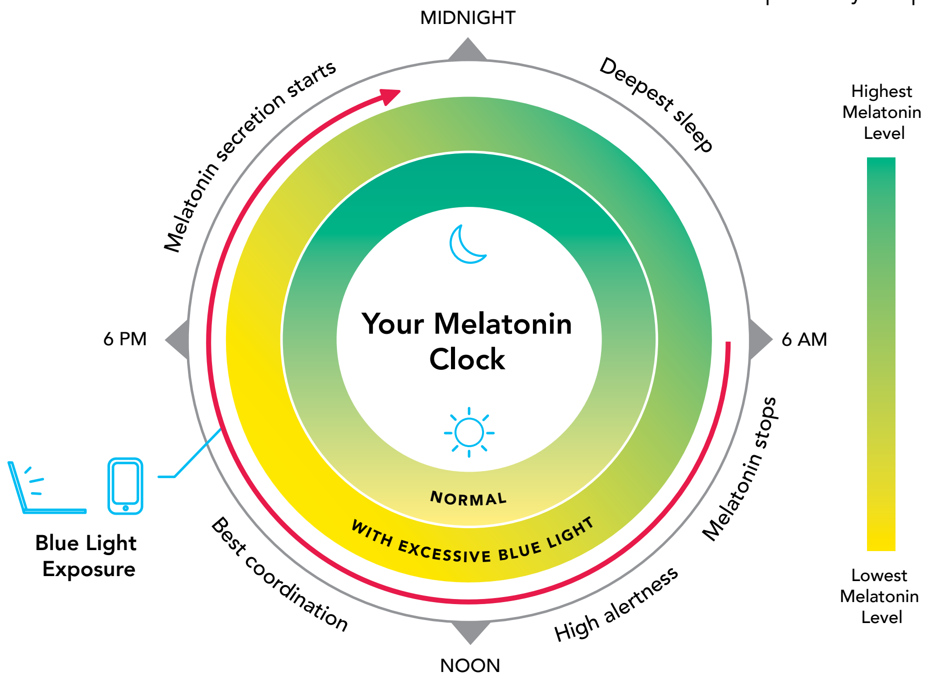
Blue light between 460 and 480 nm, through the stimulation of SCN cells and the suppression of the melatonin production, is responsible for alertness, memory, attention span, reaction times, learning ability and cognitive performance.[2] This is a natural phenomenon; this blue component of the sunlight is primordial for our wellness through an optimized circadian rhythm. See Figure 4-3.

Light is known to effect sleep more than any drug on the market[7]

Nighttime Exposure to LED Lights

With LED lighting technology, our eyes have been more and more exposed to light and moreover to high energy blue light. LEDs nowadays are used in practically anything requiring light, from the outside street lights, offices lightings, to light in cars, toys and everyday tools such as computer screens, tablets and smartphones.

Figure 4-3. Blue light, and its absence, synchronizes our melatonin clock. Excessive blue light exposure, especially before nightfall, can potentially disrupt the melatonin clock.



Excessive exposure to digital displays, especially at night or just before sleep time, can potentially desynchronize circadian rhythm. Several studies have shown a decrease in sleep quality and late bedtimes in adolescents and adults following the use of digital technology at night.[3] Other studies are more measured with their analysis.[4] Nonetheless, with the increasing presence of technology in our life, our daily and nocturnal exposure to blue light is at an incomparable level.

97%

COLLEGE MEDICAL STUDENTS USED BLUE LIGHT EMITTING DEVICES AT BEDTIME[5]

Going to bed with a tablet or smartphone is increasingly the norm among adults. A study of college medical students found that over 97% used blue light emitting devices at bedtime.[5] Of the students surveyed, over 76% used the device in bed with ambient lights off, 60% interrupted their sleep to check messages, and 18% put their smartphones under their pillows while sleeping. The main reason was not for study but for social networking. Although most of the students in the study recognized that device usage at night was disturbing their sleep, they were unable or unwilling to change their behavior.[5]

Desynchronization of the circadian rhythm can lead to:

- persistent fatigue
- poor appetite
- sleep disorders
- chronic insomnia
- mood disorders
- depression

The influence of blue light on the circadian rhythm remains under scrutiny. Nonetheless, a desynchronization of the circadian rhythm can lead to numerous symptoms having potent health effects, such as persistent fatigue, poor appetite and sleep disorders which could lead to chronic insomnia, mood disorders and potential depression.[5] According to these health experts, exposure to artificial light, enriched with blue light, should be considered on the same level as endocrine disruptors.

Blue Light Therapy

Blue light has powerful effect on circadian rhythm, which is why it is used in some types of therapy. It is used in chronotherapy for example, in the treatment of traumatic injuries such as post-concussion treatment, either by blocking blue light or by exposing subjects to blue light, in order to reset or reinforce the circadian rhythm, and help the brain to recover and improve sleep and delayed memory after injuries. Equally these methods have been shown to be useful in the treatments of sleep disorders and mania.

The National Aeronautics and Space Administration (NASA) has mounted several studies that center on blue light.[8] Astronauts who work on the International Space Station can run into sleep issues because the space station circles the Earth every 90 minutes, disrupting the circadian cycle. One study used blue light therapy instead of caffeine and sleep medications to synchronize astronaut sleep cycles. Delivering this light by enhancing blue wavelengths in white-appearing light also allowed the crew to see well when they are working. Before bedtime, decreasing the blue content and intensity of the light promoted sleepiness, improving sleep and reducing suppression of the hormone melatonin, the brain's biochemical signal of darkness. This type of lighting manipulation shows strong potential as a safe, non-pharmacological way to counter disruption of circadian rhythm and the problems that it can create during spaceflight.

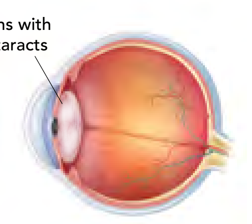


Figure 4-4. The natural yellowing of the cornea and onset of cataracts can contribute to sleep disruption.

Filtering Blue Light at Night

Blue filters have also been implemented on intraocular lenses (IOL) used after cataract surgery. Older people tend to have less retinal cells and photoreceptors. The natural yellowing of the cornea and onset of cataracts also contribute to sleep disruption. See Figure 4-4. A blue blocking lens replacement has been shown to help improve vision-related functions, re-establishing a disturbed sleep-wake cycle,[12] by allowing enough light to increase alertness.

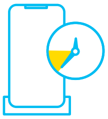
A study of night shift workers in an emergency operations center found measurable improvements in job performance associated with displays that have a lower blue light setting. The study used software filtering to change the base color temperature of the display from 6500 K to 3800 K (lower blue light).[9]

Filters that reduce blue light in displays can lead to better sleep quality, reduced drowsiness and better cognitive performance, according to a study of night shift workers.[9]

LED smartphone use at night has also been the subject of a randomized, double-blind, cross-over, placebo-controlled comparison.[15] Measurable differences in sleep onset, duration and sleep quality were observed in the study, with the most intense blue light settings being associated most strongly with circadian rhythm disruption.

2hrs

AVOID SCREENS TWO HOURS BEFORE BEDTIME[13]



Several studies indicate, however, that there is no measurable benefit to using "Night Shift," a feature of iPhones and iPads. This user-selectable feature shifts the the display to a warmer color. A similar feature, "Dark Mode," reverses the background. Neither of these features significantly reduces the amount of blue light coming from the device.[10-11]

Adolescent Sleep Problems

The incidence of U.S. children getting less than eight hours of sleep a night rose 33 percent over a five year time span starting in 2006.[13] It is clear from numerous adolescent sleep studies that smartphone use for gaming, social interaction and study at night contributes to sleepiness during the next day as well as mood changes.

Guidance from a Harvard Medical School study is to avoid blue light two hours before bedtime.[13] School age children would benefit from staying off of their tablets and smartphones before bedtime. Of course, as children get older that is harder to enforce.

Research with school age children found that blue light filters on display screens used before bed time produced significant positive health benefits by curbing blue light-induced melatonin suppression.[14]

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Visual Acuity and Dry Eyes

Eye care providers are seeing a dramatic increase in the number of patients seeking consultation from symptoms that are related to close work with digital displays.

This is generally diagnosed as digital eye strain or computer vision syndrome. Symptoms include blurred vision, dry eye and headache that can lead to reduced attention span, irritability and mood changes and an inability to perform assigned work tasks.

It is estimated that digital eye strain affects over 4 billion people across the globe.[1] It is the most common repetitive stress injury in the world and can be disabling.

Like any contributing factor, if displays play a role in the current epidemic of digital eye strain, we should understand the underlying causes so we can better address it for the individuals impacted.

Potential Phototoxicity of Extended Blue Light Exposure

Everyone is likely to experience some visual discomfort with prolonged exposure to blue light. Controlled laboratory studies, using human eye tissue, are showing that exposure to blue light, even at relatively moderate doses, can increase the production of reactive oxidative species (ROS) and free radicals, including hydrogen peroxide and superoxides.[2] The dosage levels used were calibrated to approximate the intensity of ambient light on a sunny, slightly cloudy day.

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The retina is an outgrowth of the brain. Like all neurons, retinal cells are not capable of dividing and producing new retinal cells. Surface epithelial cell replacement helps us, for example, recover from excess ultraviolet light exposure which can cause sunburn to the skin and ultraviolet damage to the surface cells on our eyes. These surface cells can recover from toxic light exposure in about 5 days, but any retinal cells damaged cannot. Although blue light exposure from prolonged use of a digital device is less toxic than excess exposure to ultraviolet radiation, in laboratory experiments using tissue cell culture techniques, it does cause production of ROS, free radicals, cell damage and even death.[3]

There are three causes that determine severity:

1. Distance of the light source
2. Intensity of light
3. Length of exposure[4]

Phototoxicity over extended periods can accelerate the aging of our eyes. There are three causes that determine severity: distance of the light source to the eye, the intensity of light, and the length of exposure.[4]

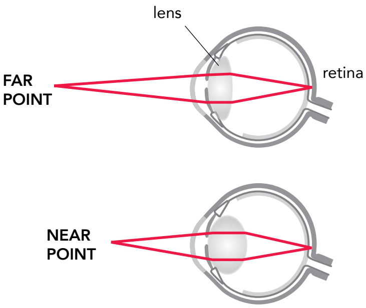
The eye is the only organ that allows light to deeply penetrate the body. Staring at a display that emits blue light at night or in a darkened room, which tends to dilate the pupils, can increase toxic light exposure to the retina.

Accommodation

Accommodation is the umbrella term for how our eyes adjust from distance to near tasks.[5] Our brains seek clear images to interpret, and without adequate accommodation near images are blurry. The natural reduction in accommodation that occurs with age leads to a condition called presbyopia. Once one develops presbyopia, reading glasses or progressive lenses are required for good near vision. Our eyes must also turn in or converge to see a near image clearly. This is achieved by coordinated activity of the eye muscles inside and outside the eye. Accommodation and convergence need to work together to achieve clear single vision at near distance with no blurring. This is a complex muscle driven task, and excess near vision demand can also lead to eye strain. The pupils inside our eyes also dilate or contract in response to changes in light intensity and accommodation. If objects are not perfectly clear, we may squint or blink frequently, consciously or not, to achieve momentary clarity.

Our eyes continuously make minute adjustments in response to the ever-changing images and visual demands they encounter. Any set of muscles tires with constant use in demanding conditions. All this focusing and refocusing can be demanding over extended periods of time and lead to ocular fatigue symptoms including digital eye strain.

A lag of accommodation and convergence is being recognized as one reason why cell phone use while driving is the #1 cause of traffic accidents.[8] Blurred distance vision and difficulty refocusing is also linked to dry eyes, which can also be caused by blue light exposure and reduced blink rate that can accompany excess exposure to digital devices.



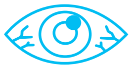
Accommodation: how our eyes adjust from distance to near tasks:

- Focus
- Muscular coordination
- Squinting
- Convergence
- Dilation
- Blinking

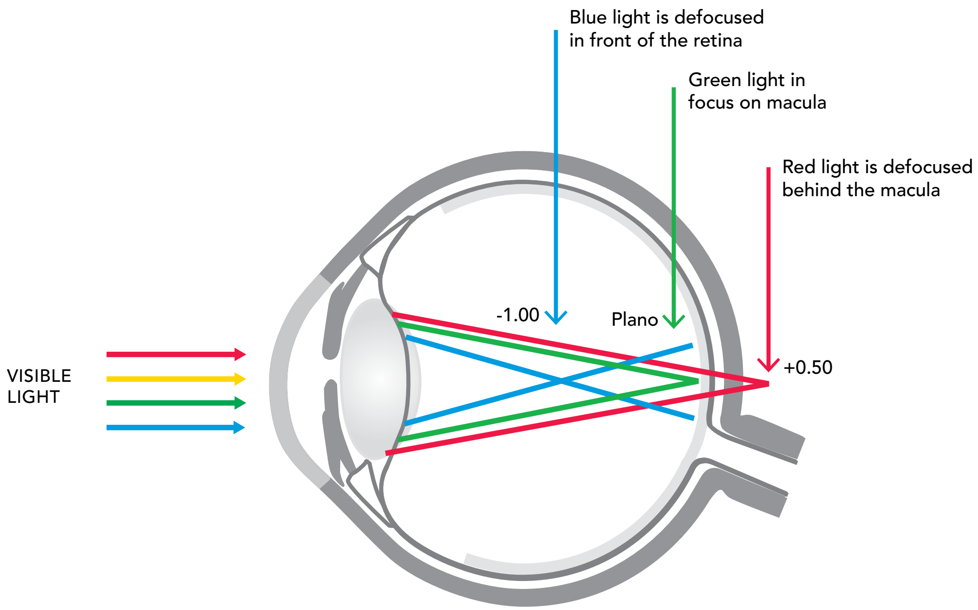
Glare and Blurry Vision

Light entering the eye refracts according to wavelength, with blue light converging ahead of the green and red portions (see Figure 5-1). This is called chromatic aberration. Shorter and longer wavelengths are more out of focus when they reach the back of the eye and illuminate the retina. Blue light creates a blur circle or haze in the light detecting portions of the eye.[4] Blue light also scatters more in the eye and increases the effort it takes to maintain focus. Excess blue light reduces contrast and causes glare. We can adjust some through pupil constriction and squinting. In a glare environment, the speed at which we can interpret images goes down. Eye care providers often prescribe so-called blue blocking eye glasses to reduce glare and enhance contrast sensitivity.

The sensation of glare, with halos, haze and blurriness, is a frequent complaint of eye patients working with digital displays.



Digital Eye Strain: the physical eye discomfort felt by many individuals after two or more hours in front of a digital screen. See Chapter 3 for more on Digital Eye Strain.



CHROMATIC ABERRATION

Figure 5-1. Blue light refracts and causes blurriness and glare. This contributes to eye strain.[4]

Dry Eye Disease

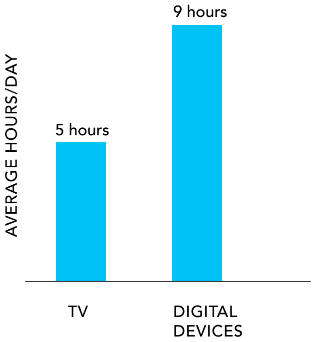
The near universal use of digital devices and growing continuous duration of usage has been highlighted in numerous studies. Among computer users, almost 50% show symptoms of dry eye disease.[1]

When staring at a screen, our blink rate goes down from a normal rate of 20 per minute to 10 or less.[5] When using a digital device, we blink at half the rate compared to reading a book. Slower blink rate is linked to high cognitive demand. Slower blinking can speed the evaporation of the tear film that lubricates and protects the surface of the eye. When dryness occurs, our eyes have to work even harder to try to present a clear image to the retina and brain.[6]

Although blue light from displays causes glare, and is linked to digital eye strain, the impact is usually transient and there are few studies that demonstrate a long term impact. The amount of time we spend looking at digital devices is far greater than the time in front of TV screens. In addition, studies show that people on average are sleeping less than previous generations, giving their eyes less rest. People on average spend an enormous amount of time in front of digital device displays, and less time outside. One study found that people reach for their phones in the morning, more often ahead of coffee, a toothbrush or their significant other.[5]

Nearsightedness (Myopia)

Nearsightedness has increased by 66 percent since the 1970s, according to The National Eye Institute.[10] About 42 percent of Americans aged 12-54 are nearsighted. Increased myopia has many contributing factors, and prolonged near-task demand, with hours of accommodation, along with excess exposure to blue light from displays are all implicated.[8]



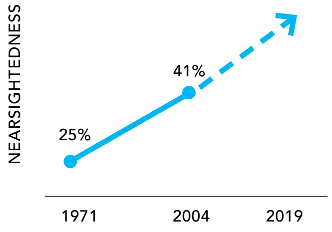
The amount of time we spend looking at digital devices is far greater than the time in front of TV screens.

Children spending more time in front of displays and less time outside, according to one theory, can trigger myopia.[10] The theory postulates that young children will sense and respond to chromatic aberration (Figure 5.1).

Children with developing eyes will automatically detect whether light is focused in front of or behind the retina. The response may include not only accommodation (focus, dilation, vergence, squinting, blinking, etc.) but over time, abnormal eye growth. With displays emitting dominant blue light, that influences eye growth in the direction of nearsightedness.

A study of infant Rhesus monkeys, some reared in blue light and some in red light conditions, appears to confirm that visual feedback does actively regulate refractive development and eye growth.[11]

Clearly, the worldwide increase in myopia is an alarming trend with real social costs. Surveys in multiple countries point to a growing incidence in children. A child's continued effort to maintain near focus can stress and



Nearsightedness has increased by 66% in the US since the 1970's. The increase is linked to prolonged near-task demand, and is growing among children.[10]

lead to an elongation the eye, resulting in progressive and permanent myopia or nearsightedness.

According to researchers, rates of myopia have doubled, even tripled, in many eastern Asia countries during the past 40 years. Hong Kong, Singapore, China and Taiwan have experienced rate increases for myopia approaching 90 percent in their children.

Social Costs of Decreasing Visual Acuity

Too much screen time on digital devices like smartphones, tablets and computers may potentially increase the risk of children developing progressive myopia. The good news is that increased time spent outdoors or in environments that relax accommodation may help slow its progression.

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.[12] Adults with varying levels of visual acuity require more muscular effort to maintain clear near focus over a long period. Vision correction, with eyeglasses or contacts, is frequently needed. In older populations there is a growing incidence of presbyopia, dry eye, cataract, age-related macular degeneration, and retinal disease (retinopathy). The direct costs worldwide of vision loss in 2012 were $2.3 trillion. Any measure that can reduce the personal and economic burden of vision loss is worthy of serious consideration. Excess blue light exposure from increasing digital device use, which contributes to our current epidemic of digital eye strain, is deserving of more attention and preventive measures.

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Retina

Even more than sleep specialists, ophthalmologists consider high energy blue light a risk factor.

About the Author:

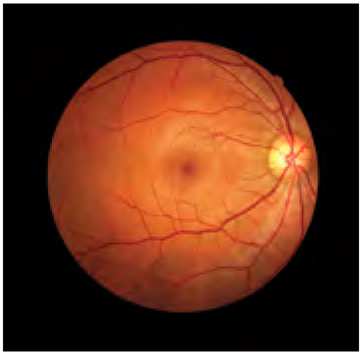
H. Burkhard Dick, MD, PhD, Professor and Chairman, Center for Vision Science, Ruhr University Eye Hospital, Bochum, Germany. For his pioneering work, Professor Dick has been awarded a number of honors like the Choyce Medal of the British Ophthalmological Society, and the Visionary Award of the American-European Congress of Ophthalmic Surgery (AECOS). He currently serves as the President of the German Society of Cataract, Refractive and Interventional Surgery (DGII).

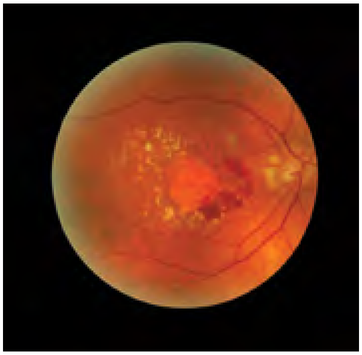
The digital revolution has not only changed our professional world, but also the behavior of people in industrial nations during their free time. We spend an increasing amount of time in front of computer screens, and with tablets and smartphones close to our faces. Experts are increasingly critical of this trend. Displays not only produce images of excellent quality, they affect us in sometimes unnoticed ways. High energy blue light can have potentially harmful consequences to our most important sensory organ.

50 years ago, when people landed on the moon for the first time, television viewers around the world marveled at the computers that had made this moment of glory possible. The devices at NASA Headquarters in Houston and the "on-board computers" in the Apollo space capsule were then the size of several wardrobes. No first grade student today would be satisfied with the performance of these ancient miracles. That's because a smartphone is 32,000 times faster and has more storage capacity than all the NASA computers combined at that time.

Nobody wants to give up on these powerful communication and entertainment devices, least of all the younger generation. In Austria, a survey has shown that high schoolers spend an average of 5.6 hours a day in front of tablet, smartphone, computer, TV and other electronic media. In Germany, another survey conducted by a major health insurance company focused exclusively on the use of social media such as WhatsApp, Snap Chat and Instagram.[1] On average, the thousand teenagers who responded to the survey spent about three hours a day just on these media. Internet surfing, online games and other software were not even included in the study.

Healthy eye





Age-related macular degeneration (AMD)

Blue Light Risk Factors

Smartphones and tablets emit light of a different quality from that of natural sunlight. Displays contain far more blue light, a light of a shorter wavelength and higher energy. Blue light plays an important role in some human bodily functions, especially in the circadian rhythm. Blue light is considered a kind of “stimulant”. The absence of blue light does the opposite. A predominance of red visible light allows the release of melatonin in the pituitary gland. This happens with sunlight at sunset, and also in the absence of artificial light.

Even more than sleep specialists, ophthalmologists consider high energy blue light a risk factor. Cumulative exposure to blue light is one of several predisposing factors to the most severe eye disease, age-related macular degeneration (AMD).[2, 14] As a person ages, their retinal photoreceptors become more vulnerable due to among other things an age-related loss of cells as well as loss of retinal pigments. Photo-stress by high energy light leads to an influx of free oxygen radicals in the cells, causing cell apoptosis (cell death) through a chain of reactions.[2]

Photothermal and Photochemical Retinal Damage

Today’s LED and OLED displays are not intense enough to cause a photothermal reaction, raising the temperature of and burning eye tissues. A surgical laser has that effect, as does the UV light from an arc welder causing a flash burn. Displays do have enough intensity, however, to cause a photochemical reaction.

As demonstrated in lab studies of human retinal cells, blue light emitted even at the relatively low intensity of an LED display can induce phototoxicity in retinal cells if the cells are exposed for a long time.[3] The photochemical mechanism has first been associated with the absorption of blue light by lipofuscin, a mixture of brown-yellow pigment granules which are known precursors of age-related macular degeneration AMD.[4-5] More recent research points toward by-products, generated during the normal visual cycle, upon high energy light exposure, leading through successive reactions to lipofuscin precursors, themselves prone to be photo-oxidized at wavelengths corresponding to high energy blue light, into reactive oxidative species (ROS). These photoproducts can alter the physiology of retinal cells, through apoptosis, potentially leading to macular degeneration. Some would argue that even though most of these research studies have been undertaken on animal cells or in vitro, they nevertheless shed a light on the potential damage of light exposure on the retinal cells.[6-9]

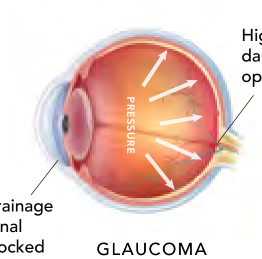
What is the connection between blue light and damage to the retina?

In one well-documented example, an adult who admitted to being addicted to smartphone use, showed strong evidence of light-induced retinopathy. The patient had a habit of spending 6-8 hours every night viewing his smartphone, usually in bed with the lights off. The patient complained of blurred binocular vision. Other sources of possible retinal damage were ruled out in this case. Under doctor guidance, the patient showed improvement after 6 months of curtailed smartphone use.[10]

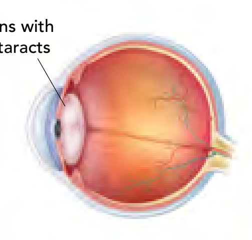
Blue Light and AMD Therapy

Although the true mechanism of macular degeneration is not clear and could be multifactorial, involving among other aspects age, light exposure and individual health issues, it is striking that the prevention of blue light exposure is one of the few prophylactic steps proposed by ophthalmologists.[11]

Ophthalmologists prescribe blue light and UV filtering glasses for elderly patients, set with a side shield to protect their eyes from diagonal sunlight. When combined with the oral intake of radical scavengers such as the lutein and zeaxanthin medications, the two carotenoid pigments naturally found in the eye, or the recommendation of a change of diet to a radical scavenging diet, the prescribed therapy aims to get one of the effects of photo-stress and other aging processes in the retinal cells under control or at least to slow them down.[11]



GLAUCOMA



CATARACTS

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Glaucoma

The second most common cause of blindness in the world, glaucoma, is also being discussed as a disease in which high-energy light plays a role. In particular, the Swiss ophthalmologist Josef Flammer has brought to attention the effect of photo-stress on the retinal ganglion cells as a pathogenetic factor, in addition or independently of the only modifiable risk factor, the intraocular pressure.[12]

It may seem premature to raise the idea of macular degeneration, glaucoma and cataract formation (because light exposure also plays a crucial role in lens opacification), as a risk factor for today's adolescents. Although we cannot foresee whether or not today's adolescents will have an increased prevalence of these diseases in a couple of decades, the complex symptom of eye strain (asthenopia) is a reality for users of all ages. The symptoms are multifaceted: burning or itching of the eyes, running of tears and increased photosensitivity.

High-energy light also leads to changes in the ocular surface, especially in tear film and cornea and can also compromise the integrity of the tear film.[13]

A recent review on blue light exposure and vision health concludes, at a certain extent blue light can promote human eye refractive development and regulate circadian rhythm, but harmful blue light-induced effects on human eyes should not be ignored.[14]

As one study concludes, "The currently available data on the effects of blue light on the retina are not sufficient to refute the hypothesis that the use of personal digital devices could, over a lifetime, produce retinal damage."[15]

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Brain and Body – Physiological Effects of Blue Light

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Eighty to eighty-five percent of our perception, learning, cognition and activities are mediated through vision.[1]

Because our eyes do so much more than just allow us to see, "vision science" overlaps with or encompasses not only ophthalmology and optometry, but disciplines such as the neurosciences, physiology, psychology (particularly sensation and perception psychology, cognitive psychology, linguistics, biopsychology, psychophysics and neuropsychology). Researchers in these disciplines are making startling discoveries with respect to the ill effects on human health of the intense blue light emitted by digital devices.

Non-Image Forming (NIF) Brain Pathways

It was not until the year 2000 that the brain signaling mechanism of optic nerves beyond vision was generally understood.[2] Intrinsically Photosensitive Retinal Ganglion Cells (ipRGC) are a small subset of retinal ganglion cells. See Figure 7-1. The ipRGC are most sensitive to short wavelength blue light, 460-480 nm. They are so sensitive that a single photon can result in an action potential from a rod's corresponding RGC.[3]

In addition to triggering the dilation or constriction of pupils in response to light intensity, ipRGCs signal brain areas that regulate sleep response, cognition, emotion, pain and other biological and physiological processes (Figure 7-2).[4]

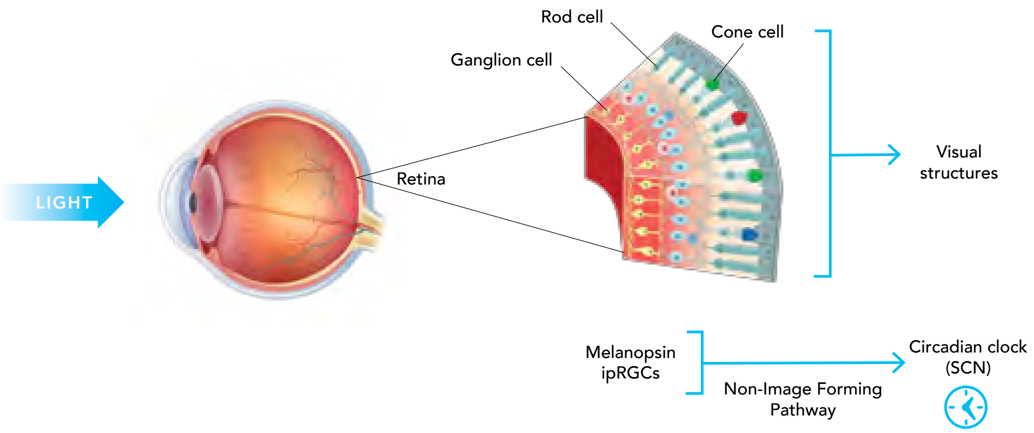


Figure 7-1. Signal receptors in the retina. The ipRGCs are most sensitive to blue light. They can affect a number of non-image receptors in the brain.

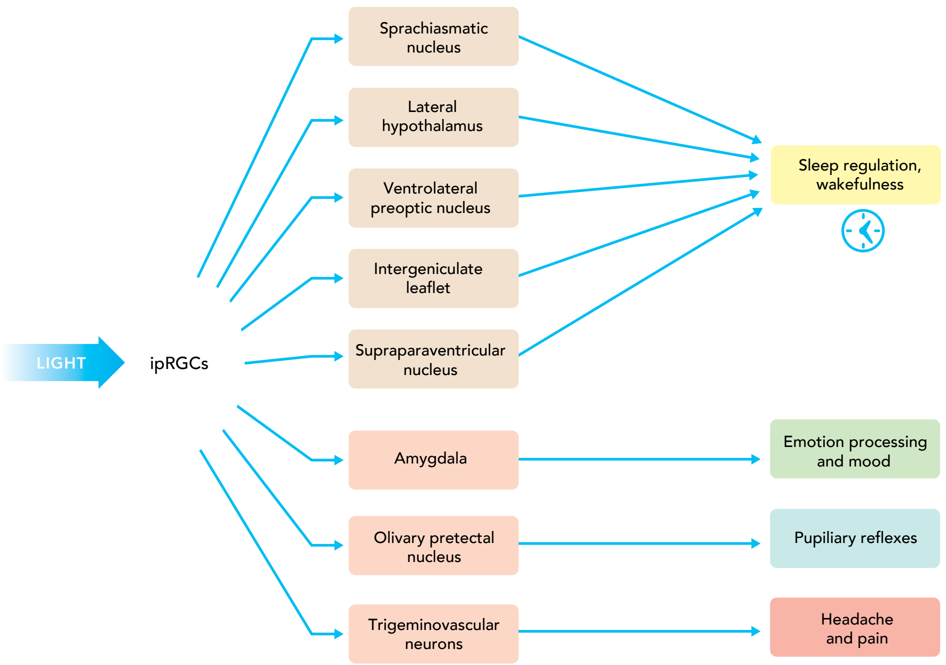


Figure 7-2. Schematic representation of the brain destinations for ambient light entering the eye. Through ipRGCs in the retina, light signals various parts of the brain that control sleep cycles, emotion, mood, pain and physical sensation.

The extent of various biochemical and physiological changes caused by blue light exposure was analyzed in a lab study of mice eyeballs, where 737 abnormal gene expressions were identified.[5] Abnormal gene expressions are linked to eye diseases such as dry eye, cataracts and AMD, but also brain signaling through non-image forming pathways.[5] Brain degeneration and a significantly reduced longevity was observed in a controlled study of Drosophila, a type of fly, given daily exposure to LED blue light.[6]

Mood and Emotion

37%

INCREASE OF MOOD DISORDER SYMPTOMS[7]

When ipRGC photoreceptors respond to light, they project to brain regions that affect emotion. This is one reason that sunlight, the dominant source of blue light, makes us feel good. Some studies suggest that ipRGC connections to some brain systems are a source of mood disorders.[7]

Excessive blue light exposure may be a component of a reported 37% increase of mood disorder symptoms among young people over a nine-year study period by the American Academy of Pediatrics.[8] Investigation into the treatment of depression is finding that ipRGC expressed, including serotonin, dopamine, and norepinephrine, when disrupted, can lead to mood changes. Circadian rhythm disruption has also been shown to cause structural changes to the brain in patients, such as international flight attendants.

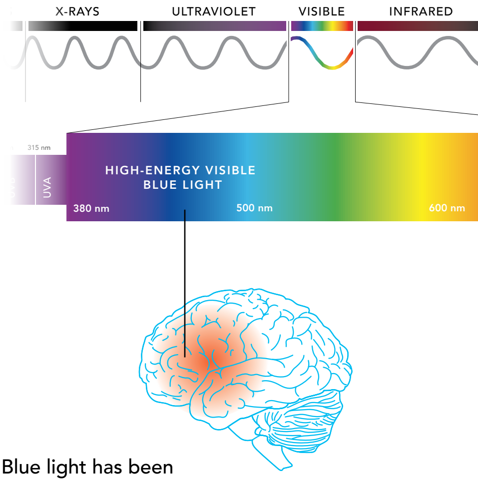
A recent study of 960 Hong Kong adolescents, although not directly implicating blue light, did highlight a strong correlation between excessive LED and OLED display use and negative social behavior.[8] Nearly 86% of those in the study used smart devices daily. That matches the almost universal usage of such devices among adolescents in some Asian countries. From the study group about 50% declared being affected by sleep deprivation, eye discomfort and musculoskeletal discomfort, 20% mentioned family conflict and 5% cyber bullying.[9]

The Hong Kong study was a behavioral survey which only went as far as making the connection with high usage of digital displays. More research is needed to connect blue light, and its influence on the brain, with physiologic effects.

Cognitive Performance

Behavioral studies of excessive smartphone use among adolescents and young adults are highlighting risk factors to learning, mental health and early onset dementia in late adulthood.[10]

For example, an average amount of screen time (two hours a day) was associated with decreased cognitive performance in children, whereas those who used displays seven or more hours showed measurable differences in memory and problem solving, as well as a thinning of the cortex. One study of college students found that they scored better in classrooms that prohibited the use of digital devices.[10]



Blue light has been linked to headache pain and may trigger migraine attacks.[2]

Some Injuries May Start with the Brain

Studies of patients who have mild traumatic brain injury show that blue light has powerful phase-shifting and cognitive properties that could be useful for treatment. One study of athletes under care for concussions suggested that there is a better chance of recovery when the patient is protected from exposure to blue light.[11]

Ongoing research is associating blue light with brain functions related to posture and extensor muscle strength. It may be that intense blue light also inhibits the activation of extensor muscles, which can lead to athletic injuries as well as chronic neck and back pain, carpel tunnel problems and other joint injuries. This is due to a functional muscle weakness causing a loss of joint support. When the joints are not being sufficiently supported by the surrounding muscles, those loads are transferred to other tissues not meant to absorb the full force, such as ligaments, cartilage, meniscus, bone, intervertebral disc and bursae, which can eventually break down.

Since studies are ongoing and not conclusive, it would be prudent to suggest that children who take part in athletics should limit their usage of digital displays, especially before intense physical activity or during breaks. Use of digital displays should also be restricted during injury recovery. Controlling blue light exposure with effective display filtering may one day become a component of athletic training and sports medicine.

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Variables of Impact

What is the cumulative effect of blue light, given our always on, always connected habits and inability to unplug? What might be the risk, if any, over a 10-50 year time span?

Let's assume that usage trends for digital devices will be the same or will grow over the next fifty years. It is quite possible that LED or OLED's will continue to be the dominant display technology. Low power consumption, thin design, rich color reproduction, vivid images and form flexibility are some of the current market drivers. OLED displays can conform to curved shapes and even fold up formats. This points to ubiquitous application, embedded in everything from toothbrushes to walls and household appliances. It could be that an average person will be literally bathed in blue light, with both good effect and unintended consequences, for their entire waking life.

A recent survey shows a considerable increase in screen time, with up to 13 hours a day in front of screens from different devices.[1] A third of adults exceed ten hours a day. Over a fifty year timespan, that's between twelve and twenty years in front of a digital display. Although exposure to blue light from displays for a few days or even a few weeks does not significantly increase the risk of vision or health problems, we do not have the data to assess risk from long term chronic exposure that laboratory science suggests is concerning.[2-3]

About the Author:

David Friess, OD, FAAO is a leading clinical research optometrist with over 20 years of combined clinical care and leadership in clinical research and medical affairs.

"Our review has included peer-reviewed studies and new guiding research on the health impacts of blue light exposure from displays. Our conclusion is that blue light should be managed more effectively, especially for cumulative and close-use of displays and within the most toxic blue light spectrum."

30%

OF ADULTS EXCEED

10+

HOURS PER DAY ON DIGITAL DEVICES[1]

To understand the impact of cumulative exposure to blue light, we need weigh the variables. They include intensity and duration as well as distance from the light source. We also need to factor in age and time of day.[4]

Variables of Impact:

- Intensity
- Duration
- Distance
- Age
- Time of Day

It is well established that intense blue light exposure impacts sleep quality by suppressing melatonin secretion and the associated shift in circadian rhythm. Melatonin is a powerful antioxidant. It is positively associated with limiting the chance of hormone production related cancers, such as breast and ovarian cancers. A recent National Institute of Health study, involving 116,000 people, found that high intensity blue light at night shares a similar melatonin repressing characteristic with cigarette smoking.[5]

Intensity

Shorter wavelengths of visible light transmit more energy. Blue light between 415 and 455 nm is the most harmful. It takes less than a minute of direct exposure from the sun or from an arc-welding lamp to damage the eye.[2] Thousands of people in Germany in 1912 suffered eye damage while viewing a solar eclipse. It is now understood that blue light did the damage.[3]

In laboratory studies, the damage from digital display blue light exposure is due to a photochemical reaction leading to the acceleration of cellular aging pathways. The reaction is directly related to the strength of illumination. Stronger intensity leads to more photochemical damage. The reaction also depends on the total exposure. In some ways, longer exposure can substitute for higher intensity.[6]

Studies have shown that cell damage occurs more with blue light than with green or white.[2] After saturating human retinal pigment epithelial (RPE) cells with A2E and exposing them to blue and green light, researchers found RPE cell death only occurred in those exposed to blue light. These are lab studies; animal or petri dish studies in other words. Very few studies have been done on actual human subjects. These studies do, however, narrow the toxic effect to the blue light range.

The cornea, at the front of the eyeball, is the first part of the eye that intense blue light can affect.[3] Blue light increases reactive oxygen species (ROS) production in corneal epithelial cells. The oxidative damage is associated with dry eye disease. Blue light also inhibits corneal stromal cell activity.

Intensity, or luminous power, is measured in candela in the International System (SI). The contribution of each wavelength is weighted based on the standard luminosity function. This is based on the eye's relative sensitivity to each wavelength. Candela per m^2 is the intensity of a source in a given direction. Candela per m^2 is also called a Nit, which is the term used most often to describe the brightness of a display. See Figure 8-1.

LUMEN, CANDELA AND LUX:

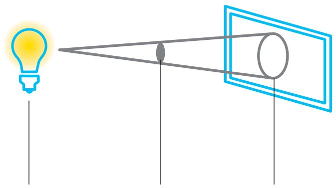


Figure 8-1. Candela per m^2, equal to 1 Nit, is a measure of luminous intensity.

Published specifications and independent reviews of smartphones and tablets show that displays start at 200 Nits, but can be up to 1000 Nits or more at peak brightness. See Table 8.1. Large TV screens are at the higher end. According to The Vision Council, nearly 67% of American adults report using two or more digital devices simultaneously, and 59% report experiencing symptoms of digital eye strain.

The sun at its brightest is about 5,000 Nits. A display out in the sunlight has to be very bright to be seen. Large LED display signs that you might find on buildings or as scoreboards and roadside signs, can be up to 10,000 Nits. Smaller displays typically do not have that power, although it has been a design goal, so that sunbathers can still have their screen time. Very bright screens are also a design goal for tablet makers with drone flyers as a target audience.

Table 8-1. Peak brightness, as measured in Nits, can be relatively higher in smartphones than tablets.

Product Type	**Name***	**Type Display**	**Peak Brightness (Nits)**
Smartphone	Samsung Galaxy S10	AMOLED	1215
Smartphone	Samsung Galaxy Note 8	AMOLED	1200
Smartphone	LG G7	LED Backlight	1000
Smartphone	Samsung Galaxy S8	AMOLED	650
Smartphone	Apple iPhone X	OLED	634
Tablet	Apple iPad Pro	LED Backlight	489
Tablet	Samsung Galaxy Tab S4	AMOLED	427
Tablet	Google Pixelbook	LED Backlight	421
Tablet	Microsoft Surface Pro 6	LED Backlight	408
Tablet	Google Pixel Slate	LED Backlight	337
Tablet	Amazon Fire HD 8	LED Backlight	307

* Amazon Fire, Apple iPhone, Apple iPad, Google Pixelbook, LG G7, Microsoft Surface and Samsung Galaxy are trademarks of their respective companies.

Of course, displays have sliders to adjust brightness for ambient lighting conditions. Many brands also have sensors that self-adjust to ambient conditions. In most cases, however, the brightness sensor is on the back side of a smartphone. Therefore, the brightness compensation is not based on the viewer's perspective. Also, the brightness adjusters are not often used. Many people leave the displays at their brightest, even in low ambient light conditions. Keep in mind also that we hold smartphones closer to our eyes than tablets or other displays.

Duration

Extended exposure to high energy light generates free radicals within the retina.[6] The radicals react with specific DNA components in the cell membrane which can cause cell dysfunction or cell death. The absorption of radiant energy causes an excitation of electrons. Retina tissue is vulnerable to free radicals and the mechanism to reduce them. As a result, photoreceptors which convert light to chemical impulses can be damaged.[2]

A second type of photochemical damage is associated with longer but less intense light exposure. This damage can occur in the retina, affecting the outer segment of photoreceptors.[2] The macula is the part of the retina which is mainly responsible for color vision. Damage can have irreversible consequences in some cases.

The cumulative effect of blue light was demonstrated in a labratory animal study, by comparing a single exposure of 5 minutes to a series of 5-minute exposures.[4] The series of 5-minute exposures, followed by a 1-hour dark interval, led to what the study authors defined as significant photoreceptor damage.

How many hours of screen time per day might increase a person's long-term risk of vision problems or eye damage?

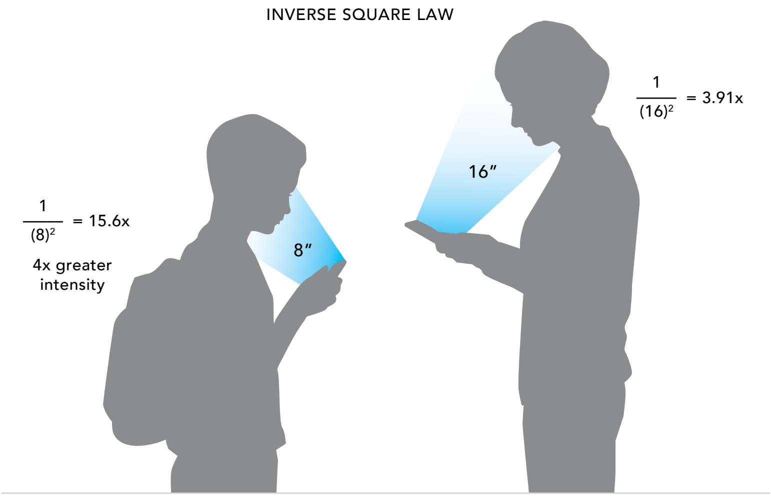
How much blue light exposure from digital devices is too much? How many hours of screen time per day might increase a person's long-term risk of vision problems or eye damage? Again, we do not have not enough data to say conclusively what intensity level and what duration is too much when it comes to displays. Research also continues involving the cellular repair mechanisms in the eye, as well as the contribution of brain plasticity to compensate for the eye.

Another question we can't yet answer is whether or not blue light emitted by the screens of digital devices, when compared with that emitted by the sun, has a duration effect that corresponds in a linear fashion to the sun's intensity. Sunlight emits far more blue light than digital devices, but our screens are much closer to our eyes and we're staring directly at them for long periods of time.

Distance

Light intensity changes by the inverse square of the distance. A child with shorter arms holding a tablet or phone will receive a greater intensity of light than an adult, four times the intensity depending on body size. See Figure 8-2.

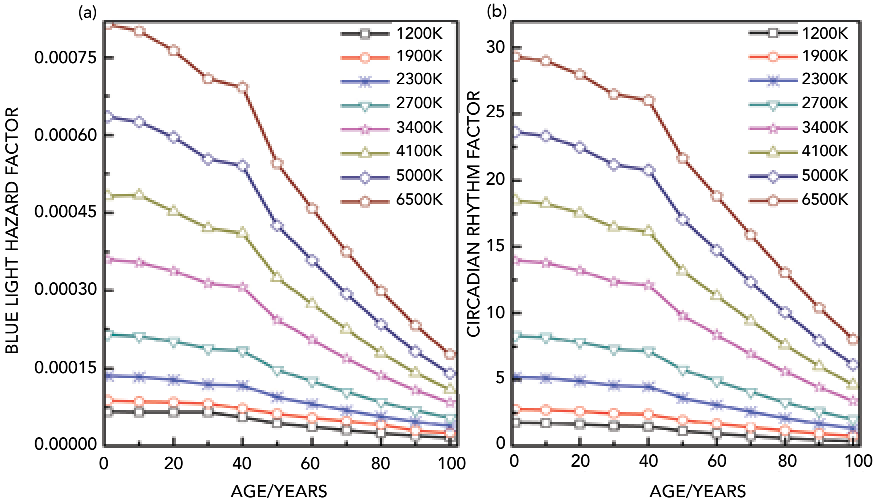
Figure 8-2. Children can be more exposed to display intensity. Holding a display twice as close quadruples the intensity.



Age

In young children, more than 65% of blue light is transmitted to the retina. The intensity of blue light as well as circadian rhythm function differs dramatically by age.[7] See Figure 8-3. When we plot comparison lines of color temperature, we can see that a 6500 K (average backlit LED) display, compared to 2300 K (incandescent bulb) is almost four times as intense for a child, compared to less than 2-1/2 times for a 60-year-old.

Figure 8-3. As people age, their sensitivity to hazardous blue light (a) and circadian disruption (b) decreases, due to a loss of transparency in the lens of the eye. Children are extremely susceptible to intense light as shown by the 6500 K plot, which is an average display color temperature.[3]



"One size fits all" does not apply to intensity settings, even though displays come this way. Intensity should be adjusted for the age of the user. A lower color temperature setting for children may help reduce sleep disruption that has been associated with significant health problems and also may be a factor in academic performance in school due to daytime fatigue. The default color temperature of a display may be more appropriate for adults only.

As we age, we experience reduced transmittance and increasing opacity in the lens of our eyes. Susceptibility to light damage increases with age, however, in a process that is distinct from age-related degenerative changes.[8] This has to do with how blue light interacts with the outer retinal layer.

See Page 46

See Chapter 6 on retinal damage

Aging has little effect on the number of cone photoreceptors in the human fovea, whereas the number of parafoveal rod photoreceptors decreases by 30% with increasing age. Early rod loss is a characteristic feature of age-related macular degeneration.

The loss of macular pigmentation, or a family history of AMD plus exposure to toxic levels of blue light, can contribute to the breakdown of RPE cells and lead to permanent retinal damage.[2]

Cataracts are one of the leading causes of blindness.[9] The lens of the eye not only focuses light but also filters short wavelength light. As the eye ages, it produces yellow pigments which gradually darken the lens. See Figure 8-4. The yellowing lens absorbs blue light and helps protect the retina. Unfortunately, the density of the macular pigments decreases with age, leaving the eye increasingly vulnerable to blue light toxic effects.

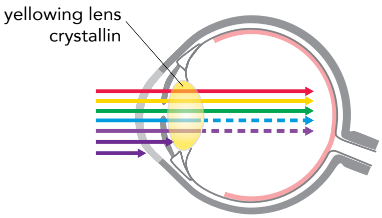


Figure 8-4. As the eye ages, it produces yellow pigments which gradually darken the lens. The yellowing lens absorbs blue light and helps protect the retina.

Yellowing and darkening lenses is one reason that older people can have sleep problems. They do not receive enough blue light during the daytime to trigger alertness. Increased exposure to sunlight has been shown to increase age-related cataract formation.[10]

Time of Day

Our eyes are more susceptible to blue light damage at night.[2] We can look to studies of nocturnal animals, such as sea turtles who have had their egg laying patterns seriously affected by LED lighting at beaches. The US National Park Service has adjusted their night lighting strategies as a result of animal studies where it is apparent that blue light at night disrupts animal behavior.

The retinas of animals exposed during the middle of the dark period or during the first 5 hours of the light period were significantly more damaged than the retinas of animals exposed during the last 9 hours. The increased exposure enhances photoreceptor damage.[3]

NASA has also begun testing blue light adaptations at the International Space Station to help astronauts adapt their circadian rhythms in space. Astronauts are warned not to look directly at the earth's reflection during sleep times.

For reasons that include the impact of artificial light and the increased use of digital devices, humans nowadays sleep fewer hours than in the past, significantly less than the recommended amount.[11] Fatigue at the workplace, at school, and behind the wheel is leading to lost productivity, study problems, and accidents on the road. As schools move to replace more costly incandescent lighting with high efficiency LED lighting, more eye care professionals are urging caution, and recommend retaining fluorescent lights, which do not have the characteristic high energy blue light emission.[11]

Cumulative Effects

Scientists who have reviewed current research about the effects of blue light on the eye have concluded that the potential effects of long-term exposure to HEV blue light on the eye are still unknown and that "additional studies on the safety of long-term exposure to low levels of blue light are needed to determine the effects of blue light on the eye."[2]

The cumulative light exposure effects of most concern include cataracts, myopia and AMD. The retina is where image formation takes place, and is also the location of blinding eye diseases. In laboratory studies, when blue light penetrates the eye, with either intense or cumulative exposure, it can cause inflammatory reactions and photoreceptor cell damage, and weaken the blood retinal barrier. The inner layer of the photoreceptor absorbs short wave blue light, with substantial damage to the retinal ganglion cell mitochondria. Blue light also degrades retinal pigment.[8]

Lab studies are showing an inverse relationship between intensity and duration for some types of cell damage. Other types appear to recover over time.

For people who undergo cataract surgery, some studies have shown that blue light exposure can accelerate the occurrence of AMD. There are remarkable similarities between light damage and the changes found in advanced atrophic macular degeneration. One study showed that "increased exposure to blue light in the teens, 20's and 30s increased the risk of onset age AMD by 10 years, effectively doubling the chances of blindness during lifetime."[8]

Finally, the risks of cumulative exposure go beyond vision health. Repeated disruptions of melatonin production during evening hours by blue light exposure depresses a person's immune system and could increase the risk for diabetes and other conditions.[8]

"increased exposure to blue light in the teens, 20's and 30s increased the risk of onset age AMD by 10 years, effectively doubling the chances of blindness during lifetime."[4]

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SECTION 2

Health and Policy

This section offers guidance from vision health, policy and standards makers on blue light exposure from digital devices.

Screen Time

About the Authors:

William Wiley, MD was among the first physicians in the country to implant the Crystalens accommodative intraocular lens also available for cataract surgery. To date, Dr. Wiley has performed over 10,000 cataract and refractive surgical procedures.

Chuck Roseman, OD is a member of the Cleveland Eye Clinic. He provides a full scope of eye care with emphasis on ocular disease and perioperative patient care.

Country by country we are seeing a dramatic increase in the amount of time spent in front of a digital display.

Device use is changing society around the world, and we are not handling it very well. Screen time is a singular issue of concern affecting adults and especially young children. What is also evident from multiple studies is our inability to manage screen time despite a realization that we probably should.

In previous chapters, we highlighted research that identifies high energy blue light from LED and OLED displays as contributing to digital eye strain, sleep disruption, visual acuity, dry eyes, retinal diseases, brain and musculoskeletal anomalies. A NEI-funded study found that children's eyes absorb more blue light than adults from device screens. Clearly more research is needed, especially on the effects of blue light cumulative exposure.

Over half of adults, 63%, do not realize that a health controversy exists around blue light from LED displays. Setting that aside, it is important to understand screen time as a social phenomenon. It will help us appreciate the magnitude of behavioral change that might be necessary if we believe we have an issue with exposure to blue light from displays.

Global Screen Time

There are over 3.8 billion smartphone users worldwide (June 2021). Almost half of the world's population own one. What makes this even more remarkable is that 14% of the world's population, or 1.1 billion people, do not even have access to electricity.[1]

Ranking usage by country, China has the most smartphone users (851 million), followed by India and the United States. The rate of smartphone ownership is highest in the United Kingdom (83%), with the US in fourth place (79%).[1]

Smartphone ownership is highest with young adults, but children are not far behind. See Figure 9-1. From 78.8% to 93% of Taiwan teens aged 12-17 years own smartphones. 48.7% of Taiwan children aged 6-11 years have smartphones. The rate of smartphone ownership nearly doubled to 80% among adolescents in Switzerland over a two-year period. In Germany it more than doubled. Adolescent smartphone ownership in South Korea is 85%, about 65% in Japan and the Philippines, 55% in Malaysia and Hong Kong and over 40% in China. That compares to a 50% adolescent ownership rate in the United States.[2]

Smartphones are the most widely used computing devices among adolescents, closely followed by laptops, tablets and desktop computers. Although most studies focus on smartphone usage, screen time accumulates across all digital devices.

85%

SOUTH KOREAN ADOLESCENTS WITH SMARTPHONES (2017)

50%

U.S. ADOLESCENTS WITH SMARTPHONES (2017)[1]

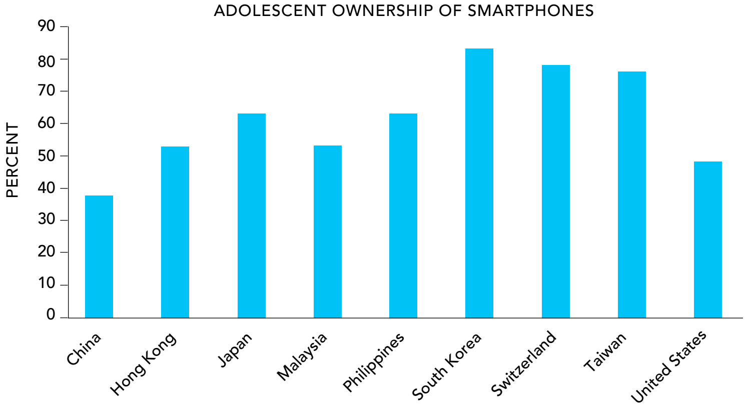


Figure 9-1. Adolescent ownership among various countries, 2017 study.

Screen Time Trends Amid COVID-19 Pandemic

The COVID-19 pandemic in 2020 and 2021 accelerated the already rapid increase in device usage and average screen time. Prior to the pandemic, we saw increased screen time among children up to 8 years old.[3] These younger children just entering school-age already averaged about two and a half hours of screen time a day (USA).

On-line videos and other forms of entertainment, watched directly on a smartphone or tablet, accounts for the rise in usage pre-pandemic. Twice as many young people watched a video every day on a device in 2019 compared to 5 years ago.[4] This was coupled with a slight decrease in daily TV viewing.

Average screen time was higher for children in lower income households, and measurably higher among Black and Hispanic households in the USA. Parents within these demographics perceive educational benefits from screen time. Studies tend to validate that reading has increased among these demographics consequently.[3]

The pandemic dramatically raised screen time among school-age children. Approximately 1.37 billion students (80% of the world's student population) were affected by pandemic lockdowns, with distance learning replacing in-person, classroom-based learning.[5]

Screen Time Addiction

65% of parents are concerned about digital screen time and teens[1]

65% of parents say they worry that their teens are spending too much time in front of their digital devices. About 30% of teenagers in South Korea are considered addicted to mobile phones.[2] Mobile phone addiction is assessed by specialists who evaluate responses such as "I'm easily unaware of the passing of time when I'm using my cell phone," "I feel isolated when I don't have my cell phone with me," "I feel nervous without my cell phone," "I feel nervous when I have not received any message or call in some time," and "I feel too uncomfortable to live even a day when I don't have my cell phone with me."[7]

Adolescents tend to have lower levels of self-control than adults. That makes them more vulnerable to screen addiction. Among adolescents with screen time addiction, the most common psychiatric disorder is Attention Deficit Hyperactivity Disorder (ADHD). Listed below are a number of other correlated issues:

Adolescent Screen Time Issues[8]

- Sleep Quality
- Eye Health
- Physical Discomfort
- Parent-Child Relationships
- Academic Achievement

Is screen time hurting our kids?

Sleep Quality

Using screen time for gaming in a Belgian adolescent study was associated with lower sleep quality and shorter sleep duration.[6] Gaming for one hour before bedtime among German adolescents was associated with a disruption of full and consistent sleep cycles necessary for learning and memory function. An Australian adolescent study on gaming prior to bedtime found similar sleep changes, and less alertness during wake time.

Mobile phone use after "lights out" have been the subject of numerous studies. 94,777 Japanese adolescents were surveyed and 632 UK adolescents in another survey. They showed strong correlation with excessive daytime sleepiness.

Among all the studies, the least negative association with sleep quality was television usage.[8] This is perhaps due to distance from the screen and a more passive mode of use.

In the study of Korean children, sleep problems worsen with age.[7] This might also have to do with increasing academic pressures for older students. Screen time addiction persists and may lead to sleep disorders well into adulthood according to the study.

Eye Health

In a Hong Kong study of primary school students, excessive screen time was correlated to symptoms of blurry vision and eye strain.[6] More than one hour per day appears to increase eye discomfort. It was found that adolescents had a higher level of accommodative spasms and temporary myopic shifts due to constant close viewing of screens.

In addition to eye comfort issues, there has been a massive increase in nearsightedness among adolescents that is being linked to screen time. Studies are showing, however, that balancing screen time with additional outdoor time can help reduce the risk of myopia.[5]

Physical Discomfort

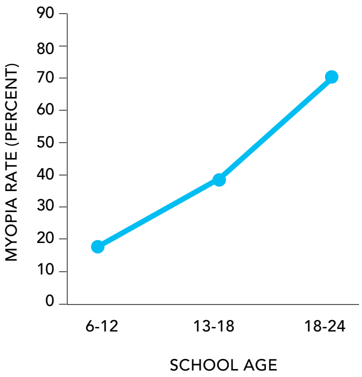
A study of 3,016 Chinese adolescents found that using mobile phones over two hours per day strongly correlated with a high incidence of neck and shoulder pain.[6] Mobile phones effect posture differently from that of a laptop screen. Ergonomic design allows a laptop to be positioned on a flat surface at an adjustable angle and distance to help reduce physical discomfort. Mobile phones and tablets, on the other hand, can subject the user to a stressful head position that affects the neck, back and shoulders.

Parent-Child Relationships

Screen time has been associated with parental conflict in a Canadian study of 1,591 adolescents, a Finnish study of 478 adolescents, and a survey of 1,136 South Korean adolescents. Parents in Hong Kong quarrel with their children about screen time 60% of the time.[6]

Academic Achievement

Excessive screen time leads to less daytime alertness and lower academic achievement. This tends to trigger parents and teachers to intervene with screen time restrictions. In other cases, parents are ignoring restrictions in order to meet academic performance goals for children.



Myopia rates in China progress as children get older (2018 study).[11]

Policing Screen Time

In Taiwan, it is now illegal to allow screen time for children under two years of age.[9] Children under 18 are only permitted screen time for a “reasonable” length of time. Parents can be fined the equivalent of $1,500 for breaking the law.

The government of Australia is debating laws regarding age of ownership of smartphones. The average youth age of ownership is ten years.

The South Korea National Assembly enacted the Youth Protection Revision Act, also known as the Shutdown Law. The law forbids children under sixteen from playing on-line video games after midnight.[10]

Myopia rates among Chinese adolescents are approaching 70%. As a result, China is moving forward with a number of screen time related policies.[11] There is a freeze on approvals for new video games available in China. The share price of a number of gaming software companies were affected by this 2018 announcement.

The Ministry of Education has issued guidelines on screen time in order to combat the rise of nearsightedness. According to President Xi's "Comprehensive Prevention and Control Children's Myopia Implementation Scheme," adolescent nearsightedness is high and rising. It is mandated that the whole of Chinese society take action. The mandates include limits on screen time for both learning and non-learning activities, and that children spend more time outside doing physical activity.

In China, eye care measures will be implemented in all schools, including eye exercises morning and afternoon, and recorded vision screening and assessments. Students are forbidden to bring screens, including mobile phones and tablets into the classroom. Screen time use is restricted to 30% of total teaching time. The goal of the China policy is to meaningfully address the rise of myopia. Targets are set for 2023 and 2030 by age group.

Government policies may be the only recourse if screen users and companies that sell them do not recognize the implications of cumulative exposure through excessive use. Education is needed on the issues. Society may lack the resolve and the discipline to address the problem. Country by country, the research confirms both.

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Children's Eye Health in the Digital Age

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In addition to the adverse effects of increased screen time on children's behavioral and psychological development, the impact on their vision and eye health cannot be ignored.

Many parents of pre-school and school-age children have not recognized the risks of excessive smartphone and display usage. That's understandable because the issue has crept up on us. Parents have been largely unaware and unprepared; like frogs in a pot of water slowly coming to boil.

In the past, screentime for kids was discretionary, largely up to the judgement and control of parents. That is no longer the case in a pandemic world. At an increasingly younger age, kids are compelled to study, socialize and entertain themselves with smartphones and displays. Pandemic restrictions made this a worldwide norm. There may be no going back from here.

A Doubling of Eye Strain Among Pandemic Kids

Screen use doubled for pandemic kids according to several studies. Coinciding with that is a doubling of cases of digital eye strain, the most common health issue related to excessive screen time.[1]

See Page 22

See Chapter 3 on Digital Eye Strain

Digital eye strain (DES) can be diagnosed from a list of symptoms including itching in the eyes, a burning sensation, watering, eye pain, excessive blinking, redness, blurring, dryness, double vision, near vision difficulties, light sensitivity, colored halos, unclear vision and headaches. The symptoms or combinations of them may be temporary or prolonged.[1] The most common symptoms of DES in children are burning sensation (nearly 55% of instances) and headaches (53% of instances).[2]

The most common symptoms of DES in children are burning sensation and headaches.[2]

The prevalence of DES among children using digital displays ranges from 25% to 93% in various studies.[3] In one study of over 200 participants, DES risk was significantly associated with:

- Using smartphones over five hours daily.
- Boys more than girls, although girls reported DES more often.
- Playing mobile games for more than an hour a day.

Smartphones were more strongly associated with DES partly because the screen distance to a child's eyes is usually less than 18 inches. It also happens that in many parts of the world a smartphone is the most common device used for online classes.[3]

The World Health Organization (WHO) emphasizes restricting screen use with children, strongly recommending children less than one year old not to be exposed to electronic devices, while limiting screen time to an hour a day for children under the age of six. These guidelines are set in the interest of maintaining good cognitive and physical development.[4]

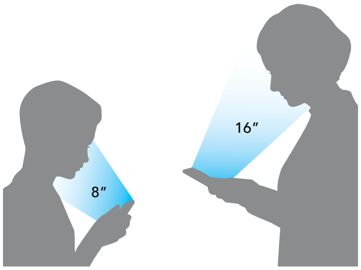
Dry Eye Disease Starts Earlier and Can Be Progressive

The incidence of dry eye disease can be thirteen times higher in children who use smartphones according to one study.[5] Chronic dry eye disease is a condition of the meibomian gland. If left undiagnosed and untreated, it can become progressively worse.

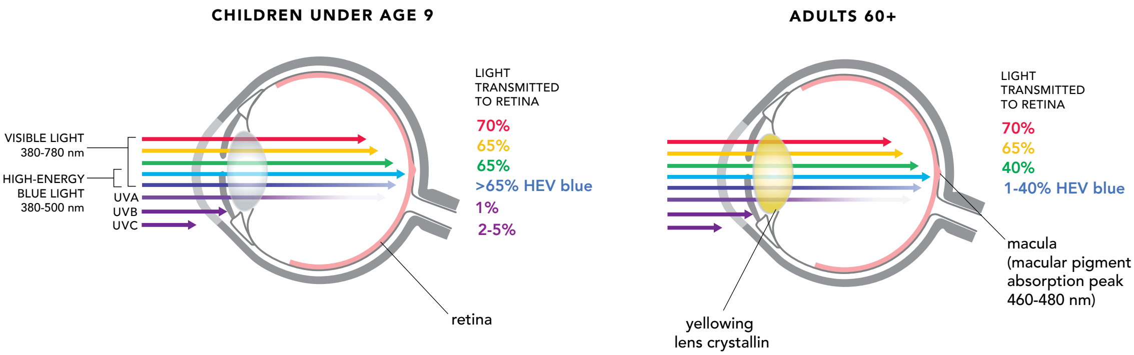
In a study of severe meibomian gland atrophy cases in 17 children, 86% of the cases admitted to at least 4 hours of daily screen time.[6] The study author, Sandra Lora Cremers, MD, an ophthalmologist at Visionary Eye Doctors in Washington D.C. and a surgeon at Johns Hopkins Suburban Hospital, expressed concerns about excessive screen time, blink rates, and the intake of blue light from digital displays.

"While there are published papers showing blue light is potentially damaging to the macula, there are no published reports showing causation of blue light with damage to the ocular surface or meibomian glands: though it may take years to prove causation," Dr. Cremers said. "By that time, it might be too late."

As we age, our natural lens becomes yellow, filtering some blue light, but this is not the case for children. In young children, more than 65% of blue light is transmitted to the macula. With children holding a smartphone or tablet, shorter arms equates to closer distance, and potentially more blue light exposure.[7]



Children can be more exposed to display intensity. See page 62.



Children are especially vulnerable. As people age, a yellowing of the lens changes the amount of blue light that penetrates the eye. See page 8.

Nearsightedness Affects More Kids

Nearsightedness, or myopia, may affect 50% of Americans by 2050.[8] How and why kids become myopic is complex due to a combination of genetic and environmental factors. Most eye care professionals agree, however, that there is a relationship between near vision work and myopia.[9]

50%

OF AMERICANS MAY BE AFFECTED BY NEARSIGHTEDNESS BY 2050[8]

In addition to the potential dangers of blue light exposure, the impact of near work on the development of myopia is substantial. Children go through a critical period of eye growth and development before their vision finally stabilizes in early adulthood (early to late 20's). In some cases, the eyeball elongates too much (increased axial length) during this period, causing the light that enters the eye to be focused in front of the retina instead of directly onto the retina resulting in blurred vision. This is known as axial myopia, the most common etiology for nearsightedness. In addition to genetics, it is now known that specific environmental factors, such as increased time spent on near work like reading, can affect the onset and progression of myopia in children.

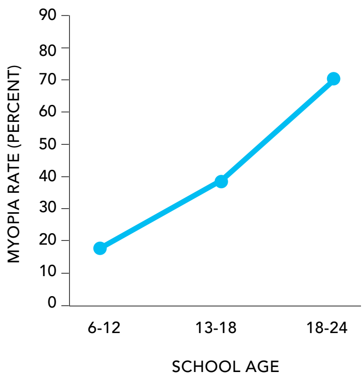
Much of this research has come out of East Asia, where myopia affects over 90% of high school students. Worldwide, myopia is expected to become one of the greatest public health challenges of our time and is predicted to affect over 50% of the world's population (over five billion people) by 2050. This trend will likely continue to worsen with increased digital device use.

As a LASIK and refractive surgeon, my colleagues and I have seen myopia rise steadily in younger and younger patients every year. The consequence of myopia is not simply having to wear glasses to see. Those with high myopia (over 10% of the population in 2050) are more prone to developing sight-threatening conditions like glaucoma, cataracts, retinal detachment, and retinal degeneration.

How strong is the evidence that near work increases the risk of myopia? A meta-analysis of multiple studies looking at over 25,000 children ages 6-18 years concluded that increased reading time was linked to myopia onset and progression.[10] As one might presume, the same effect has been seen with the increased use of digital devices with studies showing a link between both increased computer and smart phone use and myopia prevalence in school-aged children. Interestingly, despite these studies, a recent meta-analysis showed that the overall current evidence for increased screen time and myopia is inconclusive. However, it may simply be a matter of time before a greater number of large studies show an effect.

In addition to reducing the amount of time spent on near work and digital devices, multiple studies have shown an independent, protective effect of increased time spent outdoors on reducing myopia onset and progression. Specifically, it is hypothesized that exposure to moderate outdoor light intensities reduces the onset and prevalence of myopia.[11]

One study from China showed that an additional 40 minutes of outdoor time per day achieved a 23% reduction in the incidence of myopia.[12] A public policy intervention imposed on Taiwanese school children promoting at least 120 minutes of outdoor activity actually reversed the uptrend of decreased visual acuity amongst schoolchildren over a 5-year period. While some have promoted two hours of outdoor activity as a good number to target, the optimal amount of outdoor time to significantly reduce myopic progression in children is unknown, and more research is needed.



Myopia rates in China progress as children get older (2018 study).[13]

Myopic Rates Tripled Among Young Children in Home Confinement

Addressing the causes of myopia is a subject of both research and policy in China.[13] With increasingly higher rates of myopia among school-age children, the China Ministry of Education established guidelines which include mandatory outside activity, limited screen time in classrooms, and eye screenings. The massive eye screening effort is now giving us a window into understanding certain environmental risk factors for myopia.

China's efforts to stabilize myopia rates, unfortunately, have been undermined by the COVID-19 pandemic and associated lockdowns. The latest research shows a distinct connection between the home confinement during the pandemic, higher screen usage, and an increase in the systemic rates of myopia in children.[14]

School-based eye screenings revealed a -0.3 D shift in myopia among 194,904 tests conducted in 123,535 children. "This substantial myopic shift was not seen in any other year-to-year comparison, making the cause possibly due to the unusual occurrence of home confinement in 2020," said the JAMA Opthalmology study.[14]

The study found that age is a major factor in myopic change. 6-year-old children in the study had a 3-times higher myopia prevalence in 2020 (during home confinement) than in other years. For 7-year-old study participants, the increase was twice as high as previous years. In the 8-year-old group, the increase was 1.4 times higher than in the past.[14]

"Such a substantial increase in the prevalence of myopia was not seen in the older age groups (9-13 years), despite the fact that the older children (grades 3-6) were offered more intense daily online learning courses (2.5 hours) compared with the younger students (grades 1-2, 1 hour daily)," according to the report. "These findings led us to a hypothesis that younger children are more sensitive to the environmental change than older children."[14]

Another study points to blue light from displays as a risk factor. Blue light is defocused when it reaches the back of the eye due to chromatic aberration.[15] Children with developing eyes will automatically detect whether light is focused in front of or behind the retina. The response may include not only accommodation (focus, dilation, vergence, squinting, blinking, etc.) but over time, abnormal eye growth. With displays emitting dominant blue light, that influences eye growth in the direction of nearsightedness.

6-year-old children had a 3x higher myopia prevalence during home confinement[14]

See Page 41

See Chapter 5 on Nearsightedness (Myopia)

Research with school age children found that blue light filters on display screens used before bed time produced significant positive health benefits by curbing blue light-induced melatonin suppression.[16]

See Page 31

See Chapter 4 on Circadian Rhythm

Screen Time Can Affect Sleep

Besides the risk of myopia development in children, increased screen time can affect children's eyes in a number of ways similar to adults. There is good evidence that the blue light emitted from digital devices and LED lights can alter circadian rhythm and disrupt our quality of sleep. Therefore, it's a good idea to avoid screens around bedtime for adults and especially children who need good sleep for proper development.

The incidence of U.S. children getting less than eight hours of sleep a night rose 33 percent over a five year time span starting in 2006.[16] It is clear from numerous adolescent sleep studies that smartphone use for gaming, social interaction and study at night contributes to sleepiness during the next day as well as mood changes.

Research with school age children found that blue light filters on display screens used before bed time produced significant positive health benefits by curbing blue light-induced melatonin suppression.[16]

Guidance from a Harvard Medical School study is to avoid blue light two hours before bedtime.[17] School age children would benefit from staying off of their tablets and smartphones before bedtime. Of course, as children get older that is harder to enforce.

Guidance for Parents

The good news is that there are a number of things that parents can do to decrease their children's risk of eye strain, dry eye disease, myopia and sleep disruption. First, limit their amount of screen time. While the American Academy of Ophthalmology does not have specific recommendations on the amount of screen time for children, they do recommend taking frequent breaks by following the 20-20-20 rule: Make sure to blink often and to look up from your screen or close-up work every 20 minutes and focus at least 20 feet away for 20 seconds.

Tips to Help Maintain Children's Eye Health

Consult an Eye Doctor:
Talk to an eye care professional or pediatrician about ways to protect your family and your child's eyes from blue light.

Rest the Eyes:
Try to decrease the amount of time spent in front of screens. Have children take frequent breaks and remind them to blink when watching TV or videos.

Follow the 20-20-20 Rule:
For every 20 minutes spent looking at a screen, look at something 20 feet away for 20 seconds. Parents can help children accomplish this by setting a timer to remind them.

Reduce Blue Light Exposure
- Blue light filters are available for smartphones, tablets, laptops and computer monitors.
- Many laptops and monitors now have technology designed into the hardware or software which helps reduce blue light emissions.
- Try setting your devices to night mode which adjusts the screen display to a warmer temperature.
- Computer glasses with yellow-tinted lenses help reduce blue light and may increase contrast.

Reduce Glare and Brightness:
Avoid using screens outside or in brightly lit areas, where glare can create strain. Adjust screen brightness and contrast so that it feels comfortable.

Improve Posture:
Poor posture can contribute to muscle tightness and headaches associated with eye strain.

Hold Devices Further From the Eyes:
Encourage your child to hold tablets and phones farther away: 18 to 24 inches is ideal.

Avoid Using Devices at Night:
Limit or avoid screen time at bedtime to reduce sleep disruption.

In China, where public health interventions for myopia are prioritized, the Ministry of Education recommends that students rest their eyes for 10 minutes after every 30-40 minutes of educational screen time. They also state that the continuous use of digital devices for non-educational purposes should be no more than 15 minutes and total less than one hour per day.

The American Academy of Pediatrics recommends no digital media use (except video chatting with family) in children younger than 18-24 months. Screen time should be limited to one hour per day of high quality educational content for children ages 2-5. The WHO recommends no screen time before age one and less than one hour of sedentary screen time for children age 1-5 years.

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Screens Are Moving Closer to Our Eyes

From movie theaters in the 1930s to living room TVs in the ’50s; from desktop computers in the ’80s to mobile phones in our pockets today, screens have moved increasingly closer to our eyes.

In that time span, the average screen-to-eye distance has decreased from over 100 feet to less than 1 foot (Figure 11-1). Over the next decade, that distance is expected to shrink even further as VR headsets and AR glasses bring screens within inches of our eyes.

We believe that by 2030 there will be about 750 million VR headsets and 1 billion AR glasses in use, up from 10 million and 0 respectively, today, see Table 11-1.

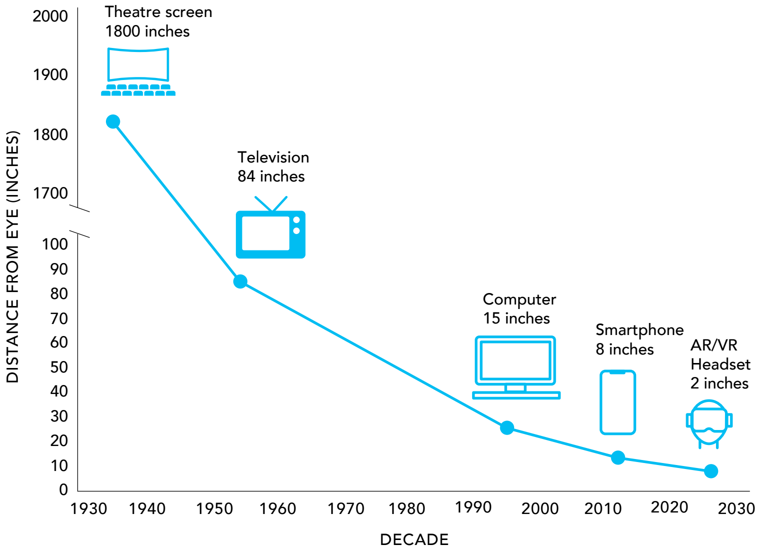

Figure 11-1. Screen distance from human eyes has gotten closer, accelerating in the last few decades.[1]

About the Author:

Gene Munster is a managing partner and co-founder at Loup. Gene is a member of the investment committee at Loup and leads the firm with a focus on culture and research. Prior to Loup, Gene was a managing director and senior research analyst at Piper Jaffray, where he covered Apple, Amazon, Google and Facebook. During his 21-year tenure, Gene received acknowledgements including: Best on the Street from The Wall Street Journal, Top Stock Picker from Forbes, and was widely recognized for his work on Apple.

Table 11-1. By 2030 there will be about 750 million VR headsets and 1 billion AR glasses in use, which in effect will encapsule our eyes in displays.

Device	2020	2030
Smartphone	3.5 Billion	5 Billion
Computer	2 Billion	2 Billion
Tablet	1.5 Billion	2 Billion
Smartwatch	125 Million	1 Billion
VR Headsets	1 Million	750 Million
AR Glasses	0	1 Billion

Global Trends That Move Screens Closer

The COVID-19 pandemic forced people throughout the world to manage social interactions differently. It also changed how we interact with digital displays. Social distancing, remote work, distance learning – these new behaviors led to accelerated display activity. Many of these new display-centric activities show dramatic increases:

More smartphone, less TV – The mass migration from broadcast TV to on-demand – and from big-screen to mobile – started a decade ago. During 2020, Americans spent 8% more time on mobile than watching live TV per day.[2]

240 billion

HOURS STREAMED OF MOBILE VIDEO BY 2020

More streaming, less broadcast – Pandemic lockdowns moved smartphone use to a new level, with app-based video streaming up 40% in a year. By the end of 2020, consumers were streaming around 240 billion hours. By 2021, the average mobile streamer in the USA will download 85% more streaming apps compared to pre-pandemic levels.

App-driven economy – Mobile apps are driving 45% more financial transactions than a year earlier. That includes 55% more stock market transactions globally. Time spent on shopping apps globally (excluding China, an early adopter of mobile shopping) grew 45% year over year. Mobile advertising grew 95% year-over-year in the USA.

Smartphones for gaming and entertainment – Consumers spent 50% more on smartphone gaming apps than all other forms of gaming combined.

Screens are magnets for children – The screen habits of children have changed dramatically, with traffic to children's smartphone apps up nearly 70%. Viewership of children's TV programming is up 58%, likely due to social distancing. Average weekly time spent on gaming or nongaming apps worldwide trended up 20%, with a tripling in tablet traffic and doubling on phone traffic. Distance learning of course, also drove up screentime. For many children, spending days at home on a display for schooling purposes was a new phenomenon.[3]

70%

TRAFFIC INCREASE TO CHILDREN'S SMARTPHONE APPS

The Dilemma

On one hand, phones, VR, and AR are enabling a tech-enriched lens through which to view the world. On the other hand, a question emerges: are screen displays closer to our eyes impacting our wellness? Most of us likely remember a parent telling us to move back from the TV screen when we were children. There is a natural tendency to worry about the potential harmful effects of technology, especially when it concerns our vital organs. In the case of screens, we care because there are still outstanding questions as to how

Take breaks from screens? Our devices are simply too addicting... Display companies are working with device makers to create high-resolution displays that emit less blue light.

diminishing screen-to-eye distance affects the health of our eyes. Eye health is vital because it affects our overall energy and mood. When our eyes feel tired, our whole body feels tired.

Are the Concerns Justified?

One concern with screens moving closer to our eyes is exposure to blue light. Blue light is high-energy, short-wavelength, visible light that is found in the sun (the biggest source), LED lights, TVs, computers, tablets, phones, and e-readers, among other things. Blue light plays an essential role in regulating biological and psychological processes, most notably our sleep-wake cycles. Throughout the day, blue light helps boost alertness and mood, whereas at night it works to suppress the release of melatonin, a darkness-induced hormone that helps us fall and stay asleep. There is credible research that shows blue light exposure from screens before going to bed can negatively affect sleep quality.

While companies and researchers are still in exploration mode regarding any serious long-term health impacts from closer screens and more blue light intake, the bottom line is that they are having an effect on device users' energy levels and sleep cycles.

What Should Industry Players Do About It?

While doctors say the best way to address these concerns is to simply take breaks from screens throughout the day and to not use them for at least an hour before going to bed, few people are likely to follow these guidelines. Our devices are simply too addicting.

This naturally raises the question of what tech and display companies can do to address these concerns. For starters, all new mobile devices, tablets, and computers now offer standard night-mode features that allow users to reduce the amount of blue light emitted. Further, display companies are working with device makers to create high-resolution displays that emit less blue light.

That said, creative solutions, as well as greater industry and consumer awareness regarding any health risks associated with closer screens and blue light, are needed to provide a safer, more comfortable experience for users. We believe this need will only increase with the expected adoption of AR and VR devices in the coming years.

Separately, we look to big tech to help consumers navigate blue light's impact, and hope the industry can come to a standard to keep us better aware of the health impacts from the devices we use.

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Keeping the Gaming and eSports Community Healthy

About the Authors:

Frank Azor, Chief Architect Gaming Solutions and Marketing, AMD. Frank co-founded the world's most innovative gaming brand, Alienware. Under his leadership, Dell's XPS brand became most-award winning product line, leading in technology, design and performance.

Max "Aror" Jackson plays under the handle @arorthechunk. Member of the Tartarus Titans, Max was SMITE Pro Player World Champion in 2018. He started playing SMITE because it was an evolution beyond World of Warcraft and League of Legends, he's been gaming since 2005.

Samson "Lourlo" Jackson plays under the handle @lourlo and has been a top-laner for multiple teams since 2012. Samson started gaming with World of Warcraft and has since played Hearthstone, Diablo, Bloodline Champions, and League of Legends.

With over 2-1/2 billion active players and creators, the gaming and esports market is enormous and growing.

Expected to be over $180 billion in market size in 2021, the gaming market is both a global pastime and profession. 60% of Americans play video games daily. The average player is 34 years old, owns a house and has children.[1] Most gamers, however, are 18 years old or younger.

The PC gaming market, one segment of the overall market, is $37 billion, up 5% year-over-year. The average PC gamer plays over 15 hours a week or about 3 hours daily. During the COVID-19 pandemic gaming participation skyrocketed to well beyond those numbers.

Multi-player games can have a large following, with players motivated by the love of competition and a chance at prize money. League of Legends, for example, one of the most popular games in the industry, had over 44 million concurrent viewers in its 2018 world finals championship.

The earnings potential of a professional esports player can be as good as that of any professional athlete. The prize pool was over $37 million for the top 10 esports events in the first half of 2020 alone. Johan Sundstein, a top player from Denmark, earned an estimated 7 million USD during his recorded gaming career.[2]

Given such a large, growing and dynamic community, there is plenty of motivation within the industry to keep players healthy and engaged. Game creators and technology providers want to improve the gaming experience in every way. Like many other pastimes and sports, however, there are recognized risks for an individual. The risks can include physical and mental strain. Some individuals have been diagnosed with addictive behavior related to gameplay.

60%

OF AMERICANS PLAY VIDEO GAMES DAILY

Gaming Technology

The gaming industry was born over fifty years ago, both as an offshoot of arcade games and as a way for mainframe computer programmers to show off their skills. The advent of the personal computer spread gaming to the masses. Early gamers had to play in front of green and amber CRT displays.

Today's gaming systems are serious business for consumer electronics and display companies. Players can choose from a variety of purpose-built systems from leading brands in consumer technology. Display performance and graphics rendering has accelerated astronomically over the last 20 years. The latest platforms push the envelope when it comes to color gamut, brightness, contrast ratio and refresh rate.

Screens for modern gaming systems can have intensities of 600, 800 and even 1000 Nits of brightness. Refresh rates can be 144, 240 and in some cases over 360 Hz.

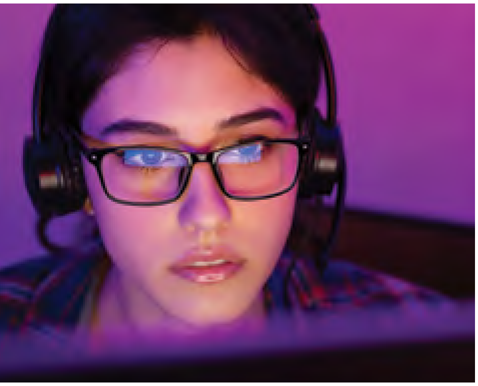
Refresh rate is the speed at which pixels are repainted on a display. A typical TV display refreshes at 60 or 120 Hz. Having a higher refresh rate is particularly important to competitive gamers. It lets them literally see around the corner before the opposing player in a combat game, for example.

5 Oldest Video Games in the World[3]

- *Pong*
  Release Date: November 29, 1972
- *Space Race*
  Release Date: July 16, 1973
- *Gran Trak 10*
  Release Date: May 1974
- *Tank*
  Release Date: November 5, 1974
- *Gun Fight (Western Gun)*
  Release Date: 1975

Mitigating Blue Light Risks

When you couple the fact that today's games have evolved to be as engaging as they are, and that today's gaming systems can display them at intensities and refresh rates exceeding that of most work-a-day computers, it is fair to say that gamers are at the front lines of excessive exposure to blue light.



Some gamers seek a competitive advantage in highly intensive games so they play at a screen distance as short as 6-8 inches.

In many cases gamers are playing at screen distances closer than the 20-40 inches (50-100 cm) that most people use to interact with a computer. Some gamers seek a competitive advantage in highly intensive and competitive games like Counterstrike Go, so they play at a screen distance as short as 6-8 inches (15-20 cm).

For these reasons, gaming systems providers such as AMD recognize the responsibility and opportunity to integrate blue light reduction tech into displays to help alleviate this issue. AMD products and technologies are in over 550 million gaming devices including desktop computers, laptops, and the latest generation Xbox and PlayStation consoles.

AMD recommends blue light mitigation technologies be incorporated into all of its solutions. The intent is to give gamers the absolute best gaming system they possibly can own and own for many years to come.

Gaming Disorder and Player Health

In 2018 the World Health Organization recognized a new disease classification, called Gaming Disorder, Code 6C51 in IDC-11. The International Classification of Diseases, IDC-11, is a list of diseases and medical conditions that health professionals use to make diagnoses and treatment plans.

According to the WHO's definition, a person who has gaming disorder will show the following characteristics for at least 12 months:

- Lacking control over their gaming habits
- Prioritizing gaming over other interests and activities
- Continuing gaming despite its negative consequences

For a diagnosis, these behaviors must be so severe that they affect a person's family life, social life, personal life, education and work.

In addition, a person who remains physically inactive for extended periods due to gaming may also have a higher risk of obesity, sleep problems, and other health issues.

Addiction to gaming is similar in many ways to other types of addiction. People with the disorder often spend many hours playing games, have a strong emotional attachment to this behavior, and may experience fewer social connections as a result.

Even though gaming disorder is not widespread, people should be aware of the amount of time that they spend playing games. They should also monitor the effect that gaming has on their other activities, their physical and mental health, and their relationships with others.

Those who are worried that gaming may be negatively impacting their health or relationships should speak with a doctor or a mental health professional.

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A Public Health Perspective on Blue Light Protection

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Public health is a field that seeks to protect the health of the community at large.

The public health mission is to assure that the environment in which people work and play is safe and will allow people to enjoy good health. Often public health programs work to be sure that we have fresh air to breathe and clean water to drink. The work is often done with research to study the environment and then strive to build public policy and pass laws to protect environmental resources and keep people safe.

Light is a natural resource. It comes to most of us every day as sunlight and can be produced by fire or other heat sources. Since it is such an important part of the environment of modern man, we also produce light artificially and often with little regard to potential side effects.

Natural light has been studied by many public health programs and it has been found to have many beneficial effects on the human body. For example, it can enhance mood, relieves stress, and improves sleep. However, it has also been found to have damaging effects to the body. It can cause sun burn, heat stroke, several forms of cancer and it has been found to prematurely age the skin. In the human eye, it can damage the cornea, cause cataracts and damage the retina. The World Health Organization issued a policy in 2006 on sun health with education on how to protect oneself from overexposure.

Artificial light has also been studied by the public health community and there has been some guidance offered on this topic. In 2003, the World Health Organization published a policy on artificial tanning sunbeds. It advised against the use of these methods and offered assistance to public health groups in each member nation to develop public policy for the safe use of these artificial light sources.

With the advent of digital devices which strive for brighter and more vivid visual output, there has been little time or opportunity for the public health community to study the safety of these new sources of artificial light. These devices emit high levels of visible light including harmful blue light[1-3] and are used close to the human eye for extended periods of time.

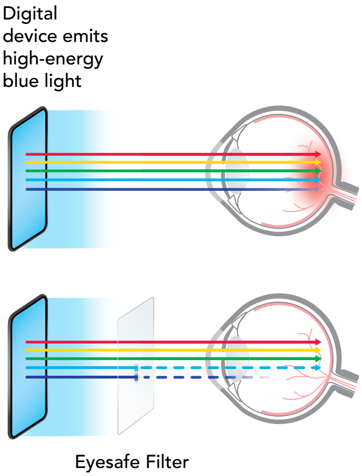
The amount of time that school children spend on digital devices has increased dramatically.

With the COVID-19 pandemic[4], the amount of time that school children spend on digital devices has increased dramatically. According to a recent report[5] from the United Kingdom, screen time has increased by 15%. In the Harvard Health Letter, published by the Harvard school of Medicine, the authors warn of the harmful effects of the blue light emitted by digital devices.[6]

Display Intensity Increases Blue Light Absorption

Today's digital devices are not the low impact devices of the twentieth century. For many of the modern gaming systems, very bright, high resolution and the full visible spectrum are desirable features of the digital display. Brightness is measured in Nits. One Nit is equal to the brightness of one candle shining onto a surface that is one meter by one meter. A typical theater movie screen has about 50 Nits of brightness. A modern smartphone needs to be useful when outside on a sunny day and therefore requires more Nits that the sun. A typical smartphone or tablet will generate between 200 to 1,000 Nits. Many high dynamic range televisions generate over 2,000 Nits and one new prototype can generate 10,000 Nits.

In addition to the extreme brightness of digital devices, they also use Liquid Crystal Displays (LCDs) with an LED backlight. Typical LED emission peaks at approximately 435 nm. The range for harmful blue light is between 415-455nm.



Eyesafe filtration of peak high-energy blue light

Blue light at the peak of the LED emission spectrum passes through the optical elements of the eye, both cornea and lens and is absorbed by the layers of the retina and cause photo-oxidative stress.

The histopathological studies of retinal tissue exposed to blue light between 415-455 nm show that the retinal pigment epithelium and the outer segments of the photoreceptors are most susceptible to damage. Repeated exposure to these wavelengths in an unprotected eye may be part of the mechanism of age-related macular degeneration. Changing the output of the digital device with protective measures has been found to reduce the phototoxicity in retinal tissue.[7]

Encouraging Public Acceptance of Low Blue Light Solutions

By blocking the narrow band of blue spectrum from entering the eye, the effect on the retina as well as the brain is eliminated at the source. This dramatically improves the safety of the digital devices that are essential to modern life.

From the public health perspective, protection from the harmful blue light that is emitted from digital devices should be an important part of a comprehensive health care program. At UnitedHealthcare, we strive to endorse public health initiatives and promote prevention and wellness care. Our vision care products are integrated with our medical products to assure a seamless patient experience as good vision is an important aspect of good health. The Eyesafe solutions play an important role in the safe use of digital devices and we are happy to be part of the education process to assure that our members have a lifetime of good vision.

UnitedHealthcare and Dell – A Case Example

Incentives that help people live safer lives has always been a component of public health policy. Examples include discounts on car seats for children, coverage for regular doctor check-ups, and age or gender-related health screenings.

In the case of low-blue light displays, UnitedHealthcare is partnering with Dell to offer its members a choice of Eyesafe laptops at preferred pricing. Such incentives give UnitedHealthcare members and employees a reason to take the issue of light emissions from screens seriously. And as the largest health insurer in the United States, UnitedHealthcare is able to shape public health policy in a significant way.

With the COVID-19 pandemic, such policies have magnified benefits. Employers with large numbers of remote workers are suddenly now brushing up against a new reality and a new realization: employees are spending more time than ever in front of screens. It has impacted productivity. That is in addition to figuring out all the IT, security, and communications issues associated with setting up a remote work configuration, as well as issuing laptops and monitors for home use.

For executives, business managers, and IT professionals, one of the rather unexpected impacts of the pandemic: all this extra employee screen time and the resulting loss of productivity, has moved what was a "back-burner" issue about blue light and screen time into a major concern.

The employer perspective is not a complete picture, given the effect of the pandemic on families. People working from home and personal, school, and professional lives are converging toward a dependency on desktops, smartphones, TVs and laptop computers.

The big question facing business is not only how to manage security and optimize productivity but to do so while keeping

See Page 205

Learn more about Dell XPS with Eyesafe Display and UnitedHealthcare

The big question facing business is not only how to manage security and optimize productivity but to do so while keeping employees' eye health intact.

employees' eye health intact. Fortunately, with dozens of commercial laptops and monitors on the market with built-in low blue light filtration, many of them meeting the industry leading Eyesafe requirements, there are plenty of solutions at hand.

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▶ **eyesafe.com/research**

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Blue Light Safety

Potential confusion about whether blue light is helpful or harmful continues.

On the one hand, blue light can be beneficial (sunlight is the primary way humans access blue light), but on the other hand, it can also be toxic (as it can cause cell death in the retina).[1-5] Blue light is said to help regulate human circadian rhythm,[6] but researchers are now finding that too much blue light exposure in the nighttime hours (particularly within a few hours of bedtime) from using smartphones, tablets, gaming consoles, or computers can disturb these wake/sleep cycles.[7] Blue light transmits at higher energy levels than other colors on the spectrum, and these higher doses may be detrimental to the retina and your vision as well (since there is no such thing as "sunscreen" for your eyes).[8,9] Blue light therapy has been used to treat people with depression or depression with a seasonal pattern, suggesting the medical community recognizes its benefits as well.[2,10]

About the Author:

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"When we talk about blue light safety, we are specifically discussing how to protect the retina from irreparable harm blue light may cause."

What is Blue Light Safety?

While other chapters have discussed blue light, blue light safety has not been appropriately addressed. It involves both the recognition of potential hazards and a science-based approach to minimizing them.

Blue light (and ultraviolet light) absorbed by the eyes has been shown in lab studies to induce oxidative stress (a disturbance or imbalance of free radicals and antioxidants that can result in cell and tissue damage).[11] Some research has suggested it may possibly be a risk factor for the development of age-related macular degeneration (AMD),[12] and may contribute to tear film instability, cataract, eye strain, and sleep issues.[2,11,13]

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See Chapter 4 on Circadian Rhythm

Circadian rhythm (what tells the body to wake up in the morning or become tired in the evening) can be affected by blue light. The key component in regulating circadian rhythm, melatonin, increases in the absence of blue light.[14] In other words, when the body is prevented from manufacturing melatonin, as happens with daylight exposure to blue light, the body knows to stay awake. When the body is allowed to manufacture melatonin, the body wants to go to sleep.

In 2016, the U.S. National Toxicology Program started to evaluate "mounting research" that links exposure to artificial light at night to sleep issues, weight gain, depression, cancer, and heart disease.[15]

Astronauts are a well-known group of professionals with sleep issues, and issues with sleep in this group has been studied since the 1980s.[16] Perhaps in response to that undertaking, in 2017 NASA began to switch the type of artificial lighting on the International Space Station so that the new lights will dim at night and provide a longer wavelength (deemed "healthier" than blue light).[17] Astronauts typically go through sixteen daily rotations around the Earth while in space, which is too many for the body's circadian rhythm to naturally adjust. NASA also discourages looking at the Earth from space within two hours before assigned sleep.

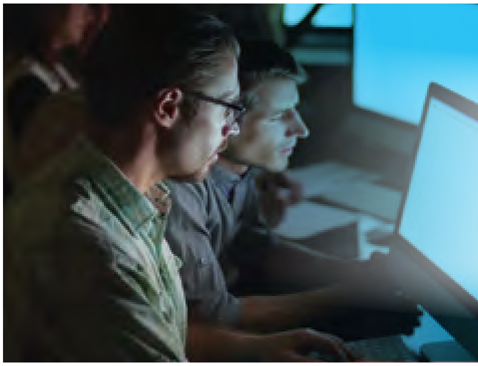
Blue Light Hazard

Blue light hazard: "an acute photochemical damage to the retina caused by staring at an intense light source"

Occupational health and safety professionals have been aware of blue light hazards for decades, pre-dating the advent of digital device prevalence. Blue light hazard is best described as "an acute photochemical damage to the retina caused by staring at an intense light source," such as the sun or a welding arc.[18] More than 88% of the risk of damage from blue light is due to light wavelengths in the range of 400-480 nm, but the blue light hazard peaks at around 440 nm, falling to 80% of its peak at the higher end (460 nm) and the lower end (415 nm).[19] Light-induced damage to the eye is also related to blue light hazard.

Blue light can cause oxidative stress, and exposure over a lifetime may also be an underlying cause of AMD (albeit a minor risk factor when compared to others, such as genetics, smoking, or diet).[20] The American Medical Association has also weighed in on this health issue, noting that some light-emitting diodes (LED) lights can be harmful, and urges caution when using them as they could be contributory to chronic disease.[21] Blue light may potentially hasten the response to medications that are photosensitive, including antidepressants, some antibiotics, non-steroidal anti-inflammatory drugs (NSAIDs), some neuroleptics, heart medications, and some herbal remedies.

Numerous occupations increase the risk of blue light hazard, including nighttime shift workers.[22] These workers expose themselves to artificial light that could potentially suppress normal nocturnal melatonin secretion, and have been shown to receive less daily bright light and at less optimal times than people who work during the day. The use of glasses that block blue light for nighttime workers is somewhat controversial: some believe night-shift workers need light to remain alert, but others say the disruption to the circadian rhythm should be minimized and these types of glasses can help.[23] Further, as digital devices have become necessary work tools, almost all professions have some type of increased risk. In office environments, avoiding white desks (which reflect the light) can help alleviate some of the risk. People in the welding profession are exposed to ultraviolet and blue light and have increased risk of "arc-eye," that can be mitigated to an extent by wearing protective head gear.[24]



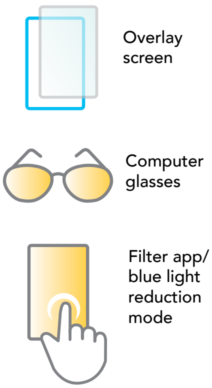
Ways to Avoid Blue Light Hazard

1. Limit exposure
2. Eyewear with blue light filter
3. Eyesafe® products

Blue Light Filters

A recent study from the University of Toledo[25] was sensationalized by consumer news outlets by suggesting blue light from digital devices is blinding people, but the lead author emphatically states that was not the conclusion. Instead, the study evaluated a specific chemical and what occurs when it is exposed to blue light, but the chemical does not interact with the cells in the eye that are responsible for vision. (In other words, what they created in the lab does not occur in nature.)

BLUE LIGHT FILTERS:



We bring this up to note studies can be misinterpreted. Information and advice from the American Academy of Ophthalmology notes that blue light filters used in some intraocular lenses may or may not be useful in combatting the effects of blue light.[26, 27] Other groups suggest minimizing exposure to blue light in nighttime hours is the easiest way to prevent damage.[28] Wearing computer glasses may be appropriate for shift workers or others who are concerned about their exposure or who have had issues with digital eye strain.

Workplace exposure can also be limited by using blue light-blocking overlay screens, taking numerous breaks away from the computer, using filter apps, and/or setting the computer into blue-light reduction mode.

A study of night shift workers in an emergency operations center found measurable improvements in job performance associated with displays that have a lower blue light setting. The study used software filtering to change the base color temperature of the display from 6500 K to 3800 K (lower blue light).[29]

Blue Light Toxicity

There are methods and techniques to protect the eye from harmful blue light while still allowing the beneficial blue light, including using lenses or screens as mentioned above. Fatigue, dry eyes, bad lighting overall, or how people sit can also cause eye strain. Blue light toxicity can also be mediated by limiting the amount of blue light someone is exposed to at night.

Blue light in the morning, however, may be effective in treating people with depression with a seasonal pattern.[10]

Studies have found daytime exposure to blue light increases alertness and improves mood and cognitive function (much like caffeine). Nighttime exposure to the blue light of smartphones can negatively affect sleep and increase the number of mistakes someone makes.

Some Harvard researchers claim there is no real toxicity from digital devices, but even they are not in overall agreement as other Harvard experts say excessive artificial light can have a "profound deleterious" effect on human health.[7, 30]

One well-documented case did link macular damage to smartphone addiction.[31] The individual, who over a 3-year period spent 6-8 hours nearly every night viewing the smartphone screen in bed at night with the lights off, sought help for extremely blurred binocular vision and was unable to work as a result. Examination by the physician team ruled out all known macular diseases.

The individual was instructed to:

1. Stop viewing the smartphone in the dark.
2. Limit screen time to normal social networking.
3. Switch the phone settings to filter out bright light.

Following these guidelines, the individual started showing improvement after two-weeks.

A National Eye Institute-funded study found more blue light is absorbed by children than by adults when using digital devices. Although this has not yet been studied, children also hold digital devices closer to their faces which may have an effect on the absorption amount as well.

Expert Opinion

The American Academy of Pediatrics recommends:

- No screen time for kids until they are 2 years old. Of course, a parent-led video chat session with apps like FaceTime or Skype should be okay.

Decreasing screen time is an ideal goal, but may not be realistic given the realities of today's always plugged-in work and lifestyle.

- No more than one hour of screen time for children ages 2 to 5. The goal is to balance screen time with activities that involve physical and interactive play. Such activities are fundamental to a child's physical and intellectual development.[32]

Blue light is both beneficial and detrimental to healthy vision and eyes. Some of these topics are covered in greater detail elsewhere in this book, but we believe circadian rhythms may be linked to AMD, and that decreased melatonin production and the altered rhythm of secretion may play a role in developing AMD as well.[33] However, melatonin may be protective against other ocular diseases such as glaucoma, photokeratitis, and cataract.

We do need to be cautious, however, that completely filtering out blue light in an attempt to prevent blue light hazard may be more detrimental than simply limiting exposure. For example, blocking light at 470 nm has been shown to disrupt the sustained phase of the pupil constriction reflex.[34] A very specific band of blue-violet light (435 nm ±20 nm) seems to be the culprit;[35] selectively blocking this narrow band may improve public health and become part of preventive eye care (much like UVA/UVB blocking lenses). For professionals who need very sharp outdoor vision, we would recommend blue-light filtering lenses.

Decreasing screen time is an ideal goal, but may not be realistic given the realities of today's always plugged-in work and lifestyle. Some companies are attempting to incorporate filters into their software, which does not reduce blue light but does filter it through an amber range, with the goal of reducing eye strain by offsetting the blue light by increasing red-wavelengths.[36]

We continue to advocate the use of computer filters and the use of computer glasses, although having blue light filters built into devices would alleviate this recommendation.

Large population studies do raise enough issues that those in the eye care profession as well as those who are tangentially affecting vision (such as digital device manufacturers) should be vigilant about recognizing these issues and working towards blue light hazard prevention.

More rigorous studies on human subjects are needed so that researchers and clinicians can better understand how common electronic devices in use today may affect vision.

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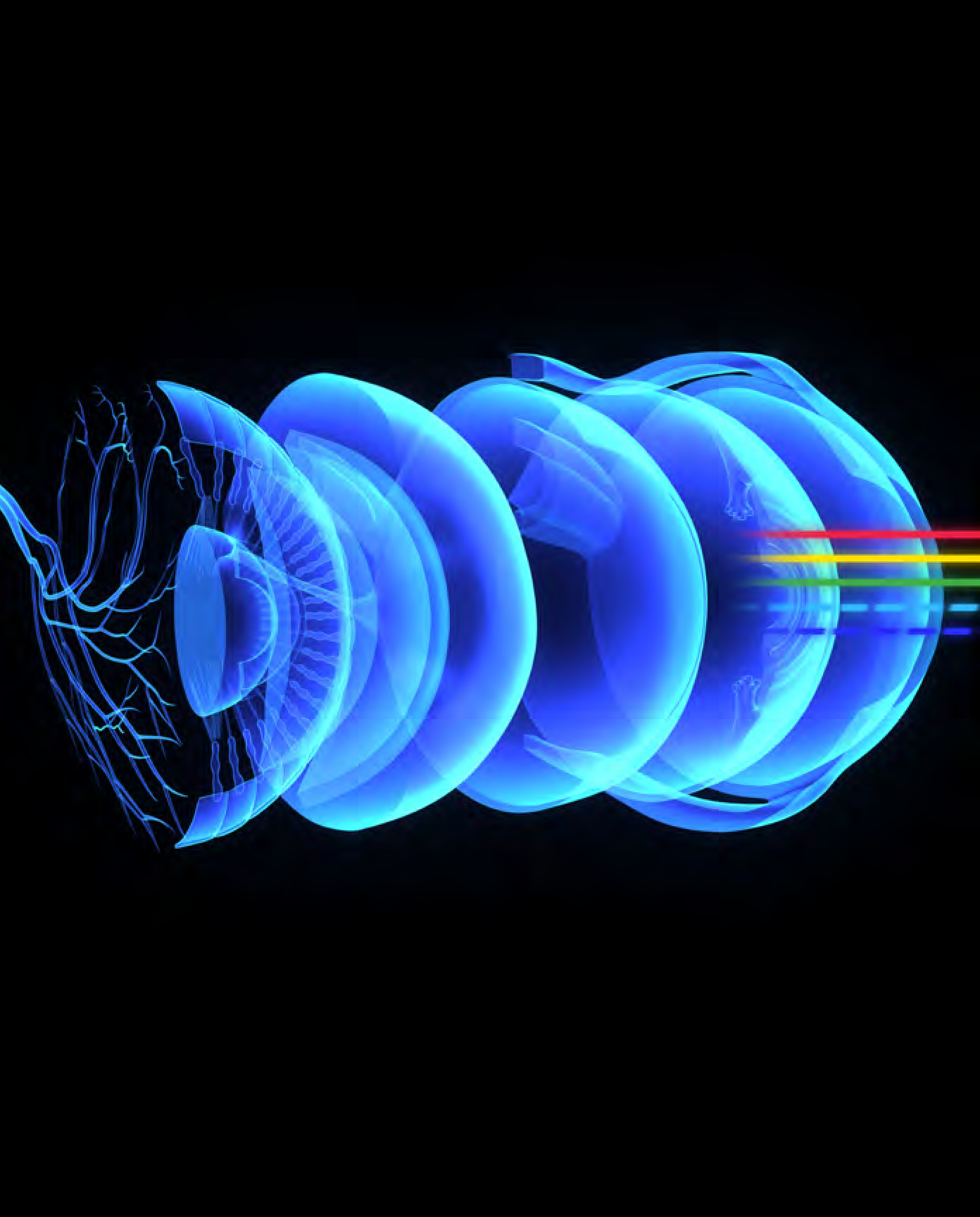

Display Distance and Usage Adaptations to Reduce Problems

"Daily screen time has reached record highs and for many exceeds 10 hours per day. With this growing use of devices comes higher amounts of high-energy blue light to our eyes."

[Excerpt from *Vision Health Advisory Board Screen Time Guidance*—May, 2019]

If you are someone who does have 6-10 hours of screen time on a regular basis, you may be interested in available remedies that will help lessen the effects of prolonged exposure.

Display Distance

The mean distance from a screen to a person's eyes is 13.3 inches for smartphone use and 15.6 inches for tablet use (See Figure 15-1).[1] Since we usually hold a smartphone or tablet, we dynamically adjust the viewing distance to accommodate for the size and clarity of the screen. Generally, the smaller the screen the closer the distance.

One of the main issues at hand is the naturally clear lens of a child, that has developed no light filtration yet. As we age, our natural lens becomes yellow, filtering some blue light but this is not the case for children. The concern is that high intensity blue light can enter the eye at a higher level. And as for children, shorter arms equates to closer distance, and potentially more blue light exposure. Based on the inverse square law, where intensity is the inverse square of the distance, a child holding a smartphone or tablet can receive four times the intensity as an adult (See Figure 15-2).[2]

About the Author:

Sheri Rowen, MD is is a pioneer in the field of ophthalmology, with a reputation for quality eye care. Dr. Rowen has been recognized for her teaching and surgical expertise. She currently offers eye surgery at her practice, along with many newer procedures that can now correct distance and near vision using the most advanced technology.

"Studies show that the intense blue light emitted from digital devices can contribute to eye health issues, and potentially sleep disorders. Given that eyes are still developing through the teenage years, this issue of prolonged screen use is concerning for children's eyes."

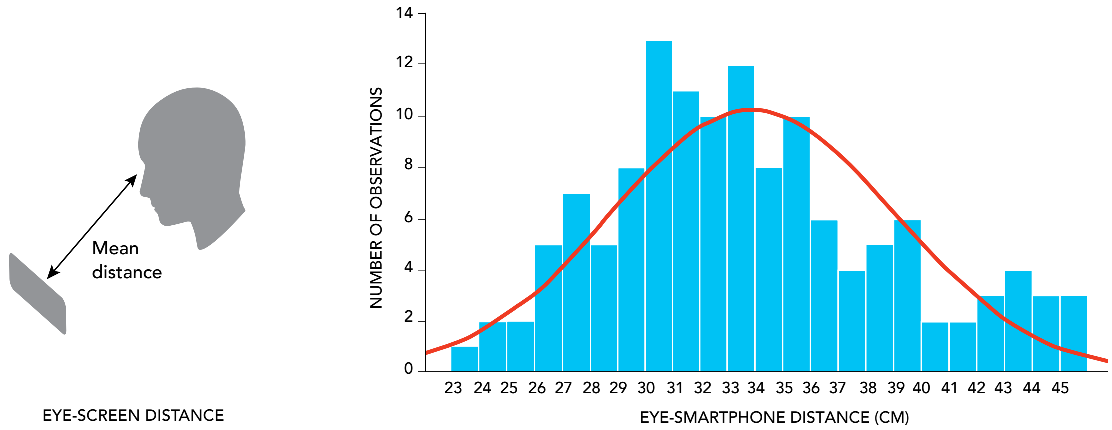

Figure 15-1. Dispersion of eye-Smartphone distance measurements for 22 subjects and 6 activities. Mean distance is 13.3 in (33 cm), and averages 8 in (20 cm) for children.

Text size, screen glare, ambient light and gaze angle also affect display distance and how much light penetrates the eye. When compared to staring at a piece of paper, we typically hold a screen closer to our eyes. We also lower our gaze, especially with a smartphone. Our head and neck angle is twice as low as with reading a piece of paper.[2] Dramatically lower gaze angle can unnaturally affect our neck and shoulder muscles, leading to physical discomfort (see Figure 15-3).

Posture adaptations and physical discomfort associated with screen time may seem trivial until you calculate the lost wages and productivity. A 2002 report detailed $20 billion of annual losses paid by US employers as a result of work-related musculoskeletal disorders.[3]

COVID-19 Pandemic Display Usage

The COVID-19 pandemic created an unprecedented rise of device use among all ages. Children with no regular device use outside of school are now spending hours more on loaned devices to facilitate distance learning.

“Here you have kids who don’t use devices on a regular basis or maybe only at school and now they’re using them

Figure 15-2. Children hold displays closer to their eyes.

pretty much full time for their education, their games and entertainment, and they're going to eventually come to us with all these eye strain problems," says Karl Citek, O.D., Ph.D., Pacific University College of Optometry professor and member of the American National Standards Institute's Accredited Standards Committee for Ophthalmic Optics.[4]

A study of screen time on pre-school children concludes that, based on MRI scans and standardized assessments, the brain can be affected. Children with excessive screen time evidence lower microstructural integrity of brain white matter tracts that support language, executive functions, and emergent literacy skills.[5]

Screen distance and intensity is one aspect of why WHO guidelines are to limit children under 5 years to no more than 1 hour a day. Excessive screen time is a risk for everyone, however. That is why the American Optometric Association endorses the benefits of unplugging. March is designated as "Save Your Vision Month" The AOA advocates for a "National Day of Unplugging."[6]

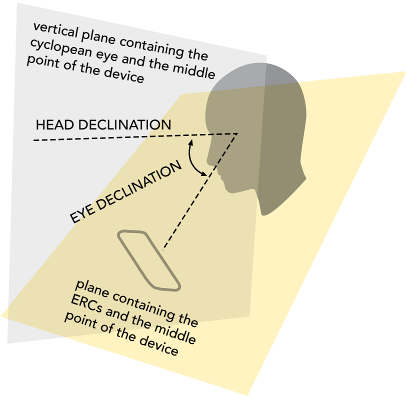

Figure 15-3. Our head and neck angle is twice as low when staring at a smartphone when compared to reading a paper. This can unnaturally affect our neck and shoulders.

Screen time habits to avoid

1. Driving while texting or viewing a phone
2. Crossing a street while staring at a phone
3. Screen time without a blue light filter prior to going to bed
4. Continuous screen use in a darkened room

Suspect Screen Time Habits

We should avoid or minimize these all too common screen habits:

1. Driving while texting or viewing a phone – the #1 cause of accidents worldwide
2. Crossing a street while staring at a phone – another cause of accidents involving vehicles
3. Screen time without a blue light filter prior to going to bed. This can disrupt sleep an average of 90 minutes. At night, the distance we hold a smartphone to our eyes tends to be closer (8 inches versus 13.3). Similarly we position a tablet closer (12 inches versus 15.6). If we don't adjust the intensity of the screen, we are absorbing more blue light as a consequence.
4. Continuous use in a darkened room. Worth noting is a rising trend on commercial airplanes, especially on longer flights, of passengers "treating" themselves to extended screen time. Not so long ago passengers enjoyed the view out of plane windows. Now passengers prefer closed window shades and a darker cabin. Ambient light has become a source of passenger complaints. Airlines appear to be favoring this trend, since passengers are more docile and don't request as many service items. Nonetheless, in an attempt to relax and reduce stress during air travel, screen time might be causing passengers more discomfort. The shortened distance between seats translates to even closer display distance and an increased gaze angle.

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See Chapter 21 on Standards and Radiance Protection Factor (RPF)

Making Screen Time Better

1. A blue blocking filter that meets the RPF standard on all device screens.
2. Adjust screen intensity at night or in a darkened room. The latest devices have screen intensity of 400 Nits or higher. At night, they should be adjusted down to 100 Nits if possible. Many devices have an automatic brightness control that adjusts according to ambient light conditions. Most people do not use these controls; rather, they set and leave displays

at full intensity. Another approach is to turn on the color inversion feature, so that text is illuminated white against a darker background. This can reduce intensity by ten times, but reverses color on images.[7]

3. The 20-20-20 guideline says that for every 20 minutes of screen time, a person should focus their eyes for at least 20 seconds on an object that is 20 feet away to help with digital eye strain. Although it is a popular recommendation of vision care professionals, the 20-20-20 guideline does not deal with blue light exposure, and does not work at night or in darkened conditions where there is no object in sight other than a screen.

Although more research is needed on cumulative exposure to blue light from LED displays, taking steps to manage screen time in appropriate ways will help with eye comfort, contrast sensitivity, sleep cycles and help avoid muscle strain.

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Health Considerations of Display Intensity

The integration of effective blue light management is a critical step towards long-term health, especially as device use only continues to increase in the global population.

With a justification that they are energy efficient, LEDs were quickly adopted by most industrial countries to replace the conventional lighting for roads and street lighting. Some detractors would say most countries have rushed too quickly into the change. Despite the great economical savings that LED lighting represent for cities, some detrimental effects have been observed.

LED lights emit a large amount of blue light. Even though it appears white to the eye, blue light creates more nighttime glare than conventional lighting, and also has an impact on circadian rhythm. In 2016, a publication from the American Medical Association (AMA) emphasized that bright residential nighttime lit neighborhoods were often associated with a decrease in sleep time and sleep quality, impacting day time cognitive and functioning performances and increasing obesity factors.[1] AMA further mentioned how U.S. National Parks have adopted different lighting designs in order to minimize the effect of light pollution on the environment, citing various species such as birds, insects, amphibians and mammals disturbed by the lights too bright for their ecosystems.

We study the various effects that chemicals, pharmaceuticals, radiations etc., can have on people based on research done on animals, but we tend to ignore the effects brought on by new technology. Why not follow those cues? LEDs and OLEDs are used in computers, tablets and smartphone displays and it is quite possible the light affects us all.

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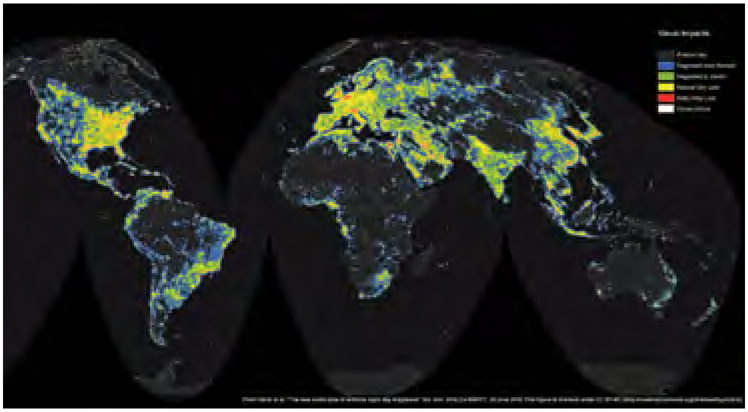
Artificial light, as seen from space. Light pollution is a growing concern.



Even though the intensity of digital displays is considerably lower than that of street lights and projectors, their effect is still potent. With constant progress in technology, we are more and more exposed to blue light at levels never experienced before. High-energy blue light has been linked to sleep disruption through the absorption of blue light between 455 and 485 nm by the ipRGCs of the retina.

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iPRGCs: intrinsically photoreceptive ganglion cells, Chapter 7 on Brain and Body

Recent studies on retina photoreceptors have also evidenced the potential damaging effect of blue light on retinal cells, showing localized cytotoxicity resulting from high energy blue light excited molecules intervening in the normal vision cycle.[2] This should be kept in mind when considering the potential effect of long term and accumulated exposure to digital displays.

Blue Light Transmittance Varies by Age

As we age, we transmit less blue light to the retina in the back of the eye. Therefore, the intensity of blue light as well as circadian rhythm function differs dramatically by age.[3] See Figure 16-1. When we plot comparison lines of color temperature, we can see that a 6500 K (average backlit LED) display, compared to 2300 K (incandescent bulb) is almost four times as intense for a child, compared to less than 2-1/2 times for a 60-year-old.

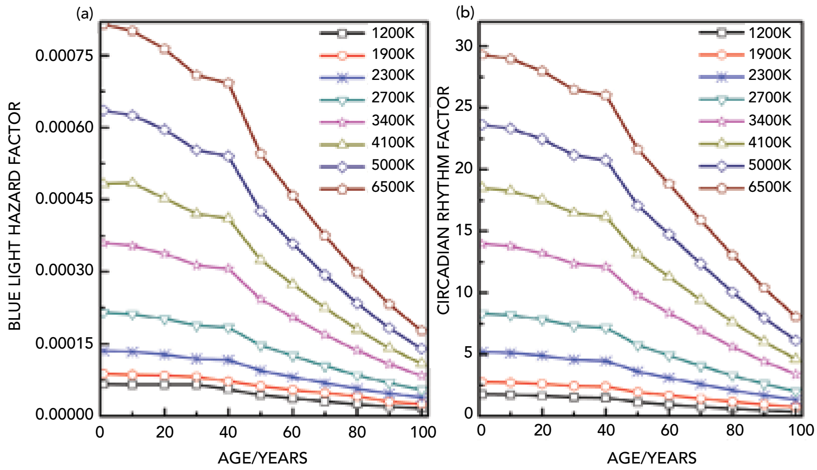


Figure 16-1. As people age, their sensitivity to hazardous blue light (a) and circadian disruption (b) decreases, due to a loss of transparency in the eye. Children are extremely susceptible to intense light as shown by the 6500 K plot, which is an average display color temperature.[3]

A collection of data on intensities of digital screens shows how bright the tested screens of commonly used smartphones and tablets have become (Table 16-1). Note that device makers sometimes do not publish exact CCT (correlated color temperature) data. Devices typically average 6500 K in order to replicate the desired white point. As the manufacturers improve the image rendering of the devices, it is often done with a detrimental increase in intensity and a cooler appearance (high CCT values), making these devices, characterized by short wavelength enriched emissions, very likely to be the cause of delay in melatonin suppression and sleep disruption.

The health repercussions arising from the lack of sleep and circadian desynchronization, such as persistent fatigue, poor appetite, sleep disorders, may in turn lead to chronic insomnia, mood disorders or depression. This can also increase the risk factor for obesity and the diseases promoted by obesity: high blood pressure, diabetes or chronic kidney disease.

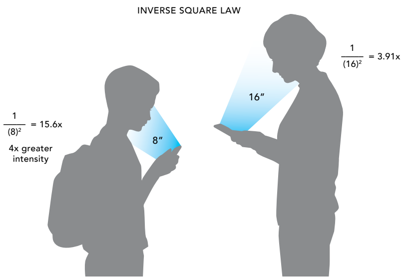
It is even more true at night where a display's intensity should be lowered in order to minimize their immediate effect on the circadian rhythm. Some research has shown that melatonin suppression does not so much differ when the light of a digital screen is modified to suit evening use, without changing the intensity of the display, indicating clearly that the display's brightness is one of the factors potentially impacting the user's health.[4]

Table 16-1. Emission data of some smartphones and tablets. Blue light peak data as related to the blue light maximum emission measured, CCT (correlated color temperature) and the photopic luminance the intensity of the emitted light. Source: https://fluxometer.com.

	Blue Light peak	Photopic Luminance	CCT	Release Date
Galaxy S5 Active	462 nm	281.0 Nits	7501 K	2014
Nexus 5	449 nm	430.4 Nits	6865 K	2013
iPhone 6	448 nm	518.5 Nits	7535 K	2014
iPhone X	459 nm	578.6 Nits	6426 K	2018
Kindle Paperwhite	458 nm	116.1 Nits	5582 K	2012
Asus Transformer Pad	447 nm	291.9 Nits	7165 K	2011
iPad Pro	450 nm	390.8 Nits	6896 K	2018
Nexus 7 Gen 2	450 nm	514.1 Nits	7205 K	2013

*Amazon Kindle, Apple iPhone, Apple iPad, Asus Transformer, Google Nexus, and Samsung Galaxy are trademarks of their respective companies.

There is a new consensus from device manufacturers and software developers to lower the intensity of the light emitted by displays, and also blue light emission, by adjusting the spectral composition of the displays. This helps to reduce the effects on sleep and circadian health, and avoid the potential of a nascent public health problem.



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Device Intensity and Children

The question of device intensity and settings is especially important for children, whose eyes are still immature, more transparent to short-wavelengths and thus more sensitive. The intensity of light from digital devices, such as tablets and smartphones, is dependent on the distance the device is held from the eyes; children having shorter limbs than adults, will hold the devices closer to their eyes, resulting in a higher intensity per unit area than for adults.

The French Agency for Food, Environmental and Occupational Health & Safety (ANSES) recommends that children under the age of six do not use 3D or virtual reality headsets as the images they project are too close to the eye.[5]

The World Health Organization (WHO) emphasizes restricting screen use with children, strongly recommending children under one year old not to be exposed to electronic devices, while limiting screen time to an hour a day for children under the age of six. These guidelines are set in the interest of maintaining good cognitive and physical development.

Considering all the observed disruptions created by the recent abundance of light in the environment, we should be encouraged to dim the lights, outside, in our homes and on our devices, as brighter and bluer is not synonymous of better for our eyes.

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Why Updating Your Monitor Can Improve Your Hybrid Lifestyle

About the Author:

Stefan Engel is Vice President and General Manager of Lenovo's Visuals Business. With 25 years in tech, Stefan has hardware expertise across portfolios including monitors, PCs and tablets, and understands how smart ecosystems benefit users. He oversees the creation, sales and marketing of the company's Monitor product lines, including ThinkVision™. Before his global role, he was Regional GM for Lenovo in Germany, Austria, and Switzerland, plus Poland, the Czech Republic and Slovakia. Stefan studied business at the University of St. Gallen and holds an Executive Master's degree in General Management from Politecnico Milano.

Tips from Lenovo to help you take control of your health.

The importance of proactively addressing the increase of screen time cannot be overstated. Lenovo stands committed to solving customer and consumer literal 'pain points' with natural low blue light technology inside a wide variety of monitors and laptops currently in market. The pandemic has forced millions of professionals, students and parents around the world to adapt to a new reality where work, school and home life are intermingled. This new reality led to increased levels of screen time, both at home, in school and in open office spaces, raising concerns about harmful blue light exposure. In fact, 94% of over 150 eye care providers expressed concerns, as did over 77% of a group of 500 employers in a July, 2020 survey.[1]

Due to increased screen time while consuming home entertainment and gaming – the working world needs tech with the most advanced, integrated eyecare technologies to protect overall eye health. Lenovo™ has been actively focusing on eye health across our entire portfolio of products, for example, a wide variety of Lenovo monitors (and laptops!) are Eyesafe® Certified to give users more confidence in their device as they work, game or consume entertainment without worrying about the health impacts of excessive blue light exposure.[2]

The following quick tips offer some important factors and healthy work habits to consider:

TIP 1

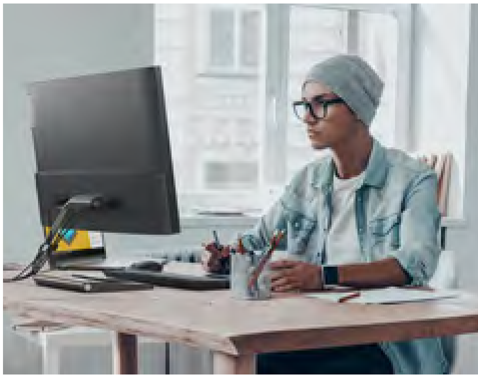
Replace Your Monitor to Help Alleviate Eye Fatigue

How often an IT manager ought to replace their company's PC monitors has accelerated from an estimated cycle of five to six years, to nearly every three years for top performance, simply owing to how quickly new advancements in monitors are improving the user experience. In the past few years alone, monitors have introduced so many 'must-have' functionalities to optimize hybrid life and work, such as natural low blue light technology, USB-C docking functions, and new screen sizes and form factors, that a device any more than three years old is considered antiquated.

Keeping a device to the bitter end of its usable lifespan may have sounded good in the pre-pandemic days, but now, it could mean delaying daily enjoyment of higher resolutions for crystal clear visuals with virtually no flicker, and helpful built-in features including an IR camera or speakers. Using a monitor designed to work seamlessly with a modular camera, that tilts and swivels, allows for flexibility and is a clever way to transform a dedicated workspace into an affordable video conferencing solution.

TIP 2

Adjust for Your Comfort



Studies have shown that stiff, fixed postures can cause long-term health issues. Striking a better balance between sitting and standing via less sedentary workplace behavior whether from a traditional office, home office, or even while traveling can help reduce the health risks. Good posture can also start with the layout of your work area and setup while using your PC and monitor. Arrange your desk equipment for convenient access based on individual needs and the kind of work you perform.

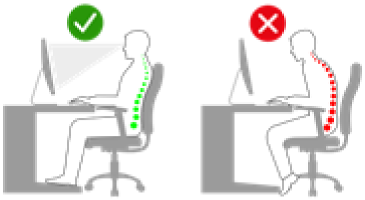


Figure 17-1. Minor changes in posture can help avoid discomfort while working.

Lenovo product designers crafting new monitors with a LTPS stand (lift/tilt/pivot/swivel) spend a lot of time thinking about the angle of a monitor and the height of your desk. Having the ability to adjust devices up, down, side-to-side, or even by 90-degrees vertically, enhances the user experience.

- For height adjustment, the user needs to press down or lift up the monitor.
- Before rotating the monitor screen clockwise/counterclockwise, adjust the screen position first.
- Adjust the tilt of your monitor to optimize the appearance of the screen content and to accommodate your preferred head and neck posture.

Monitors that adapt to your hybrid lifestyle benefit not only your digital experience but also your physical experience. Be sure to ask your retailer about any assistive technologies needed if a disability should be considered. Innovations such as curved and ultrawide monitors can help you see more without turning your neck back and forth all day. Adjusting your monitor or device to meet your eyeline or help you sit in the most comfortable position can improve your neck and back health. To find the ideal height for you, place yourself in front of the monitor so that your eyes are a little below top of the screen – you should see the middle of the monitor at a slight downwards angle of about 20 degrees.

TIP 3

Address Your Lighting

Always use adequate lighting for the type of work you are performing, but position your monitor to avoid glare or reflections on the screen from overhead lighting or daylight from a nearby window. Keep your monitor screen clean so you can focus on the screen's contents, and use the monitor brightness and contrast on-screen controls to optimize your screen's image for less squinting. Research has shown that simply changing the lighting in the room can help you to be less irritable, more productive, and distracted less often.

Staring at screens can be tiring, so what level of screen brightness is best to protect eyes when using a monitor? One that is adjusted in response to ambient light. For example, when browsing the web or working on an HDR monitor, high peak brightness is important to help small highlights stand out. The brightness should be set to allow text to be read without strain, but not excessive to the point that your face is basked in artificial light.

The brightness should be set to allow text to be read without strain, but not excessive to the point that your face is basked in artificial light.

TIP 4

Ideal Distance to Your Screen

In today's digital age, it's hard to get by without using some form of an electronic screen. Phones, PCs, tablets, TVs and – yes, monitors, are always before you and allow you to remain productive, entertained and informed. Thus, your eyes should be protected at all costs. Moderation is the key in most cases, especially if you want to avoid the damaging effects that can come from sitting too close to screens for long periods. Similarly, large amounts of blue light over time may cause damage and fatigue to the eyes.

It's a good idea to sit a little further from the screen and to give your eyes a break every so often - but sitting too far away can present its own problems. You might end up straining your eyes and neck in an attempt to see more clearly.

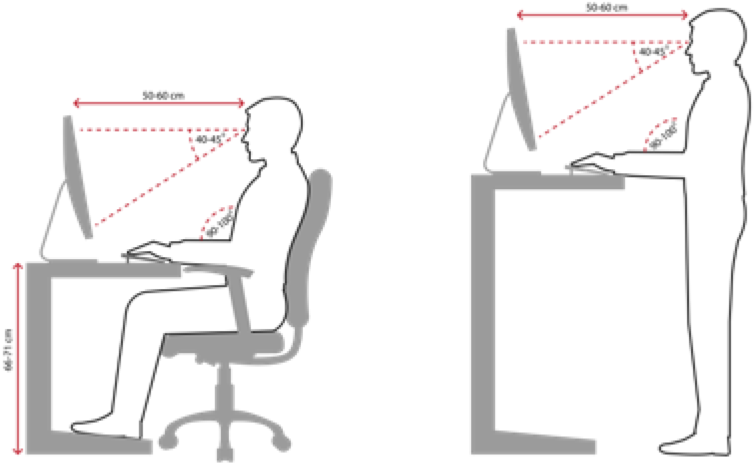


Figure 17-2. Choosing the right viewing height and distance to your screen may help reduce eye strain.

According to many industry experts, the ideal viewing distance from a flat panel is calculated as approximately 1.2 times the screen size in inches (or meters), as an example, with a 27-inch monitor (68.5 cm) the optimal distance is roughly 82 cm. A curved monitor means you can be a bit closer. Also, bear in mind if you're too close, your field of view cannot cover the complete monitor. The light from the screen can affect your vision as well. That is why more people are looking into screen filters, especially when in a dark room or at night. If math's not your thing, just position the monitor at least 20 inches (51 cm) from your eyes, or about an arm's length – if your screen is larger, simply add more viewing distance. The illustration below depicts this basic theory using a monitor roughly 24-inches in size.

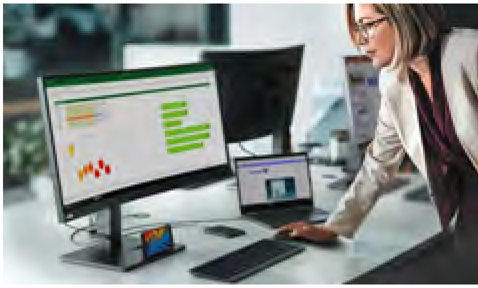
TIP 5

Blink More and Take More Breaks

When you sit too near a screen, you are likely to blink less.

When you sit too near a screen, you are likely to blink less. Also, the longer you sit and work with your device, the more important it is to observe your working posture. Be sure to periodically look away from your monitor screen. Select Lenovo monitors offer certain functions via artificial intelligence that reminds you to intermittently focus your eyes on a far object for a minute to allow your eye muscles to relax.

A short break from work or gaming gives your body a welcome posture change and helps to ensure you remain comfortable. Make use of any adjustments that your office furniture or equipment provide to accommodate posture changes. Because computing and gaming are primarily static activities, it's important to take breaks periodically. Stand up from your setup, stretch, or walk for a drink of water before returning to your screen. If you have questions on eye fatigue or visual discomfort, consult a vision care specialist and get an annual eye exam to protect your health.



TIP 6

Stay Flexible, Focused for a Happier Life

As businesses and workers continue to embrace flexible working, there's a permanent shift happening in how we define the workplace. The win-win benefits of flexible working are not going unnoticed; businesses are being rewarded for their flexible policies with less employee attrition and reporting higher levels of performance. In fact, 75% of teleworkers plan to work remotely for the rest of their careers.[3] In short, happier employees do better on all fronts – from day-to-day health to productivity to career advancement. Multipurpose monitors as smart docking stations for work and play in any location can uphold this employee satisfaction by delivering tech that works hard for them. Monitors with features like HDR content capabilities via higher refresh rates, e.g. up to 360Hz, deliver the highest quality visual experience no matter the setting.

Moreover, that familiar saying "tidy desk, tidy mind" has proven to be true.[4] A study carried out by researchers at Princeton University found that working in a cluttered environment can affect our ability to focus.[5] So, a monitor with USB-C hub can help you to focus your thoughts with fewer cables on the table. Keep your work area clean and clear for the materials that you typically use and place the items that you use most frequently, such as the mouse or your phone, within the easiest reach.

TIP 7

Make Hybrid Work a Bit Easier

Today, technology devices are our workplaces. Better device ergonomics make daily work experiences customizable to individual needs or schedules. Seamlessly switch from multiple screens to a mobile monitor to a smartphone; or choose the device with the best quality visual technology for the big presentation or meeting. Ergonomics are about maximizing your tech for your benefit. Ever tried to juggle working from home with your work laptop and your personal laptop or gaming PC while sharing the same external monitor, keyboard and mouse? It takes so much plugging and re-plugging, but not if you employ a monitor's KVM (keyboard, video, mouse) switch feature. This makes multitasking from your home or workplace setup much easier by giving you the ability to control multiple computers from a single keyboard, mouse and monitor with just one click, no re-plugging required.

For many on-the-go professionals and content creators, shouldering the pain of a heavy work bag can place extra pressure on the nerves leading to the shoulders, neck, and lower back resulting in stiffness. Your body just wasn't designed to carry that load. Squinting while presenting something on your tiny smartphone screen isn't comfortable either. Refined tools like compact mobile monitors can support a flexible lifestyle with smarter ports, USB-C connectors and multi-touch options to help you stay more productive and collaborative. Mobile monitors meet this unique moment by allowing workers to truly work from anywhere and deliver the same high quality monitor standards we expect from stationary monitors.

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Characterizing Short-Wavelength Light Exposure

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An accumulating body of evidence suggests that short-wavelength ("blue") light in particular has a greater influence on human biology than other parts of the visible spectrum.

There are numerous sources of short-wavelength light in the built environment, including visual computer displays, electric lighting, and daylight through windows and skylights. All discussions of the potential impacts of computer displays on visual health must take each of these sources into account. Researchers and engineers from Dell Technologies and from the Mount Sinai Light and Health Research Center have been collaborating to develop tools for quantifying light exposure characteristics from visual displays and from the lighted environment under different conditions. In this chapter, we share some of the elements of a framework for objective analyses of short-wavelength light exposure.

Photometric Measurements

Although light levels in buildings are typically specified in terms of horizontal illuminances on the work plane (such as a desktop), light exposure as it affects responses such as circadian rhythms, visual discomfort, and retinal damage is generally characterized by the vertical illuminance reaching the eyes of a building occupant. Field measurements of lighted spaces have shown that the vertical illuminance at the eye position in a space with electric lighting, but no daylight (such as windows), is typically less than half of the horizontal illuminance on the work plane. In a space with daylight from windows, the vertical illuminance at the eyes can be up to 20% higher than the horizontal work plane illuminance.

For example, a typical vertical illuminance at the eyes from electric lighting in an office lighted to 300 lux on the desktop from luminaires installed in the ceiling is 132 lux; a typical illuminance at the eyes from electric lighting and daylight in a windowed office with 500 lux on the desktop (from luminaires in the ceiling and from the windows) is 590 lux.

Of course, additional light exposure to the eyes comes from the visual display itself, which can occupy about 10% of the total field of view. The illuminance at the eyes from a display depends upon multiple factors:

• The maximum luminance of the ("white") display screen

• The size of the display screen

• The viewing distance of the display screen

• The application being displayed on the screen

Based on multiple measurements of several different display screens measured with different maximum luminances, different sizes and viewing distances, and while running different applications, it is possible to estimate the illuminance at the eyes of a display user under different conditions. Assuming a maximum ("white") display screen luminance of 300 cd/m^2, a viewing distance of 18 inches, and an application such as a spreadsheet with a mostly white display background color, Figure 18-1 shows the illuminance at the eyes for different display screen sizes (diagonal) ranging from 10 to 24 inches (also shown is an illuminance of 132 lux corresponding to the illuminance from the lighted environment in a windowless office lighted to a horizontal desktop illuminance of 300 lux). Holding the display screen size constant at 16 inches, Figure 18-2 shows the vertical illuminance for different viewing distances between 10 and 24 inches (as well as 132 lux as a reference for a windowless office as in Figure 18-1). The total illuminance at a person's eyes is the sum of the illuminances, so for a display size of 16 inches in Figure 18-1 in a windowless office, the total illuminance at the eyes would be about 250 lux.

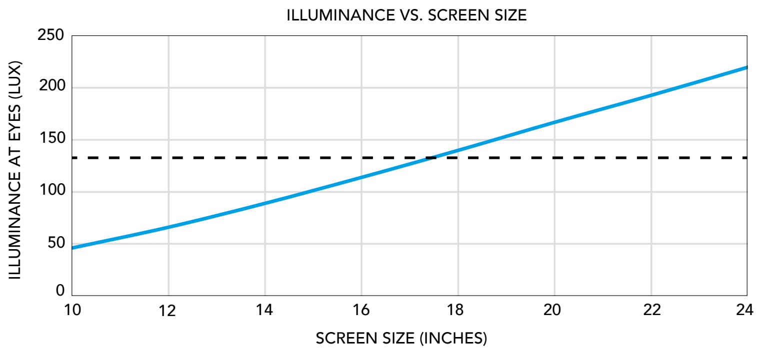

Figure 18-1. Solid curve: Illuminances at the eyes of a display user for different display screen (diagonal) sizes. Dashed curve: Illuminance at the eyes of an occupant of a windowless office lighted to 300 lux on the desktop. The total illuminance at the eyes is the sum of the illuminances from each component (display and ambient environment).

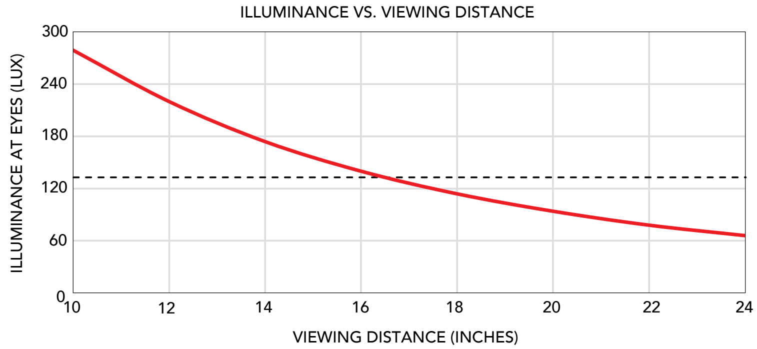

Figure 18-2. Solid curve: Illuminances at the eyes of a display user for different viewing distances. Dashed curve: Illuminance at the eyes of an occupant of a windowless office lighted to 300 lux on the desktop. The total illuminance at the eyes is the sum of the illuminances from each component (display and ambient environment).

Modeling Short-Wavelength Exposure

The illuminance values discussed in the previous section of this brief chapter refer to conventional photometric values weighted by the photopic luminous efficiency function, peaking at 555 nm (in the yellow-green portion of the visible spectrum). These values do not by themselves provide an estimate of the short-wavelength irradiance to which a visual display user might be exposed. For example, retinal damage has been most strongly linked to wavelengths between 415 and 455 nm in the violet-blue portion of the visible spectrum.

Visual display screens can be set to have their white point produce a spectrum with a wide range of correlated color temperature (CCT) values, typically from 3000 K ("warm" white) to 6500 K ("daylight" or "cool" white). Thus, white light from a display with a given luminance can produce more, or less, short-wavelength output depending upon its CCT. In order to estimate this short-wavelength exposure from a visual display, spectral measurements were made of several different displays with several different white point CCT settings within the 3000-6500 K range. There was a nearly linear relationship between the CCT and the amount of short-wavelength irradiance from the display, as illustrated by Figure 18-3, for a 16-inch (diagonal) display size viewed at a distance of 18 inches, a maximum ("white") luminance of 300 cd/m^2, and running a spreadsheet application. Also shown in Figure 18-3 is the short-wavelength irradiance from the lighted environment for a windowless office with a desktop illuminance of 300 lux from sources with a CCT of 4100 K, a common CCT value for commercial light sources.

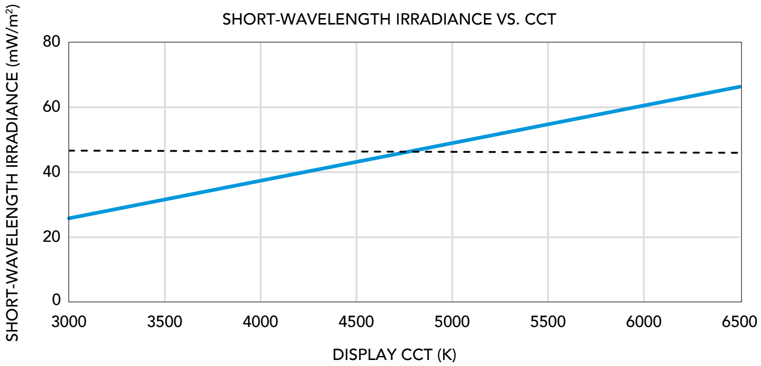

Figure 18-3. Solid curve: Short-wavelength irradiance (415-455 nm) from a visual display with a "white" point having different CCT values. Dashed curve: Short-wavelength irradiance from a windowless office lighted to 300 lux on the desktop with a source CCT of 4100 K. The total short-wavelength irradiance at the person's eyes is the sum of the illuminances from each component.

Some applications include multiple display screens. Based on measurements in real-world office spaces, the light levels reaching the eyes of people using two display screens were about 15% higher, and the light levels with three or more display screens were about 30% higher than with a single display screen.

Developing Exposure Thresholds

It can be seen from Figures 18-1 through 3 that not only visual display screens, but also the lighted environment itself needs to be considered when assessing the potential impacts of display screens on health outcomes such as circadian rhythms or retinal damage. It should also be noted that exposure levels outdoors can be orders of magnitude higher than indoor exposures from displays, electric lighting or the combination of both. Preliminary metrics for short-wavelength exposure could be developed to account for not only the instantaneous light exposures provided by displays and lighting, but also the duration of exposure, because responses such as circadian rhythms and retinal damage appear to exhibit a reciprocal relationship between intensity level and duration. In other words, a particular light level exposure for one hour may be approximately equivalent to twice that light level exposure but for a duration of only a half-hour.

Future Outlook

Identifying threshold exposure values obviously requires additional research and validation before such thresholds could be incorporated into ergonomic standards for displays and lighting. Before the advent of visual displays, research from the 1950s through the 1970s identified a horizontal illuminance of 1000 lux on the work plane as a value above which occupants of buildings may begin to experience long-term visual discomfort, eye strain or glare from the lighted environment. It is not altogether out of the realm of possibility that a computer with a calibrated display screen could record the exposure of light from that display to a user based on the specific applications run throughout the day. Many computers are also equipped with a camera and light sensors used to monitor a user's presence and to estimate the light exposure from the lighted environment as well as its CCT, whether from electric lighting or daylight.

With this information, a monitoring system could alert a display user when they were likely to approach the overall exposure levels that correspond to the threshold for long-term visual discomfort from the lighted environment. Such a system could offer several options to the user for reducing overall exposure to short-wavelength light; these could include taking a break from the visual display and lighted space, reducing the brightness of the display and/or the ambient lighting, or tuning the CCT of the display to lower values. Maximizing such a system's flexibility may be crucial to its successful implementation.

Regulatory Perspective

Concern about HEV blue light from digital displays is triggering policy discussions across the globe.

Increasingly, governments are looking closely at efforts to minimize the harmful consequences of blue light from a regulatory standpoint. As the scientific community continues to identify the growing concerns over potential long-term eye and health impacts from blue light, it seems likely additional government attention and pro-active protective measures will gather momentum in the future. Below are some recent government actions.

About the Author:

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France

ANSES[1], the French Agency for Food, Environmental and Occupational Health & Safety, released a new report on the impacts of the LED systems on human health and the environment. This report, a collective expert appraisal based on a critical analysis of scientific data, confirms the phototoxic effects of short-term exposures to high-intensity blue light, shows that even very low exposure to light that is rich in blue in the evening or at night, disrupts the biological rhythms and thus sleep, and underlines the need to protect identified populations at risk. The Agency recommends that authorities should develop the research, adapt the current regulations based on the scientific data and improve information.

In May 2021, the French Ministry of the Ecological Transition announced a new measure to limit blue light on toys having LEDs for children by 2022.[2] The measure aims to protect the health of children under the age of ten who ordinarily do not have a fully developed crystalline lens. According to the Minister of Ecological Transition, the health effects of toxic exposure could be multiple, from the creation or accentuation of myopia, to sleep disturbances.

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See Chapter 9 on Policing Screen Time

China

A 2018 communiqué[3] states that the Chinese government has committed to implement a number of regulatory measures to combat health problems caused by excessive screen time, including the alarming increase in myopia among school-age children.[4]

In September 2021, China's National Press and Publication Administration published new rules for kids and teens under 18 years old, limiting their online video game time to three hours per week.[5] These new restrictions are a continuation of China's efforts over the last 10 years to police the amount of time young people spend on video games. This originally stemmed from possible health concerns but was later expanded due to anti-addiction measures.

Citing a rise of eye health issues in China, Zhejiang province issued draft regulation to limit screen time. The Zhejiang regulation would limit the use of electronic devices to 30 percent of total teaching time and encourage the issuing of paper homework to be completed by hand.[6]

Taiwan

Taiwanese lawmakers approved the "Child and Youth Welfare and Protection Act" which allows the government to fine parents of children under the age of 18 who are using electronic devices for extended periods of time.[7] This law follows similar measures in China and South Korea that aims to limit screen time to a healthy level.

South Korea

Some laws aimed at restricting video game playing also have the effect of restricting screen time at night. The South Korea National Assembly enacted the Youth Protection Revision Act, also known as the Shutdown Law, in 2011. The law forbids children under sixteen from playing on-line video games after midnight.[8] China, Thailand and Vietnam have similar laws, all intended to protect minors from excessive video gaming.

WHO

The World Health Organization issued new and strict guidelines concerning screen time for children under five.[9] The guidelines stress that the motor and cognitive development of children is being negatively impacted by inadequate sleep on young children, as well as time spent sitting watching screens. The recommendation is for children to increase daily participation in active playtime.

State of Maryland

Maryland's House of Representatives and the Senate unanimously passed the Health and Safety Best Practices Digital Devices bill. It was signed into law by Governor Hogan soon after. The bill, HB-1110, requires the Maryland State Department of Education (MSDE) to come up with a list of "best practices" to regulate how kids interact with screens in schools.[10]

Washington, DC

U.S. Senator Ed Markey and a bipartisan group of lawmakers in Washington DC have proposed legislation calling for the National Institutes of Health to conduct a $40 million multiyear study of the effect of technology, screen time and online media on infants and older children.[11]

"No one could have imagined a year ago when this resolution had passed that virtually all California school children would be doing distance learning. This distance learning has caused children to spend ever greater amounts of time in front of electronic devices."

Dr. Richard Pan, California State Senator, District 6, Chair of Senate Committee on Health, author of SCR-73, and practicing pediatrician

State of California

In its guidelines for childrens' after school programs, the state of California Department of Education recommends to "Limit recreational screen time to 30 minutes and total screen time to 60 minutes per after school session."[12] While California State Teachers called for Apple to study impact on children's health and offer new solutions.[13]

Blue Light Awareness Day

October 10th has been designated as Blue Light Awareness Day by the State of California. In addition to unanimous passage by the California Senate, the Blue Light Awareness Resolution (SCR-73) was ratified by the California Assembly on a vote of 70-0.

Resolution SCR-73 was sponsored by Dr. Richard Pan, a pediatrician, state senator, and chair of the California Senate Committee on Health.

SCR-73 identifies known and potential health hazards associated with exposure to high-energy blue light from devices for children and adults. The Resolution urges consumers to consider taking protective safety measures in reducing eye exposure to high-energy visible blue light.[11]

Jeff Todd, President and Chief Executive Officer Prevent Blindness, said at the time, "Resolution SCR-73 passed by the California State Legislature sends a message to the eye care sector, electronics manufacturers, parents and educators that we need to be taking the issue of blue light emissions and extended exposure to digital screens seriously, and undertake the necessary research to fully understand its impact. We commend the State of California for recognizing vision and eye health as an important public health issue in the context of emerging concerns related to blue light emissions."

State of California Resolution

Blue Light Awareness Day in California

Senate Concurrent Resolution No. 73

Sponsored by Dr. Richard Pan, Chair of the California Senate Committee on Health

Relative to Blue Light Awareness Day

[Filed with Secretary of State September 19, 2019.]

This measure would designate October 10 of each year as Blue Light Awareness Day in California.

WHEREAS, There are over 80 million electronic devices with digital screens in the State of California; and

WHEREAS, Screen time viewing with electronic devices exceeds over nine hours per day; and

WHEREAS, The increased usage of, and access to, digital devices by young children and adolescents is an acute area of concern, as ophthalmologists, optometrists, and medical researchers continue to learn more about the short-term effects of increasing and cumulative exposure to artificial blue light on the developing human eye and mental health at a young age, along with long-term potential cumulative effects on adult eye health and mental development; and

WHEREAS, The scientific community and recent studies have identified growing concerns over potential long-term eye and health impacts for all age groups from digital screen usage and cumulative blue light exposure emitted from digital devices; and

WHEREAS, Blue light has been reported to cause visual discomfort in 65 percent of Americans; and

WHEREAS, Blue light has been associated with possible harmful effects on retinal cell physiology linked to the high-energy, short wavelength in the narrow range of 415–455 nanometers; and

WHEREAS, Cumulative blue light exposure from digital devices has been shown to disrupt sleep cycles by suppressing the natural release of melatonin and has also been linked to premature aging of the retina, which could accelerate potential long-term vision problems such as age-related macular degeneration, decreased alertness, and memory and emotional regulation impacts; and

WHEREAS, Screen time can take a toll on vision health and comfort, leading to symptoms of digital eye strain and dry, irritated eyes; and

WHEREAS, Given the growing body of research around the breadth and scope of potential eye and systemic health impacts related to blue light exposure, the State of California encourages citizens, particularly children, to consider taking protective safety measures in reducing eye exposure to high-energy visible blue light; now, therefore, be it

Resolved by the Senate of the State of California, the Assembly thereof concurring, That the Legislature hereby designates October 10 of each year as Blue Light Awareness Day in California; and be it further

Resolved, That the Secretary of the Senate transmit copies of this resolution to the author for appropriate distribution.

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▶ **eyesafe.com/research**

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Marketplace Standards for Lighting

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All lighting products are subject to standards governing safety and performance.

What follows is a brief summary of lighting standards as published by industry compliance and safety organizations. You will find within these standards a recognition of blue light as the subject of cautionary guidance. Many companies follow these standards in a form of self-regulation, so as to minimize legal risk and the risk of regulations that could impact business.

International Standards

IEC/EN (International Electrotechnical Commission) 62471 Photobiological Safety of Lamps and Lamp Systems — This standard classifies all lamp and luminaries brought to the market. It focuses on photochemical damage on the retina. It recognizes a level of blue light hazard that may lead to degeneration of the macula. IEC 62471 was officially adopted by the European Union as EN 62471 in 2008. Supporting guidance to this standard is provided in IEC/TR 62778 (2014).[1]

IEC/TR 62778:2014 — This technical report provides guidance in the assessment of the retinal blue light hazard of all lighting products emitting in the visible region of 380–780 nm. The relationship between correlated color temperature (CCT) and blue light hazard is also discussed in this report, namely that the more a source emits light in the blue region, the higher the CCT and the greater the blue light hazard risk.

The document classifies the optical radiations into risk groups according to their potential photobiological hazard. There are four classification groups (Table 20-1):

Table 20-1. Risk group ratings for photobiological hazard.

Risk Group (RG)	Philosophical Basis
Exempt	No photobiological hazard
RG 1 (Low-Risk)	No photobiological hazard under normal behavioral limitations
RG 2 (Moderate-Risk)	Does not pose a hazard due to aversion response to bright light or thermal discomfort
RG 3 (High-Risk)	Hazardous even for momentary exposure

American National Standards Institute

ANSI/IES RP27: Recommended Practice for Photobiological Safety for Lamps and Lamp Systems — Created by Underwriters Laboratories, ANSI/IESNA RP-27 is the original photobiological safety standard for lamp systems in the United States. This set of regulations was the basis for the International Electrotechnical Commission standard IEC/EN 62471.

The standard covers optical radiation hazards from all electrically powered sources of radiation that emit in the range of 200 nm to 3000 nm, except LEDs used in optical fiber communication systems, and lasers, which are covered in a separate series of ANSI standard (Series Z136).

ANSI Z80.3-2018 American National Standard on Ophthalmics - Nonprescription Sunglass and Fashion Eyewear Requirements — ANSI Z80.3-2018 establishes standard guidelines for noncorrective lenses intended for light's attenuation and for fashion eyewear, such as sunglasses. It explicitly excludes products that are covered by the ANSI/ ISEA Z87.1-2015: American National Standard for Occupational and Educational Personal Eye and Face Protection Devices, and by ANSI Z80.1-2015: Ophthalmics – Prescription Ophthalmic Lenses. The ANSI Z80.3 standard was updated in 2018, includes data for computing blue light transmittance.[2-3]

ANSI/ISEA Z87.1-2020 American National Standard for Occupational and Educational Personal Eye and Face Protection Devices — Intended to help in identifying and selecting the types of eye and face protectors that are available, this standard focuses on product performances and limitations, while integrating international standards. It differentiates protectors based on hazards listed. This standard has been adopted by OSHA.[2-3]

China Lighting Standards

Figure 20-1. Warning symbol for portable or handheld luminaires in excess of RG1 at 200 mm, China 2017.[4]

The China blue light hazard standard was introduced on Dec. 31, 2015 and became effective on Jan. 1, 2017. In this standard, GB7000.1-2015, the blue light hazard assessments of integrated LEDs and LED modules must meet the international IEC/TR 62778 requirements. Mobile luminaires and handheld light blue light emissions that exceed the specific distance of 200 mm should be clearly labeled "Do not stare at the light source" on a visible area on the luminaire. This label should not be placed close to an LED or where light is emitted. Also, in the product manual, the manufacturer should state the proper distance of the luminaire and recommended distance. The new adopted labeling system is shown in Figure 20-1.

Safety and Regulations

ICNIRP - the International Commission on Non-Ionizing Radiation Protection — As an independent organization, the ICNIRP provides scientific advice and guidance on the health and environmental effects of non-ionizing radiation (NIR) to protect people and the environment from dangerous NIR exposure.

In 1997, ICNIRP first proposed some guidelines for exposure to visible and infrared radiation. The current Guidelines on Limits of Exposure to Incoherent Visible and Infrared Radiation was updated in 2013, establishing the maximum levels of exposure to incoherent optical radiations from artificial and

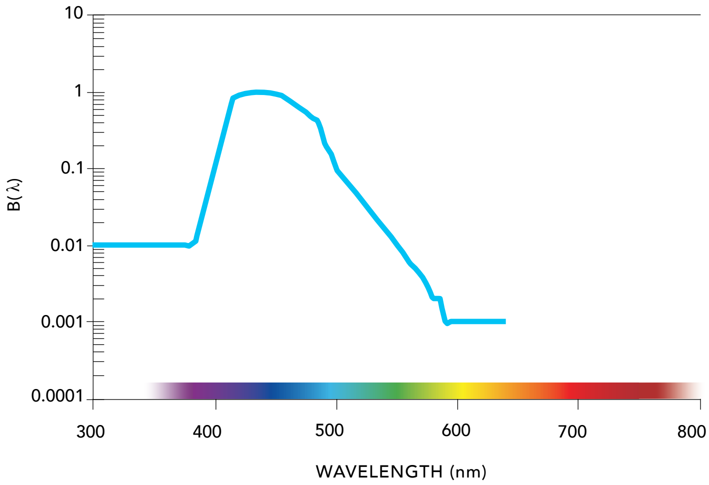

Figure 20-2. Action spectra for blue light hazard.[5]

natural sources, with the exception of lasers. Exposure below these maximum levels should not be expected to cause adverse effects. These guidelines specify the biological effects to eyes and skin most susceptible to damage by optical radiation, the various types of effects, the injury thresholds and the potential damage mechanisms occurring at different wavelengths. The eye damage overview mentions retinal injury, circadian rhythm and visual disturbances. A relative sensitivity of the retina for the blue light hazard (Figure 20-2) as a function of wavelength, and a retinal hazard spectral weighing function table, are part of the guideline.[5]

Screen Time Recommendations

In April 2019, the World Health Organization (WHO) indicated in a new report that children younger than a year should have no screen time, and children under the age of 5 should be limited to one hour. It emphasized that young children need be physically active and get enough sleep, habits that go a long way in preventing obesity and other diseases later in life.

Other organizations such as the American Center for Disease Control and Prevention, the European Academy of Paediatrics (EAP), the European Childhood Obesity Group (ECOG) and the American Pediatric Association (APA) advocate that screen time be limited to less than 2 hours daily for children and adolescents.[6-8]

VR Headsets

VR headsets are a rapidly growing category of both consumer and professional displays. The wide adoption of VR headsets is of concern to the vision health community due to the proximity of the screens to the human eye. The closer the distance, the higher the risk in terms of energy irradiation and retinal damage. This close distance of 1 to 5 inches (3 to 12 mm) to the human eye, and the encapsulation of the face in the headset removes the ability to gaze away from the screen.

It is expected that the VR headset industry will grow to $80 to $150 billion in sales within the next decade, as adaptation of this new technology will be extended to school, medicine and other areas.

ANSES, the French Agency for Food, Environmental and Occupational Health & Safety, recommends that children under the age of six not use VR headsets. Children under the age of 13 should only use VR headsets in moderation, and that parents should be concerned with any resulting symptoms. As well, people already subject to visual disorders (disorders of accommodation, vergence, etc.) and problems with balance should limit their exposure to these technologies.

ANSES recognizes the lack of data relative to the exposure of the population to VR headsets and other 3D technologies, and recommends identifying sensitive populations in relation to the various uses of such technologies, as well as setting up a system for monitoring exposure.

Visual discomfort from prolonged use of VR headsets can lead to symptoms of visual fatigue, pain, dry eyes, and visual disorders such as double vision, headaches, neck pain, and aching in the back and shoulders. These effects can be more severe in children, as they are related to vergence and accommodation development.[9]

In a 2019 report ANSES advocates for increased awareness of systems with LED enriched with blue light. For children it recommends strict limits to exposure to mobile phones, tablets and computers before bedtime and overnight.[10]

TÜV Rheinland

TÜV Rheinland, the world's leading third-party testing and certification organization, introduced TÜV low blue light certification method 1 in 2014. It is defined as the ratio of blue light to luminance level less than 20%.

TÜV published an update to this standard, naming it Method 2, in 2016. Method 2 specifies that the ratio of light in the range 415 nm to 455 nm, when compared to 400 nm to 500 nm, must be less than 50%. Method 2 also includes a color temperature between 5500-7000 K as criteria.

In 2018, TÜV Rheinland announced the RPF standard with Eyesafe. It was a new standard for certification of blue light screen protection. The new testing and evaluation protocol measures the level of protection based on the spectral weighting factors for blue light hazard, as published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 2013 and adopted by the American National Standards Institute (ANSI) in 2015.

ZAGG, the global leader in screen protection with InvisibleShield, was the first to achieve TÜV Rheinland blue light management certification for accessory products.

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InvisibleShield by ZAGG

RPF

The RPF standard provides consumers with an easy to understand numbered rating that designates the level of high-energy visible blue light being filtered from a digital display. The standard and associated RPF value also ensures that overall display color quality is maintained and the visual experience not affected.

In order to receive the RPF certification, a blue light filter must satisfy three requirements and follow the RPF classification rules (Table 20-2).

Table 20-2. RPF Classification Rules

Classification Requirement	RPF Level	Luminance reduction	Change of CCT
RPF 15	15	≤ 20 %	≤ 250 K
RPF 20	20	≤ 20 %	≤ 350 K
RPF 30	30	≤ 20 %	≤ 500 K

The first requirement, the luminance reduction ratio, is calculated to be not be over 20%. The second requirement, correlated color temperature, or CCT, shall not shift more than the limit for each RPF level. Finally, a blue light hazard weighted irradiance is calculated without filtration, and then with it, to determine the RPF level.

Eyesafe® Standards

Eyesafe Standards are specific to HEV blue light emitted by digital devices. They are based on guidelines from the American National Standards Institute to guide development of products: Z80.3-2018 and Z87.1-2020, and the IEC/EN 62471, in addition to the latest guiding clinical research.

Displays identified and certified Eyesafe® should adhere to these guidelines, while maintaining color accuracy. As such, solutions must not only manage blue light, but also maintain color accuracy and D65 illumination ratings.

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See Chapter 21 to learn more about the most recent Eyesafe® Standards.

Specifically, the following criteria must be met:

- Reduced light emissions in the blue-violet segment of the blue light spectrum
- Meet photobiological safety guidelines
- Maintain CCT value in acceptable range

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SECTION 3

Eyesafe® Solutions

Eyesafe solutions intelligently manage light energy at the source – selectively reducing blue light while maintaining the color integrity of digital displays.

Eyesafe® Standards

Amir Soleimanpour, PhD is Director of Research and Advocacy at Eyesafe. He received his degree in mechanical engineering from the University of Toledo. He has more than ten years of experience with new product development and a deep background in materials science, physics and chemistry.

This chapter summarizes the Eyesafe Standards needed to license the use of the Eyesafe® brand. These requirements are based on specific criteria defined by the Eyesafe Vision Health Advisory Board.

The purpose of the Eyesafe® Certification is to demonstrate to the end consumer that the tested device provides a clinically relevant reduction in hazardous blue light emission while maintaining color performance. Having met the specific criteria, a display product including smartphones, tablets, notebooks, desktop computers, commercial displays, and televisions, would then qualify as a potential licensee of Eyesafe.

These requirements represent the current assessment of the Eyesafe Vision Health Advisory Board on the topic of blue light reduction and aim to lead the industry and manufacturers towards a better understanding of blue light reduction. These requirements will be updated as further information becomes available.

Natural light comprises a wide array of colors whose intensities and hues vary throughout the day.

Newer LED and OLED based artificial lighting along with LED and OLED displays including LCD backlight systems contain high energy blue light (400 to 500 nm), in a light spectrum that is mostly constant. The eye's physiology is naturally better adapted to the dynamic spectrum of natural sunlight than to artificial lighting that is constantly emitting high levels of blue light. Additionally, with daily screen time continuing to increase, and close-up use of devices occurring at all times during the day, users are being exposed more than ever to higher levels of blue light than they were with conventional domestic light sources.[1-3]

A key development trend should be noted: in general, displays are increasing in luminance, some operating at color temperatures as high as 7500K. By comparison, the color temperature typical of natural sunlight ranges from 4500K to 6500K. These trends are concerning, since there is growing evidence that overexposure to blue light, which increases with higher color temperatures, may have significant vision and health consequences.

Recent studies have shown growing concerns over potential long-term eye health impacts from digital screen usage and cumulative blue light exposure.[4-7] In addition studies have recognized the impact of device use on circadian rhythm and sleep patterns.[8-11] These disruptions are associated with multiple health problems.[12-16]

Blue light exposure research and studies on animal cells have shown that the greatest phototoxic risk to retinal pigment epithelium cells from blue light peaks between 435 nm and 440 nm. The risk peaks in that range but extends through the blue region with photoreceptor cell apoptosis seen early after the retina is damaged by blue light.[17-19]

Long-term health implications are now being studied, but eye strain and other immediate effects of display use affect people on a daily basis. Therefore, a major concern is how best to protect eye health and systemic health by optimizing the spectral distribution of display lighting and simulating the periodical changes of natural light.

To capture the body of medical data that has and continues to be published, Eyesafe has assembled an advisory team of noted optometrists and ophthalmologists that maintain a current awareness of published research and methods for treatment of critical exposures to damaging portions of the color spectrum.

Eyesafe research and technical teams are continually reviewing and cataloging the latest published research about blue light to offer a clear understanding of which portions of the blue light spectrum have the greatest impact on retinal health, macular degeneration risks, and disruption of human melatonin modulated sleep cycles.[20] For more information, please visit eyesafe.com/research.

A growing number of studies suggest that cumulative exposure to blue light over time could lead to premature eye health issues, among them damage to photoreceptor cells in the retina that may increase risks of vision problems such as age-related macular degeneration.[21-23]

A combination of factors including viewing distance, frequency and duration of use, physical responses to screen habits, and exposure to blue light, have been reported to cause visual discomfort in 65 percent of Americans.[24]

Exposure to blue light from digital devices has been cited as a contributor to digital eye strain,[24-29] which is characterized by symptoms such as dry eyes, irritated eyes, blurred vision, sleep disruption, fatigue, reduced attention span, irritability, and neck and shoulder pain.[25, 26]

By stimulating retinal ganglion cells, blue light in the 460 to 480 nm wavelength range suppresses melatonin production and plays an important role in alertness, memory, attention span, learning ability, and cognitive performance.[21, 25] Several studies have shown the impact of display technology on circadian rhythm disruption in adolescents and adults,[8, 9, 12, 13, 31] resulting in reduced duration and quality of sleep. Circadian rhythm disruption is linked to various diseases such as obesity, depression, and possibly cancer.[2, 9, 13, 31, 32]

Recent research has shown that filtering blue light from digital displays before bedtime produced significant positive health benefits among teenagers by reducing LED-induced melatonin suppression.[33]

Other studies have shown that blue light filters reduce visual acuity loss among digital device users who have dry eyes and reduce glare and photo-stress associated with prolonged exposure to intense light.[32-34]

Recently, some governmental agencies have taken steps to limit the exposure of blue light to populations at risk, including infants and young children. France, for example, following a report from ANSES (French Agency for Food, Environmental and Occupational Health & Safety)[35] is taking steps to ban, subject to compatibility with European law, risk group LEDs greater than one in items intended for children.[36, 37]

The State of California has taken a stand on the blue light issue: in 2019, the State Blue Light Resolution SCR-73 was unanimously passed. Its purpose is to encourage all Californians (and their children) to "consider taking protective safety measures in reducing eye exposure to high-energy visible blue light." The resolution designates October 10th as Blue Light Awareness Day.[38]

Protective measures to reduce blue light exposure can include the use of blue light filtering glasses, the use of a blue light filter placed at the source of the emission (i.e., a filter applied directly onto the digital screen) or alternatively the use of a low blue light certified device.

Eyesafe® Requirements focus on high energy visible (HEV) blue light that is emitted by digital devices. To guide product development, Eyesafe uses photobiological safety standards Z80.3-2018 and Z87.1-2015 from the American National Standards Institute,[39] the IEC/EN 62471 standard from the International Electrotechnical Commission, and a vast amount of industry research.

Displays identified and certified Eyesafe® should adhere to these guidelines, while maintaining color transmission. As such, solutions must not only manage blue light, but also maintain color transmission and D65 42 illumination ratings.[40]

Specifically, the following criteria must be met:

- Reduced light emissions in the blue-violet segment of the blue light spectrum
- Maintain Color Gamut and CCT requirements values

	EMISSIONS (nm)	BLUE LIGHT HAZARD FUNCTION*
UV	200-380	0
HIGH-ENERGY VISIBLE BLUE LIGHT	380	0.01
	385	0.01
	390	0.03
	395	0.05
	400	0.10
	405	0.20
	410	0.40
	415	0.80
	420	0.90
	425	0.95
	430	0.98
	435 Peak	1.00
	440 Peak	1.00
	445	0.97
	450	0.94
	455	0.90
	460	0.80
	465	0.70
	470	0.62
	475	0.55
	480	0.45
	485	0.40
	490	0.22
	495	0.16
	500	0.10

*American National Standards Institute (ANSI) Z80.3 Table
International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines, most toxic portions of the blue spectrum

Blue light toxicity and its potential impact on eye health and overall human health.

▶ **eyesafe.com/standards**

For detailed instructions about how to calculate each metric, and to download the latest Eyesafe standard.

Reduced light emissions in the most toxic blue light region range is achieved by integrating the weighting factors from the ANSI Z87.1-2020 Occupational and Educational Personal Eye and Face Protection Devices standard, which identifies a peak blue light hazard factor at 435 to 440 nm. (cf. Table C4. Spectral Weighting Factors for Blue-Light Hazard, p. 38 of the ANSI Z87.1-2020 standard).

Maintaining spectral transmittance of visible light is achieved by following indications from the ANSI Z80.3-2018 Nonprescription Sunglasses and Fashion Eyewear Requirements standard, which includes data for computing blue light transmittance.

Introducing Radiance Protection Factor (RPF®) for Display

BLTF is difficult to understand for the end-user because of its complexity. To translate the complex BLTF formula and resulting Eyesafe Requirements to the end-user (consumer), Eyesafe is introducing RPF for Display. This simple metric provides a rating system to help the end-user identify and compare devices and their respective blue light emissions at a specific brightness level (200 nits). RPF for Display is calculated based on the BLTF of a display in comparison to the D65 illuminant BLTF.

$$RPF = 260 \times \frac{(BLTF_{D65} - BLTF_{Tested})}{BLTF_{D65}}$$

In which:

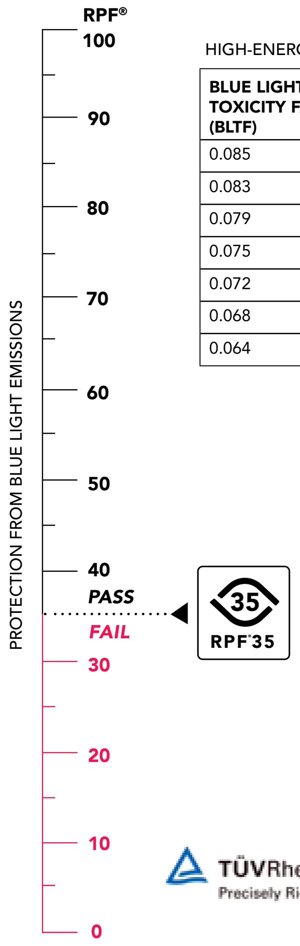
$BLTFD_{65} = 0.098$

260 – Scaling factor

$BLTF_{Tested}$: The BLTF of the tested sample

D65 is widely used in the lighting industry as a baseline because it roughly corresponds to the average midday light in Western Europe and Northern Europe (comprising both direct sunlight and the light diffused by a clear sky). D65 is not a real light source, but a simulation used to represent daylight at a given day and time.

RPF is calculated using a scaling factor that is based on the current technological limits of recent LCD and OLED technologies. The goal is to provide the end-user with a number (1-100) that reflects the blue light toxicity of the display, effectively simplifying the complex blue light toxicity formula used for measurement. Similar to how Sun Protection Factor (SPF) measures protection for the skin, the RPF scale measures blue light emissions and potential risk for the eyes. The higher the number, the better — in essence, higher RPF numbers indicate a greater reduction of high-energy blue light in a display.



HIGH-ENERGY BLUE LIGHT REDUCTION

BLUE LIGHT TOXICITY FACTOR (BLTF)	RADIANCE PROTECTION FACTOR (RPF)
0.085	35
0.083	40
0.079	50
0.075	60
0.072	70
0.068	80
0.064	90

TÜVRheinland® Precisely Right.

Radiance Protection Factor (RPF), the metric for high-energy blue light reduction in digital displays. Just like SPF, higher numbers equal greater protection. RPF measurements are certified by TÜV Rheinland.

▶ **eyesafe.com/rpf**

To meet the Eyesafe Display Requirements for blue light emissions, a display must achieve an RPF of 35 or higher. This is equivalent to a BLTF rating of 0.085. This requirement reflects the latest research and optical testing.

The following requirements were developed to assist device manufacturers in effective blue light filtration, color accuracy and adherence to leading industry standards.

EYESAFE® DISPLAY REQUIREMENTS 2.0		
High-Energy Blue Light	Weighted blue light toxicity emissions based on ICNIRP Guidelines	Radiance Protection Factor (RPF®) Pass/Fail of certification will be at RPF35. Measurement of blue light toxicity, based on research and optical testing. The RPF scale is tested and verified by TÜV Rheinland.
Color Performance	Color Gamut Coverage %	For sRGB color mode: ≥95% of standard sRGB color space in CIE 1931; 1976 For Adobe RGB color mode: ≥90% of standard Adobe RGB color space in CIE 1931; 1976 For DCI-P3 color mode: ≥90% of standard DCI-P3 color space in CIE 1931; 1976 For NTSC color mode: ≥72% of standard NTSC color space in CIE 1931; 1976 * *For battery powered products NTSC color mode : ≥45% of standard NTSC color space in CIE 1931; 1976
	Color Temperature	5500-7000K

An Eyesafe Display Certificate received by a device maker includes a report with collected results data:

- Pass/Fail of Radiance Protection Factor for display
- Pass/Fail of color gamut coverage
- Pass/Fail based on color temperature (CCT)

Each unique display hardware combination must be tested for certification. Documentation must be supplied to demonstrate this hardware configuration. Eyesafe should be notified of any product specification change. Any such changes will require recertification. For detailed instructions on the new standard and how to calculate these metrics please visit, eyesafe.com/standards.

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▶ **eyesafe.com/research**

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Color Science

Eyesafe® standards are specific to displays, and as such, they need to factor not only the blue light requirement, but balance that requirement against a key design goal of displays: rendering a vivid color palette. Color science can help us understand how displays can meet performance goals that do not compromise vision health.

Color scientists and display engineers continue to push the limits of how screens reproduce images. Across a huge variety of screen formats and operating settings, they draw on color science, photometry and colorimetry to mimic all the colors the human eye can perceive.

Color is not a physical property of the objects we see, but a sensation stimulated by light radiations reflected on those objects, which is mediated by the cones of the retina.

As described earlier in this book, photoreceptors in the retina in the back of the eye consist of rods and cones. Rods are sensitive to shape and movements, but are not sensitive to colors. This is called scotopic vision. Cones are the photoreceptors sensitive to colors. They are responsible for what is called photopic vision: color perception during daylight or similar conditions.

Cones conform to the spectral sensitivity curve (Figure 22-1), where each cone perceives the total sum of light from all wavelengths under its given curve.

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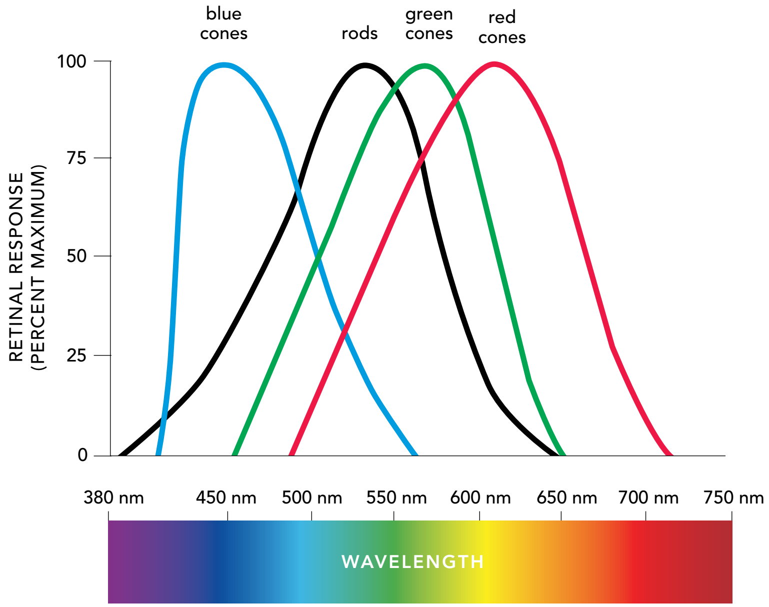
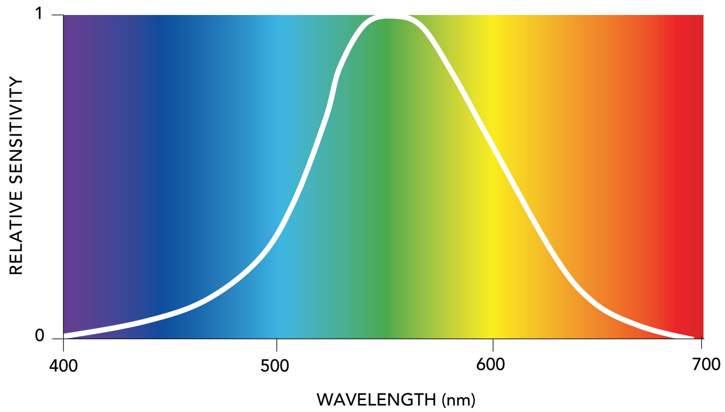
Figure 22-1. Cones and rods spectral absorption.



The eye does not perceive all wavelengths of equal intensity the same way. The combined sensitivities of cones are at their maximum at 555 nm, in the green color range, as represented on Figure 22-2. The sensitivity curve helps explain why some colors appear brighter than others. At equal intensities, two colors such as green and blue, will appear to the human eye as if the green is brighter than the blue. When colors are mixed on a display, to appear as bright as green, blue and red will have to be at higher intensities.

Figure 22-2. Photopic response: spectral sensitivity function of the average human eye under daylight conditions, defined by the CIE spectral luminous efficiency function V(λ).



Cones will transmit to the brain a visual signal corresponding to the sum of light detected within their spectral sensitivity. Although each of the curves has a maximum in a specific color: blue for S-cones, green for M-cones and red for L-cones, the three different signals of various intensities will translate in one specific color (colorimetry), in the same way that all the colors of the sunlight spectrum together, as well as various types of lights with different spectral distributions will appear white to the human eye.

Colorimetry and Photometry

In order to be able to reproduce what the eye sees human eye response needs to be quantified. Colorimetry is the science and measurement of color as perceived by the human eye, while photometry is the science and measurement of perceived brightness. Countless subjective studies of how people register brightness and variations of color have resulted in several accepted standards, and a mathematical system for reproducing color to those standards.

See Page 16

See Chapter 2, Figure 2-3.

We see color in response to light reflecting off an object. There are three components in this system: the light source (or illuminant), the object on which the light reflects, and the eye of the observer. A color has its own unique appearance based on its hue (red, orange, blue, etc.), chroma (saturation, or how close a color is to the gray or to the pure hue) and value (its degree of lightness, whether it is a dark or light color).

Two objects, such as a red flower and a red car, can appear to have the same color according to the eyes of an observer. The objects may be of different material and surface properties, and reflect light differently. Nevertheless, we may perceive them as having the same color under specific conditions. This is the basis of color science and it is called metamerism. A color can be reproduced if the spectral distribution of light giving the same cone response can be reproduced.

Color Spaces

A color space is a system of colors created from three primary colors, red, green and blue, which allows a display to digitally represent those colors and their combinations. A single point in that space represents a unique combination of colors.

Colors are represented geometrically, set along three axes, x, y and z, but with x, y and z representing the colors red, green and blue (RGB). A pure color, such as red, can be plotted as a two-dimensional wall on its own axis. Thus, the three primary colors occupy three faces of a virtual cube, with their color combinations filling the volume within the three axes. Hence the idea of a color space.

Color space references are the CIE XYZ, CIELUV and CIELAB. They are specifically designed by the International Commission on Illumination to represent all the colors the human can perceive. The first color matching system, called CIE 1931, was established in 1920.

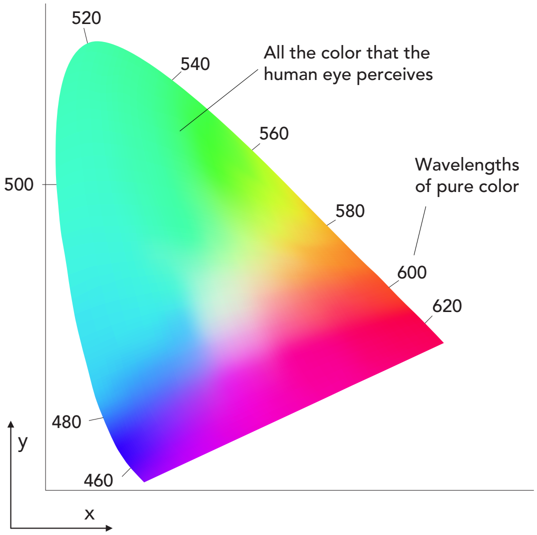


Figure 22-3. CIE 1931 chromaticity diagram.

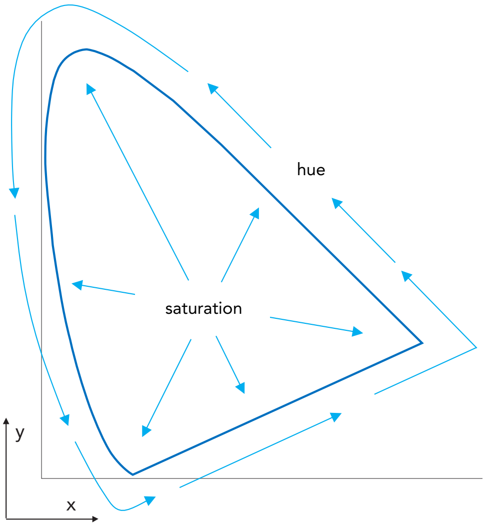


Figure 22-4. Schematic of the color distribution within the chromaticity diagram as a function of the hue and the saturation level.

By mapping the color space perceivable by the human eye, and plotting the limit of what the eye can perceive for each wavelength, the figure outlined has a horseshoe shape. The purest colors are at the limit of the shape, and the shape contains all the perceivable combinations of colors within that space. This is the CIE Chromaticity diagram (Figures 22-3 and 22-4).

In order to identify a color within the chromaticity diagram, its coordinates have to be calculated. The spectral power distribution (SPD) of the color or the illuminant has to be measured and matched with the chromaticity functions.

The CIE defined three chromaticity functions $\bar{x}$, $\bar{y}$ and $\bar{z}$. based on an understanding of the neurophysiology of the eye and some experimental works, leading to a model for a standard observer. Among the three functions (Figure 22-5), the function $\bar{y}$ is recognized as the photopic response of the eye under daylight conditions.

Calculating the CIE coordinates Cx and Cy for a color is first done by calculating the tristimulus of values X, Y, Z, from the spectral power distribution (P) of the color or illuminant, and the CIE color-matching functions (see x, y, and z equations).

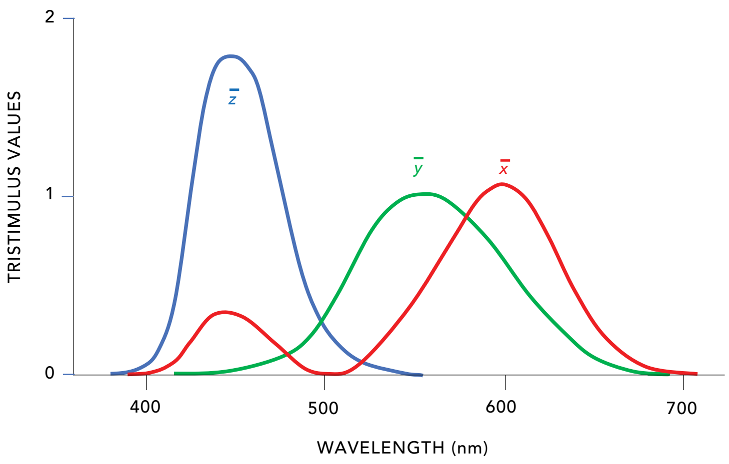


Figure 22-5. CIE standard observer color matching functions

CIE 1931

$$C_x = \frac{X}{X+Y+Z}$$

$$C_y = \frac{Y}{X+Y+Z}$$

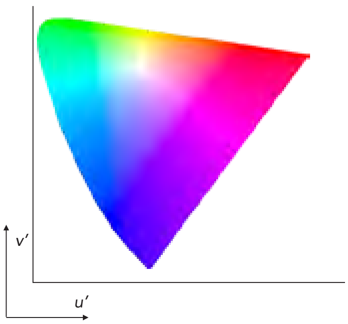


Figure 22-6. CIE 1976 chromaticity diagram

CIE 1976

$$u' = \frac{4X}{X+15Y+3Z}$$

$$v' = \frac{9Y}{X+15Y+3Z}$$

$$X = \int P(\lambda)\,\bar{x}(\lambda)d\lambda$$

$$Y = \int P(\lambda)\,\bar{y}(\lambda)d\lambda$$

$$Z = \int P(\lambda)\,\bar{z}(\lambda)d\lambda$$

Equations for calculating CIE coordinates

In 1976, the CIE defined new color spaces, CIE 1976 - CIELAB (or CIE L*a*b), and the related color space CIELUV (or CIE L*, u*, v*). In the CIELAB color model, a color is assigned the three values *L*, *a* and *b*, where L corresponds to the luminance component, and *a* and *b* respectively represent the red-green and the blue-yellow parts of the color. The CIELUV preserves the same L* as L*a*b* but has a different representation of the chromaticity components u' and v' (Figure 22-6). Both result from a mathematical transformation of the CIE XYZ. The idea being to get a uniform space, easier for interpretation of the color mapping, especially in the blue-green region. The CIE recommends using the CIELUV color space for the characterization of color displays, and using the CIELAB color space for the characterization of colored surfaces and dyes.

The CIELUV has its own mathematical equations to calculate the chromaticity coordinates of a color u' and v', using the chromaticity functions.

Even though the CIE 1976 is newer, the CIE 1931 is still a chromaticity diagram often used as reference.

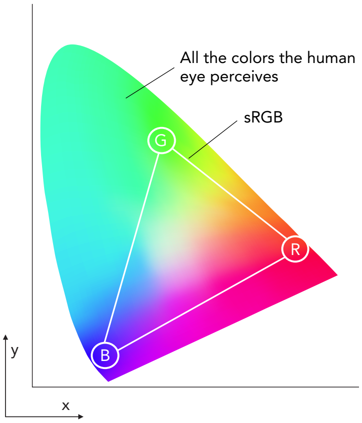


Figure 22-7. The sRGB gamut within the CIE 1931 chromaticity diagram. The letters R, G, B identify the corners of the gamut, where the colors are at their purest within that system.

Color Gamut

Computer monitors, projectors and displays can only reproduce some of the perceivable colors. When measuring the three points closest to the pure R, G, B colors, a display can produce and plot them within the chromaticity diagram. The triangle obtained will define all the colors the display can produce. This is the color gamut of the display (Figure 22-7).

From a mathematical point of view, a gamut is a subset of the color space. The bigger the gamut, the bigger the palette of colors of the display.

RGB and CMYK: What is the Difference?

RGB (Red, Green, Blue) and CMYK (Cyan, Magenta, Yellow, and Key or black) are two terms associated with color mixing and matching. RGB is used in the digital world and CMYK in the printing world. The former is an additive model, the latter a subtractive model. See Figure 22-8.

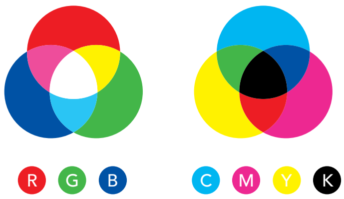
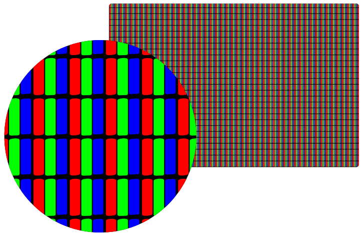


Figure 22-8. RGB is an additive model used with light emitting devices, whereas CMYK is used with light reflecting substances, such as those used in printing and dye making.



RGB Pixels

In lighting, red, green and blue are additive colors. They produce white light when the respective emitted light waves are added together.

In digital devices the three additive colors Red, Green and Blue are created by a current-activated phospho-luminescence. Each RGB sub-element will create a color. The three sub-elements compose a pixel. Many such pixels are assembled in a dense array or mosaic to form a picture, hence the terms PPI, or Pixel per Inch as unit of measurement.

In printing, painting and other printed media on the other hand, pigments are added, as dots (DPI – Dot per Inch), to a substrate. Some light waves from ambient lighting are absorbed and the rest reflected from this substrate. The subtractive colors used in printing are generally Cyan, Magenta, Yellow, and Black. Adding all first three colors together produces black, and in this model lighter colors are produced by removing pigments.

Printing substrates such as paper do not emit light, which makes the CMYK model not as bright as the RGB, hence limiting the whole color range.

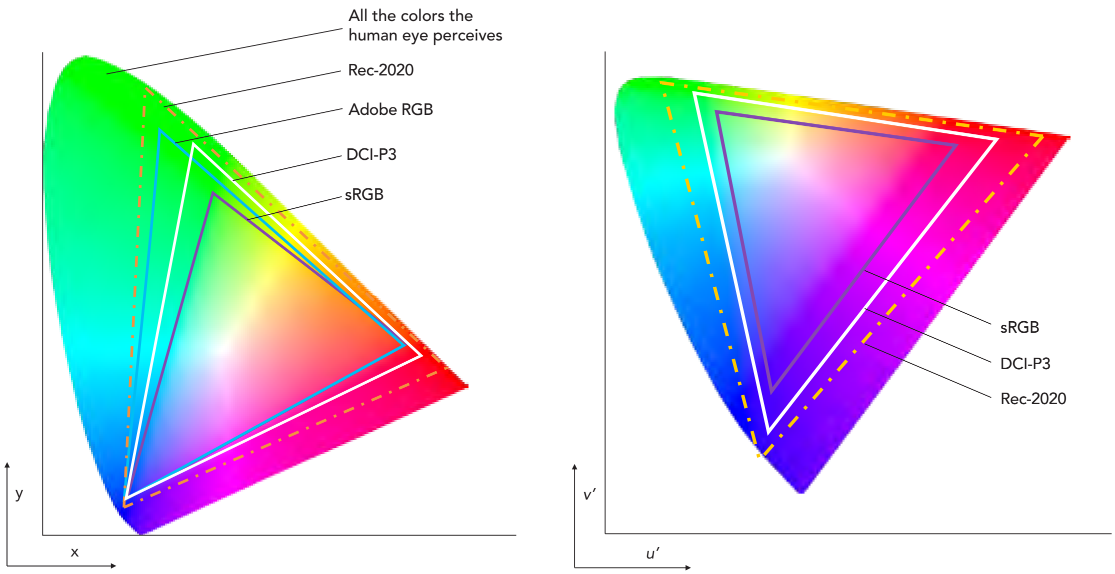
Standard Color Gamuts

Color gamut standards are as follows, and illustrated in Figure 22-9.

sRGB – "standard Red Green Blue," introduced in 1996, is an international standard very widely used in the digital industry. It is an essential way to communicate about colors for digital cameras, scanners, printers, projectors or digital displays. Colors displayed on internet web pages are defined in sRGB.

NTSC – The NTSC color gamut was developed at the same time as television, in 1953, by the National Television Standards Committee. It is a wide gamut, similar to Adobe RGB, but with red and blue values varying slightly. This gamut is mainly used for comparison, rating monitors as a percentage of the NTSC color gamut. Most computer monitors will display between 70 and 75% of the NTSC color gamut, and 72% of NTSC is roughly equivalent to 100% of the sRGB color gamut.

Figure 22-9. sRGB, DCI-P3, Rec 2020 and Adobe RGB gamuts represented within CIE 1931 and CIE1976.



Adobe RGB – It is an enhanced color gamut compared to the sRGB color gamut. It is bigger, at 52.1% of the CIE 1931 chromaticity diagram. It is advantageous for color printing, facilitating more vivid printed colors. Adobe RGB, however, requires software supporting this standard as well as an adapted digital display.

DCI-P3 – Introduced by Digital Cinema Initiatives (DCI) to fit the range of colors used in cinema, DCI-P3 has 45.5% of the color space of CIE 1931, 25% more color space than sRGB and about 4% less than NTSC. Since more and more movies are displayed on digital displays, manufacturers have started to align their color arrays to DCI-P3 to have better image rendering than when using sRGB. DCI-P3 could likely become the new standard for devices, websites and software.

Rec 2020 – As technology evolves and display makers try to produce wider color gamuts, new standards emerge, such as Rec 2020 for UHD TV (Ultra High Definition 4K and 8K). At this point no display has yet fully covered the Rec 2020 color gamut.

Color Range and Dynamic Range

The color range of a display is defined by its color depth, which is the total number of colors that can bedisplayed by the device. A color depth is expressed in bits, typically 8 or 10 bits per pixel to represent a specific color. The more bits per pixel, the higher the color variety and image quality. Using the three primary colors, 8 bits can render 24 bits (3 colors x 8 bits) of color per pixel. For each color, there are 256 levels on luminosity or color shades. Calculating the sum of 256 x 256 x 256 equates to over 16 million discrete colors, already much more than the 10 million colors the eye can perceive.

In a 10-bit image we could have 1024 shades for each color; thus 30 bits of colors, giving more than a billion colors.

Dynamic range is the ratio between maximum and minimum in light intensities or the difference between the brightest white and the darkest black the display can produce. In a low dynamic range there is less difference between black and white, while in high dynamic range (HDR), there is a larger difference.

The rendering of the colors will depend on different aspects. At present, the major display technologies used are LCD (LED backlit), OLED and QLED panels.

LCD panels produce light through the LED pixels in the backlight unit as liquid crystals change shape; they are challenged to show very dark blacks, use the same amount of power for bright and dim images, are generally brighter than OLED and have less saturated colors.

OLEDs, organic electroluminescent diodes, produce light directly from current-activated organic compounds that make up the emissive layer and conductive layers. The color of light will depend on the type of organic molecule or polymer used, and often several types of organic films can be placed in the same system. A great advantage of OLEDs is their flexibility. OLED disposition on flexible plastic allows for more applications, such as foldable smartphones. OLED panels have perfect blacks (no light emitted), brightness uniformity, saturated colors and use less power for dark scenes but more power for light scenes relative to LED technology.

Recently introduced to the display market are QLEDs. They are LED displays with quantum dots instead of green and/or red phosphors. The concept is to replace phosphors that would otherwise be inside the LEDs with a luminescent quantum dot film made of semi-conductor nano particles with controllable color output. The result is more saturated color with a wider gamut, making LCD panels competitive with OLED in this regard.

The color gamut of the display is an important factor in the rendering of images. Most modern displays are capable of supporting the sRGB color space and more and more tend to display the colors of the DCI-P3 color space. However, most displays do not cover 100% of these color spaces, which partly accounts for color accuracy differences observed from one display to another. The other cause of accuracy differences is panel variation, which can be addressed via calibration to a given color space.

Color Temperature and Correlated Color Temperature (CCT)

Along with color gamut, display performance is also measured by color temperature. The overall color temperature helps indicate how close the white point of a display matches that of ambient light. Different light sources produce different colored lights. The difference can be expressed by a number, on the Kelvin scale, which is known as the color temperature. See Figure 22-10. Colors over 5000 K are said to be "cool" colors, with more blue tones, while colors in the range 2700-3000 K are "warm" colors, with more yellow and red tones.

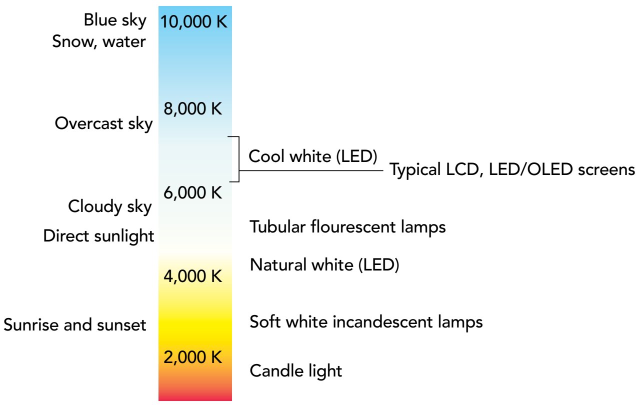


Figure 22-10. Kelvin scale for color temperature.

Correlated color temperature (CCT) is a way to characterize a color by matching it with the temperature of a blackbody radiator, a body that radiates light with a specific color at defined temperature. For example, a piece of iron when heated will glow red, then orange, yellow and blue-white at defined temperatures. The Planckian locus (Figure 22-11) reproduces the temperatures of blackbody radiators. Each color temperature represents a unique point on the locus, however each correlated color temperature (as shown by looking at the isothermal lines on the locus on Figure 22-11) can be attributed to different colors near the locus.

To match the light emitted by blackbodies, the CIE illuminants series D emulate the spectral power distribution of natural daylight, and have color temperature situated on the blackbody temperature curve. Among the D illuminants, D65 has been defined with a color temperature of about 6500 K (6504 K to be exact), corresponding to the color temperature of the sky around noon. It is used as a reference for white across many industries and applications, as different spectral distributions of white can lead to different

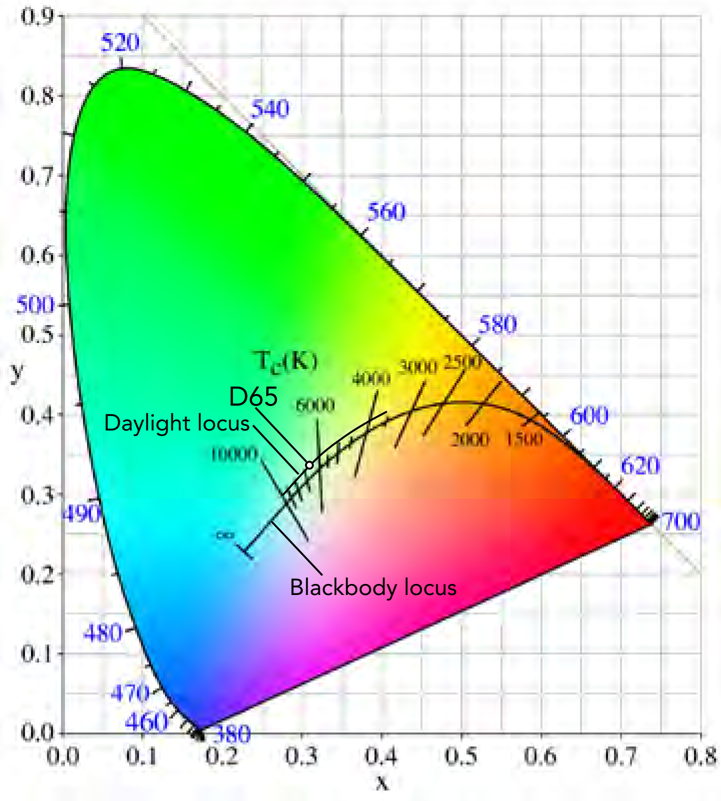


Figure 22-11. Color of light emitted by a blackbody at given temperatures, also called Planckian locus, used to calculate CCT of white light sources.

shades. D65 defines a specific spectral distribution and a color point, and is one of the standards used for display calibration, where the combination of each RGB primaries set at a level of 255 emit a white color, which must match D65.

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Technical Approaches to Limiting HEV Light in Displays

There are a number of approaches to limiting HEV light in displays, all aimed at reducing the potential of toxic blue light exposure. Some of these approaches can be implemented in after-market solutions, like screen protectors or implemented directly into the display.

Regardless of method, the primary requirements remain consistent:

1. Limit HEV light in the region of the display emission spectrum of most clinical concern, 415-455 nm.
2. Minimize impact on display color performance.
3. Minimize impact on display luminance.

Software Solutions

Most desktop and mobile operating systems feature a software option to minimize HEV light. These applications typically have some level of configuration, allowing for varying levels of HEV light, and automatic scheduling for evenings or user specific times of day. The apps reduce the blue spectral emission, which in turn reduces HEV light. While the reduction may be significant, so is the impact on color performance. In default modes for example, the display of a Windows® PC may experience a greater than 2000 K decrease in CCT and a greater than 25% decrease in luminance. Figure 23-1 is an example of how such a reduction of blue light can shift color in a display so that the

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Paul Herro, COO of Eyesafe, has led many successful first-of-kind market introductions of innovative technology solutions. Prior to Eyesafe, Paul was General Manager at Carestream Advanced Materials leading a new growth initiative developing optical films for the display industry.

Herve Gindre has 37 years in the electronics, semiconductor and display materials industries in Europe, Asia and the US. He previously served as VP/GM for 3M electronics materials and display materials businesses.

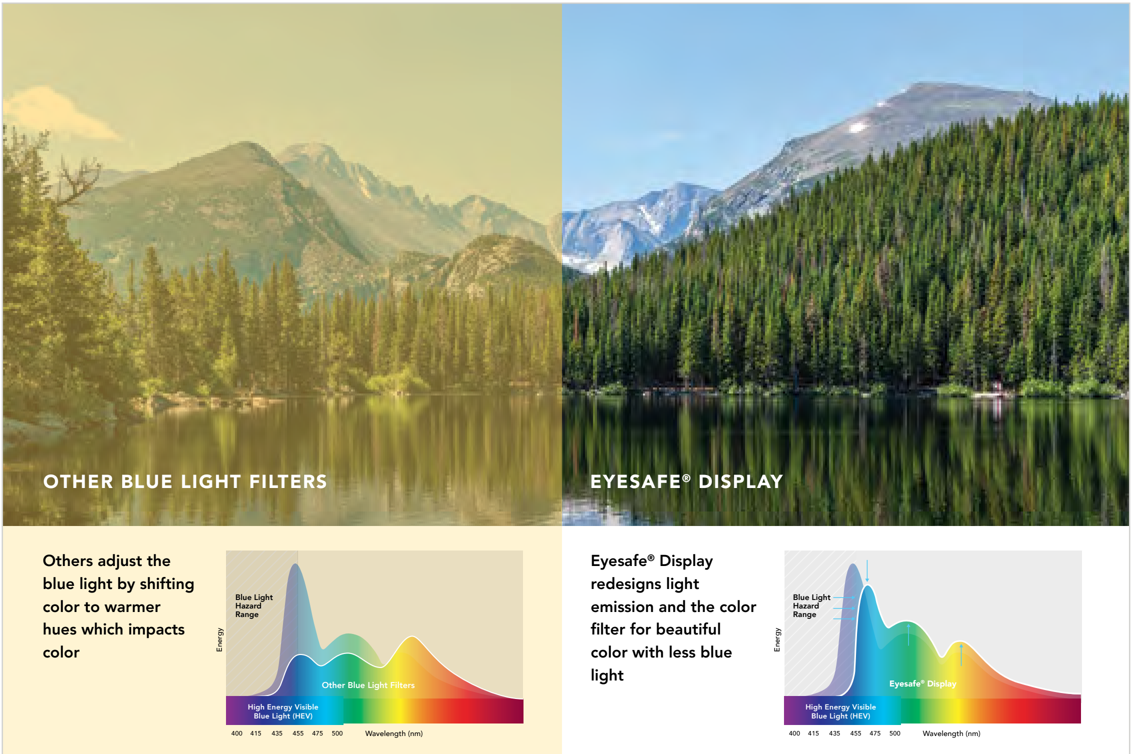


Figure 23-1. Software solutions do provide significant reduction in HEVL. They can be scheduled to activate in the evening before bed. The drawbacks include significant impact to color performance, and they are usually turned off.

resulting image will appear yellow or amber in color with noticeably less brightness and contrast. While these apps can be scheduled to turn on, they are off by default, and provide no HEV light limiting during the day.

Advanced Materials Solutions

Advanced materials can be used to modify the light emitted from displays. The vast majority of these materials are light absorbing dyes that are implemented in a number of different methods, typically thin film coatings, in after-market screen protectors. The absorption peaks of these solutions vary differently in the market, as do the results. These solutions can be segmented into broadband filters, broad blue filters and blue notch filters.

Broadband filters absorb light uniformly across the entire color spectrum. While these filters effectively limit HEV light in the region of clinical concern, overall color and luminance is significantly impacted. These thin film coatings appear grey. The resulting image is significantly less bright, encouraging users to increase brightness and, for mobile devices, use batteries at a faster rate.

Pros: reduction in HEV light

Cons: significant impact to display brightness

Broad blue filters absorb light in a broad blue range, typically targeting display emission from 500 nm and below. These filters effectively limit HEV light but have a significant impact on overall display color performance and display luminance. These thin film coatings appear yellow and when used, the resulting image appears yellow or amber and much less bright.

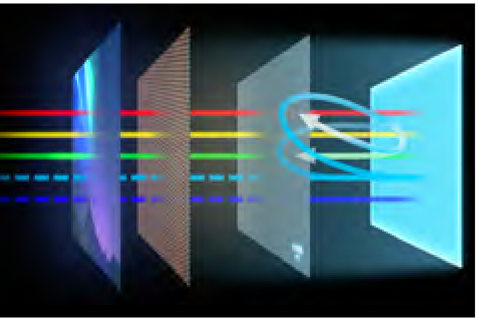
Pros: reduction in HEV light

Cons: significant impact to color and display brightness

Blue notch filters feature an absorption peak targeting the HEV light region and the blue light spike. The advantage to blue notch filters is they have less an impact on overall color performance. With blue notch filters, the design goals should be to target the most clinically relevant region (415-455 nm, specifically 435-440 nm) with minimal impact to total blue to limit overall display color performance. While an improvement to broadband filters, blue notch filters still have a noticeable impact on display color and luminance.

Pros: reduction in HEV light

Cons: impact to color and display brightness



See page 183 for more information on Eyesafe DTX Technology

Eyesafe® DTX

Eyesafe DTX combines a specialized blue notch filter with overall emission spectrum color management. It maximizes the benefits of a blue notch filter while applying additional specialized light absorbing materials to balance color. Eyesafe DTX is highly optimized for display applications to balance a maximum limitation of clinically relevant HEV light while limiting the impact to overall color performance. Additional light absorbing materials manage the entire color emission spectrum of a display to minimize impact to RGB primary locations, white point, color accuracy and display luminance.

Pros: reduction in HEV light with minimal impact to color performance and display performance.

While the above filter materials are most prevalent in after-market solutions like screen protectors, Eyesafe is actively implementing Eyesafe DTX into displays. Depending on display manufacturer preference, Eyesafe DTX can be implemented in a number of approaches including:

- Eyesafe DTX coating on an existing optical film in the display stack, such as the diffuser
- Additional Eyesafe® thin film coating in the display stack
- In each of these implementations, the results are similar in that there is effective limitation of HEV light with minimal impact to display color performance and display luminance.

Light Source Solutions

Displays in today's consumer electronics devices have two primary sources of light: LED backlights and organic light emitting diodes (OLEDs). These light sources themselves can be optimized to limit HEVL emission from the display.

OLED displays have gained some attention recently as exhibiting "low blue light". The primary rationale behind this claim is that the blue peak of OLED displays is shifted slightly toward the wider bandwidth region, peaking around 450-455 nm. With the blue peak shifted more outside of the toxic blue region (415-455 nm), it is expected that there is less overall blue light emission. While there is an overall impact to lower blue light emission, it is important to look at a number of factors when determining them. As described earlier, these factors include:

- Blue light hazard, emission energy weighted by the blue light hazard function as defined by ANSI Standard Z80.3
- Total Blue Light, light emission from 380-500 nm
- High Toxicity Blue, light emission from 415-455 nm

The blue light hazard above takes into account the importance of the blue light hazard function. And all take into account the overall intensity (or brightness) of the display. As Figure 23-2 shows, many OLED displays that promote "low blue light" because of the shift in location actually exhibit a higher blue light hazard and higher toxic blue emission than LED backlight displays.

Pros: shift in blue peak results in lower total blue light

Cons: higher display intensity results in high blue light hazard and increased high toxicity blue

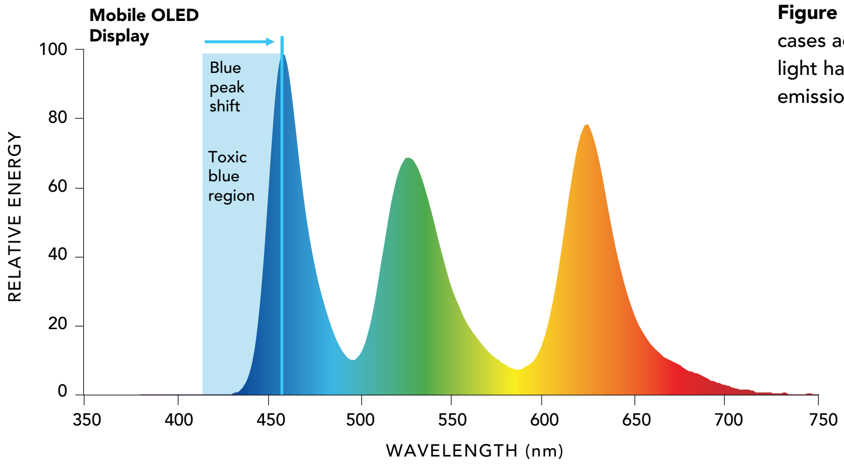


Figure 23-2. OLED displays in some cases actually exhibit a higher blue light hazard and higher toxic blue emission than LED backlight displays.

LEDs in LED backlight displays can be optimized to minimize the intensity of the blue peak or shift the blue peak toward the wider wavelength region. Typical LEDs peak around 445-450 nm. Optimized LEDs have shown this peak can be slightly shifted several nm decreasing the overall blue emission. This solution is similar to an OLED approach but less drastic. In some cases, there will be a significant impact to overall display performance requiring a redesign of other parts of the display like the color filter. Finally, this solution can be expensive as the specialized LEDs required are manufactured in much lower volumes than typical LEDs for display applications.

Pros: shift in blue peak results in lower total blue light

Cons: may require redesign of display components, costly

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Eyesafe® DTX Technology for LED Backlit Displays

Utilizing High-Energy Blue Light to Improve Display Performance

New materials for LED backlit displays can help reduce the emission of shorter wavelength blue light. This can be done without sacrificing luminance or color gamut.

Addressing potential blue light risk from digital devices requires a closer look at the LED blue light spectrum. Not all wavelengths within the blue light range represent equal risk. The Blue Light Ratio (BLR) categorizes toxicity as either level 0 or 1 by wavelength, as defined by the ANSI Z80.3-2018 standard. The toxicity potential peaks at 435 to 440 nanometers (nm) but extends at decreasing levels throughout the blue range of the spectrum.

Blue Light Ratio and Blue Light Toxicity Factor

Display makers have historically evaluated blue light hazard as a ratio of light energy originating within the 415-455nm range compared with the energy across the full blue range (400-500nm), commonly referred to as the Blue Light Ratio (BLR). This was perhaps done to ease the design for the display manufacturers, simplifying it to a binary "toxic or not" scaling within a truncated range of 415nm to 455nm.

The shortfall of assessing blue light risk as BLR becomes evident in looking at the blue light wavelengths that fall just outside 415-455nm as shown in Figure 24-1. For example, at 460nm, the toxicity factor is 0.80, indicating potential risk that is unaccounted for when relying on BLR as a primary metric of blue light exposure risk.

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Davis Lee, CSO of Eyesafe, formerly Senior Vice President at Dell Technologies where he served as the General Manager of the company's global display business. His nearly 25 years at LG Display culminated as SVP of Global Sales & Marketing, leading LG Display to be the #1 display company worldwide and launching OLED in mobile and automotive applications.

Derek Harris, PhD and VP R&D at Eyesafe received his PhD in Chemical Engineering from Georgia Institute of Technology. He has over 30 years spanning experience in liquid and vacuum deposited coating processes and formulation with the early parts of his career focused on electrochemistry.

Figure 24-1. Various wavelengths are assigned a toxicity factor in this table, but a relatively narrow band is designated level 1 on the BLR scale.

	EMISSIONS (nm)	BLUE LIGHT HAZARD FUNCTION*	BLUE LIGHT RATIO (BLR)	BLUE LIGHT TOXICITY FACTOR (BLTF)
UV	200-380	0	0	0
HIGH-ENERGY VISIBLE BLUE LIGHT	380	0.01	0	0.01
	385	0.01	0	0.01
	390	0.03	0	0.03
	395	0.05	0	0.05
	400	0.10	0	0.10
	405	0.20	0	0.20
	410	0.40	0	0.40
	415	0.80	0	0.80
	420	0.90	1	0.90
	425	0.95	1	0.95
	430	0.98	1	0.98
	435 Peak	1.00	1	1.00
	440 Peak	1.00	1	1.00
	445	0.97	1	0.97
	450	0.94	1	0.94
	455	0.90	1	0.90
	460	0.80	0	0.80
	465	0.70	0	0.70
	470	0.62	0	0.62
	475	0.55	0	0.55
	480	0.45	0	0.45
	485	0.40	0	0.40
	490	0.22	0	0.22
	495	0.16	0	0.16
	500	0.10	0	0.10

*American National Standards Institute (ANSI) Z80.3 Table
International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines, most toxic portions of the blue spectrum

As research progresses, organizations such as TÜV Rheinland, a global leader in independent inspection services and low blue light certification, are increasingly adopting Blue Light Toxicity Factor (BLTF) as a better benchmark for blue light risk. BLTF factors in the entire range of blue light hazard scaling factors (Fig. 24-1).

The equation for BLTF is as follows:

$$\mathrm{BLTF} = \frac{100}{683} \times \frac{\int_{380}^{780} L(\lambda) \times B(\lambda) \times d\lambda}{\int_{380}^{780} L(\lambda) \times \bar{Y}(\lambda) \times d\lambda}$$

In which:

- $d\lambda = 1$ nm
- $L(\lambda)$: spectral radiance in $\mu W \cdot cm^{-2} \cdot nm^{-1}$
- $B(\lambda)$: Blue Light Hazard Function
- $\bar{Y}(\lambda)$: CIE 1931 XYZ luminosity function
- 683 - maximum spectral luminous efficacy constant (683 lumens per Watt at 555 nm)

Another way to view the improvement possible with BLTF versus the BLR is shown in the curve in Figure 24-2. This shows both calculations for a given display and compares them to the Blue Light Hazard (BLH) function. If you consider the difference between the two ratios and the BLH as error, one can see that BLR has an error more than 44% in predicting the toxicity of a particular display. With today's technology, there is no reason to settle for this kind of error.

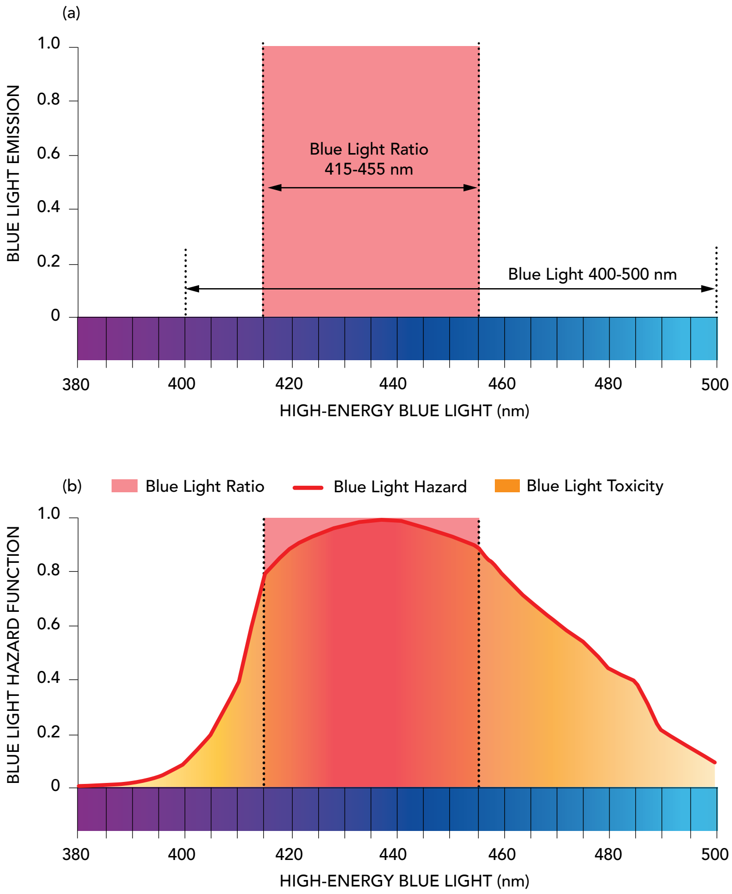
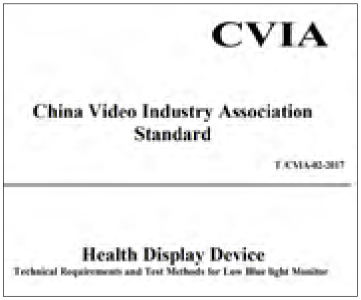


Figure 24-2. Differences in methods to characterize blue light toxicity. BLTF factors in more of the potential toxicity.

Approaches to managing the blue light hazard of a backlit LED display must balance front-of-screen performance characteristics (color brilliance and accuracy, switching rates, working life, etc.) with an effective reduction of harmful blue light.



CVIA, the China Video Industry Association had also adopted a ratio similar to BLTF in their 2017 standard for low blue light displays. In that standard, the emission from the display is weighted against the same blue light hazard scaling factors listed above in Figure 24-1 and then divided by the total luminance from the display.[1]

Eyesafe® DTX Technology

Eyesafe DTX is the recently announced marketing name for the advanced low blue light protection described herein. The problem approached is to find a more effective, cheaper, and easier way to reduce blue light hazard inside the display than existing technologies. The existing technologies include software and low blue light LED solutions. Aftermarket filters are not considered as they are not part of the base display product.

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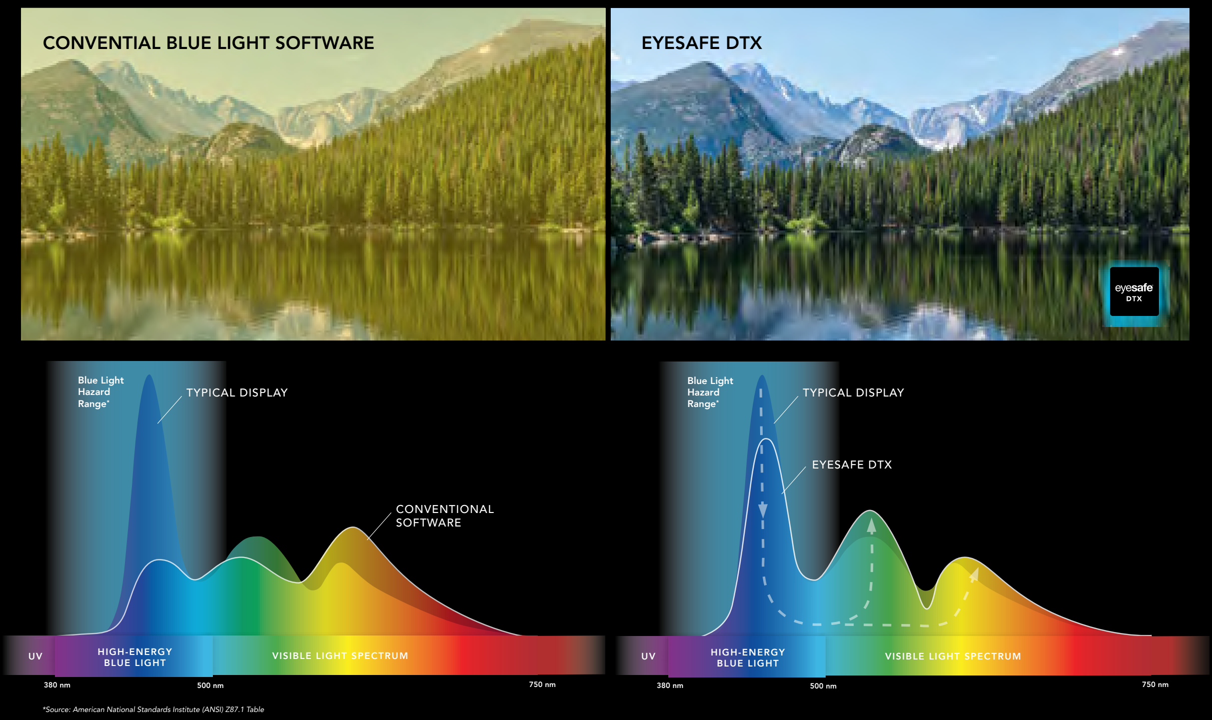
See Figure 23-1. Software-based screen adjustments by themselves can impact to color performance.

Software solutions, whether implemented in display scalar firmware or device operating system/application software, all fundamentally work on the assumption that the blue value in RGB can be reduced by some arbitrary scaling amount. This brute force method causes a rapid deterioration in CCT and white point. Users are likely familiar with the yellowish coloration of the display with this feature enabled. As a result, users may shy away from this solution, especially for applications requiring better color.

Low blue light LEDs are generally white LEDs that have shifted the peak blue wavelength higher, generally to 455 nm and above. Many complexities are introduced which lead to other changes being required in the LED's phosphors and the panel's color filter. At longer blue wavelengths, luminous efficacy, and therefore power efficiency, are lost due to a reduction in quantum yield of the phosphors. As blue wavelengths increase, due to color filter design, blue intensity front-of-screen increases. This causes a counter-intuitive increase in CCT and changed white point.

Additionally, as blue emissions are shifted more toward the green area of the spectrum, the blue/green valley required for a good color gamut is compromised, resulting in less color gamut coverage overall. These are a few of the complexities that lead to an expensive and time-consuming redesign of the panel to use more costly phosphors with different peak wavelengths, quantum efficiencies, and Full Width Half Maximums (FWHM).

This summary of the low blue light LED approach is by no means complete, but illustrates the difficulty and expense involved. Perhaps the primary flaw, however, is that actual toxicity is not reduced significantly according to a review of current Eyesafe® Certification test results. Rather, the wavelength is shifted minimally to move 50% of the energy outside of a specific window targeted by the BLR metric. Feasible decreases in actual hazard are minimal compared to Eyesafe DTX technology presented here, typically less than a third.



Convential software solutions typically adjust high-energy blue light by shifting color and luminance, compared to Eyesafe DTX, which utilizes blue light toxicity to improve display performance and energy efficiency.

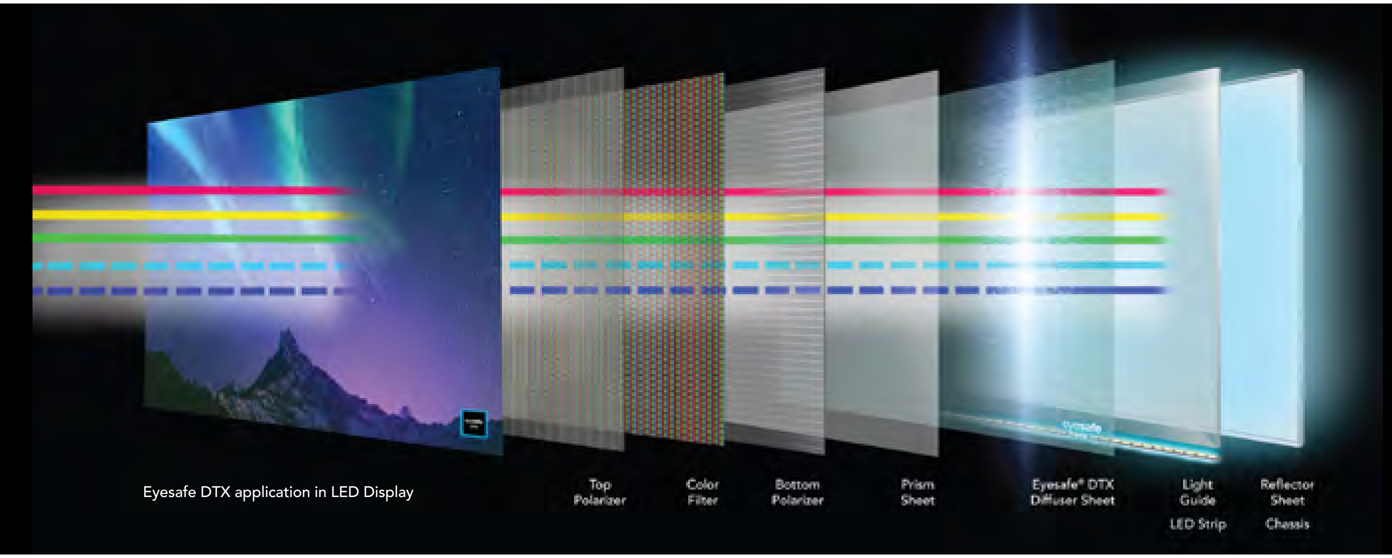
Cost-Effective Approach that Minimizes Redesign

Eyesafe DTX technology is superbly effective at reducing blue light hazard and compensates for color change with color correction. By adding proprietary materials to the backlight, problematic source energy is absorbed directly rather than being shifted several nanometers.

Depending on the display design, one approach includes adding coating materials to the smooth side of the diffuser. Light absorbing materials are augmented with proprietary materials that recycle toxic blue energy to green for optimal luminous efficacy.

Eyesafe DTX materials can achieve these goals:

1) Decreased blue light hazard/toxicity (approximately 3-times more than LED solutions)
2) Increased color gamut coverage
3) Balanced CCT and white point
4) Increased luminance and power
5) Simplified cost-effective drop-in technology



Eyesafe DTX application in LED Display

Results Show Reduced BLTF

The results can be measured on existing panels by simply replacing the diffuser with a sheet of similar diffuser material that has been coated with a formulation of Eyesafe® materials.

Tables 24-1 and 2 compare the before and after performance metrics of two commercially available panels chosen for their differences. The first is a 31.5 inch UHD wide color gamut (WCG) flat panel from Company A that is sold into the content creation market. The second is a 27 inch FHD sRGB curved panel from Company B that is sold into the gaming market.

All spectral measurements were taken with the same panels, driver electronics, and spectroradiometer. Panels were measured in native mode, with no scalar adjustments for color. Scalar-supplied voltages controlling LED current were left unmodified between measurements for the most accurate comparison of color and brightness. CIE 1931 coordinates are used.

As Table 24-1 indicates, for the WCG panel, Eyesafe DTX reduces BLTF significantly. In addition, Eyesafe DTX increases sRGB and DCI-P3 gamut coverage and maintains a reasonable white point. DCI-P3 coverage increases by up to 2.0%. Luminance increases by up to 4.8% with the same input power.

Table 24-1. 31.5 inch Wide Color Gamut Panel Results

(A) 31.5” UHD Flat	Original Panel	Eyesafe DTX
BLTF	0.084	0.072 (-14.3%)
Color sRGB	99.8%	99.9%
Color DCI-P3	93.4%	93.6%-95.2% (up to +2.0%)
Luminance	390	390-409 (up to +4.8%)
CCT	6500K	6000K
Ease of Implementation	N/A	✔

As shown in Table 24-2, for the sRGB panel, Eyesafe DTX reduces the BLTF significantly, up to 23%. sRGB and DCI-P3 gamut coverage is increased while maintaining a reasonable white point. sRGB coverage increases up to 1.7% (and near 100%) while DCI-P3 coverage increases up to 4.6%. Luminance increases by up to 7.9% with the same input power.

Table 24-2. 27″ FHD sRGB Curved Panel Results

(B) 27″ FHD Curved	Original Panel	Eyesafe DTX
BLTF	0.096	0.074 (-23.0%)
Color sRGB	98.1%	98.7%-99.8% (up to +1.7%)
Color DCI-P3	78.0%	78.5%-81.5% (up to +4.6%)
Luminance	257	257-278 (up to +7.9%)
CCT	7300K	6000K
Ease of Implementation	N/A	✔

Figures 24-4 and 5 show the before and after spectra for each panel respectively, with curves for formulations of maximum luminance and maximum color compared to the original panels.

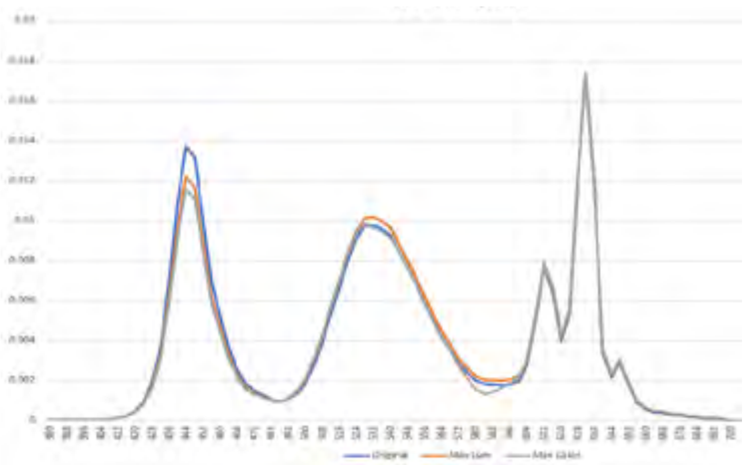


Figure 24-4. Original 31.5″ vs. Eyesafe DTX Max Luminance, Max Color

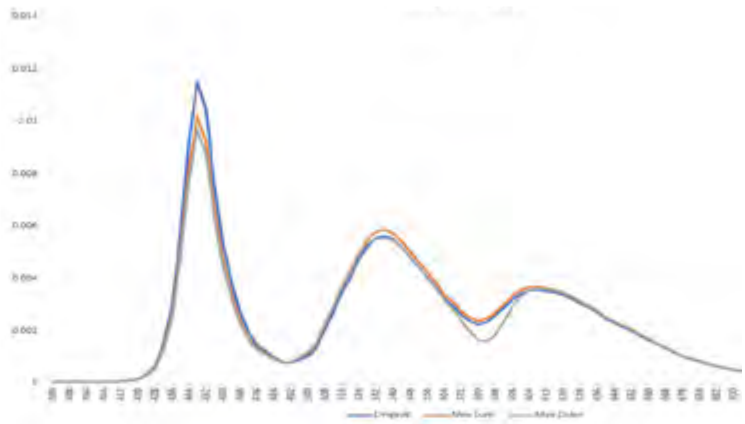
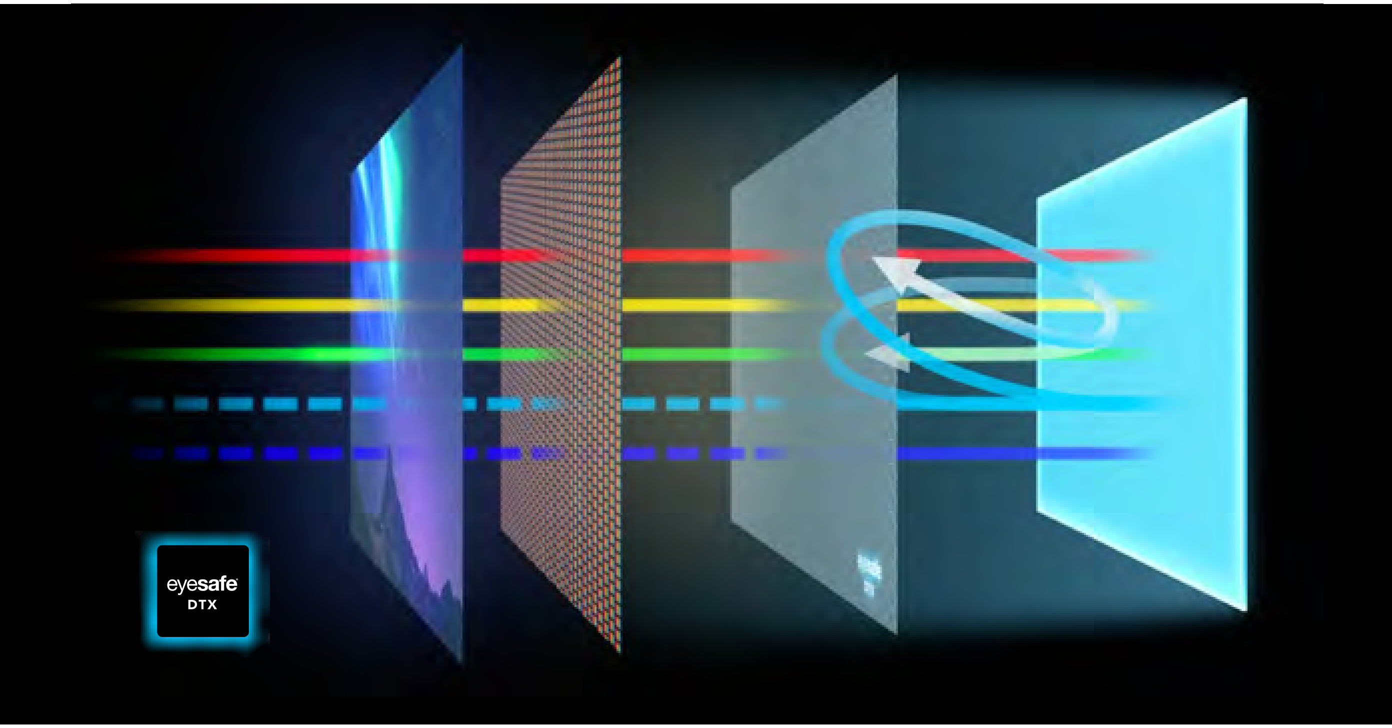


Figure 24-5. Original 27″ vs. Eyesafe DTX Max Luminance, Max Color

In conclusion, as awareness of low blue light risk increases among consumers and regulators, affective solutions need to be part of display panel designs. Health and wellness has become one of the primary purchase considerations for IT products.[2] The BLTF metric is proving to be better at measuring true hazard.

The Eyesafe approach, as illustrated in the sample results, demonstrates a superior low blue light solution applicable to today's commercially available technologies. Eyesafe DTX opens the doors to more and better low blue light solutions, with fewer compromises, and at lower cost. Initial estimates suggest about three times the toxicity reduction of LED solutions at one half the cost. Displays with Eyesafe DTX can help reduce operating costs and overall energy load on our power generation infrastructure when compared to alterative approaches. All of this can be accomplished while still meeting customer experience expectations for brightness and color.

Eyesafe DTX is a patented technology that absorbs and recycles blue light energy to the red and green parts of the color spectrum for improved luminance without color distortion.



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The Low Blue Light Technology of OLED TV

OLED TVs are better at addressing eye comfort issues.

Digital devices are used in every aspect of our lives, for gaming, sports, health, fitness, education and more. Our digital connectivity has escalated even further with the onset of COVID-19 in 2020, as the world moved to deliver programs and information through digital media to preserve the safety of the audience. These factors combined with others makes blue light emissions from televisions a growing area of concern not only among eye care professionals but among display manufacturers.

About the Author:

Jang Jin Yoo is currently research fellow at LG Display. He received his BS and MS in chemistry and physics at Sogang University, Korea, in 1993 and 1996. He also studied color science at Leeds University, UK, for his PhD. He has more than 25 years of research experience in display technologies and display picture quality. Specialty areas include picture quality evaluation, enhancement and international standardization.

Smart TV Technologies

The fastest growing TV segment is smart TVs. The global smart TV market grew from almost $150 billion to nearly $200 billion in 2021. An equally amazing trend is the sheer size of these TVs. Only a few years ago a 55-inch TV was considered large.

For many consumers a 65-inch TV is now the minimum size they would consider. The larger TV segment of the industry is where you will find newer technology marketed with buzzwords like 8K, mini-LED, QLED and OLED.

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See Chapter 22 on Color Science for more on backlit LED, OLED and QLED

8K is generally considered to have better picture quality and resolution than 4K, with 33 million pixels compared to 8 million pixels in a 4K package. An 8K Ultra HD TV has double the resolution of 4K Ultra HD resolution, and it is 16 times the full HD resolution.

LG Display has been a driving force behind OLEDs, the most disruptive technology to hit the TV industry in nearly a decade. OLED TVs are unique because they do not use an LED backlight to produce light. Instead, light is produced by millions of individual OLED subpixels. The pixels themselves – tiny dots that compose the image – emit light, which is why it's called a "self-emissive" display technology. That difference leads to all kinds of picture quality enhancements.

OLED TV provides the user with better eye comfort and viewing experience.

Linking TV Watching to Eye Comfort and Overall Health

One of the benefits of OLED TV is its naturally low blue light emissions compared to traditional LCD TVs on the market. While maintaining perfect black, high contrast characteristics and excellent picture quality, an OLED TV provides the user with better eye comfort and viewing experience.

Healthier TV viewing could not come at a better time. The COVID-19 pandemic has driven TV viewership to new heights.

Two TVs of the same size can differ significantly in terms of eye comfort. The characteristics that can effect eye comfort include not only blue light but also flicker and glare.[1]

Healthier TV viewing could not come at a better time. The COVID-19 pandemic has driven TV viewership to new heights. According to the 2021 Deloitte Digital Media Report, 57% of those surveyed said that watching TV at home is one of their top three forms of entertainment.[2] Viewership of children's TV programming rose nearly 60% on a weekly basis during the early lockdown stages of the pandemic.[3] When we combine TV with other screen time activities for working, learning and entertaining, we find that adults in the US are spending up to 13 hours a day on screens—a significant increase from 10 hours a day in 2019.[4] Similar numbers apply to screen time and TV viewership across the globe.[5]

Blue Light Affects Circadian Rhythm

Excess exposure to high-energy blue light coming from displays is an area of concern among 94% of health care professionals according to a 2020 survey fielded by

UnitedHealthcare and Eyesafe.[6] Numerous studies point to blue light from displays as having the potential to cause digital eye strain and disrupt circadian rhythm.[7]

The causes of circadian rhythm irregularities can be complex. Chronic use of digital displays during the late evening or nighttime hours is often cited as one cause.[7] TV watching can trigger melatonin suppression, but as one study found, melatonin suppression can be significantly lower in a TV that emits half the blue light of a normal TV.[8]

See Page 29

See Chapter 4: Circadian Rhythm

How OLED TVs Mitigate Blue Light Risks

Breakthroughs in light source technology are proving that TV manufacturers do not have to compromise color brilliance and display performance to address health concerns associated with high-intensity blue light.

The energy emission curve of an LED, when compared to OLED, shows a high-energy spike in the blue light spectrum. See Figure 25-1. With LED backlit LCD display technology, the high energy spike is converted to other colors through filters. OLED on the other hand has a much flatter energy emission in the blue light range.

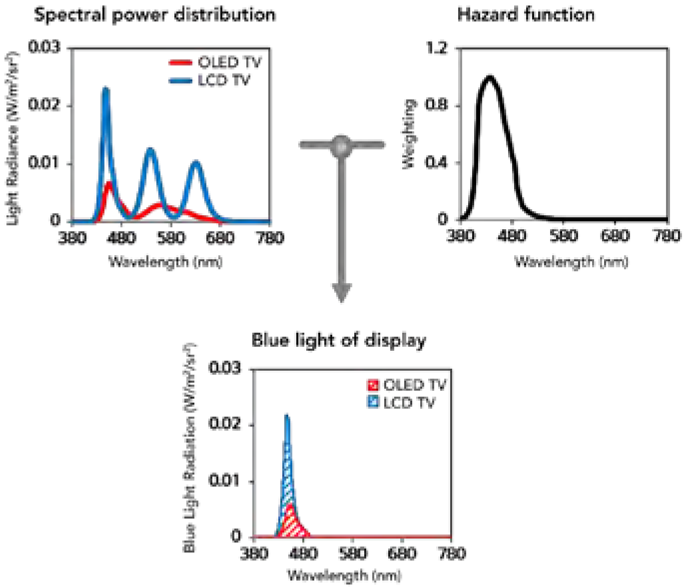


Figure 25-1. Comparison of OLED TV and LED backlit LCD TV luminance with the IEC 62471 standard blue light hazard function.

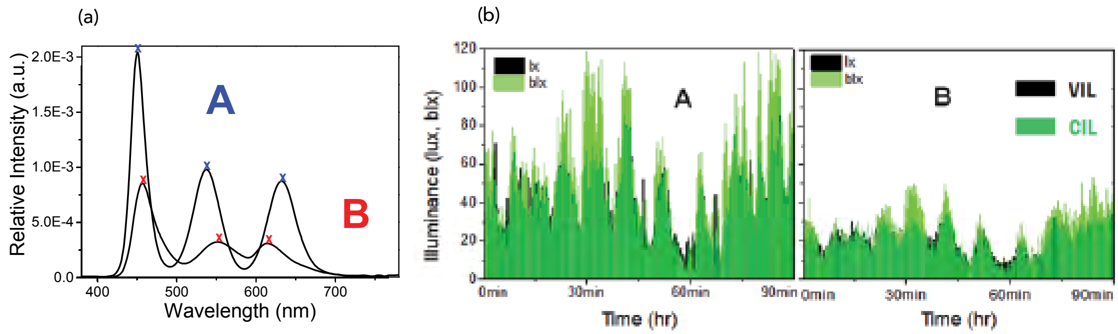
This approach is more like natural daylight. The composition of natural daylight varies by the time of day, but averages about 25% blue light. In comparison, the proportion of blue light for a 65-inch OLED TV is approximately 34%. That is the lowest in the TV industry. In addition, to maximize the contrast ratio of brightest white to black, an OLED TV does not have to emit as much light as an LED backlit TV.

An OLED TV can have a true black background simply by switching off the OLEDs in the non-image area. The backlight of an LED backlit TV, however, needs to be on to have any luminance in the image area, and that leads to light leakage around the images and the background.

A comparison of blue light emissions of two types of TVs was the subject of a study done at Kookmin University in Seoul, South Korea.[9] Volunteer subjects were outfitted with headsets that could detect blue light at eye distance from a TV. Measurements were made of two TV types at HDR mode. Calculations of visual illuminance (VIL) and circadian illuminance (CIL) effect found that visual illuminance for the type A TV was 3 times that of the type B TV, and the CIL index was 2.15 times. See Figure 25-2.

Tests done of subjects after watching the exact same content on both TVs in separate controlled sessions found that when compared to the type B TV, the type A TV showed these markers of higher blue light emissions:

Figure 25-2. The reduction of light within the blue-light hazard zone, as shown in graph (a) corresponded to a measured reduction of circadian illuminance (CIL) and visual illuminance (VIL) as shown in graphs (b).



- Decreased alertness
- More visual fatigue
- Higher level of arousal
- Less harmonious heartbeat
- Suppressed melatonin secretion at night (Figure 25-3)

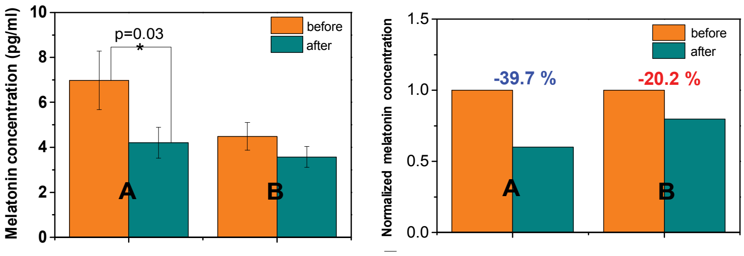


Figure 25-3. Graphs of melatonin secretion before and after watching TV type A and type B show almost twice the reduction of normalized melatonin secretion with type A. This can be the difference of a normal deep sleep and a disturbed one.

OLED TV by LG Display Meets Industry Leading Low Blue Light Standards

OLED TV displays from LG Display received low-blue light certifications from TÜV Rheinland in 2019. In March 2021, LG Display OLED received Eyesafe certifications on all the 4K and 8K models from 48-inch to 88-inch screens.

Ten ophthalmologists from the US and Europe participated in the Eyesafe certification. The proportion of harmful blue light measured was about 34% (65-inch OLED TV), which is the lowest in the industry, and satisfies the criteria of 50% or less. This is about half that of a premium LCD TV of the same size. LCD TVs generally show higher values than the criteria due to the strong light of the LED light source used as a backlight.

The proportion of harmful blue light measured was about 34% (65-inch OLED TV), which is the lowest in the industry, and satisfies the criteria of 50% or less.

In addition to TÜV and Eyesafe, OLED TVs also received "Low Blue Light Display (OLED) – 50% Below Exempt Blue Light Risk Group Limit" verification through the UL, a global safety certification company, in September 2019. The UL certification is also based on the IEC 62471 standard.

Blue Light Ratio:

$$L_B = \sum L_\lambda \cdot B(\lambda) \cdot \Delta\lambda$$

See Page 142

See Chapter 20 on Marketplace Standards

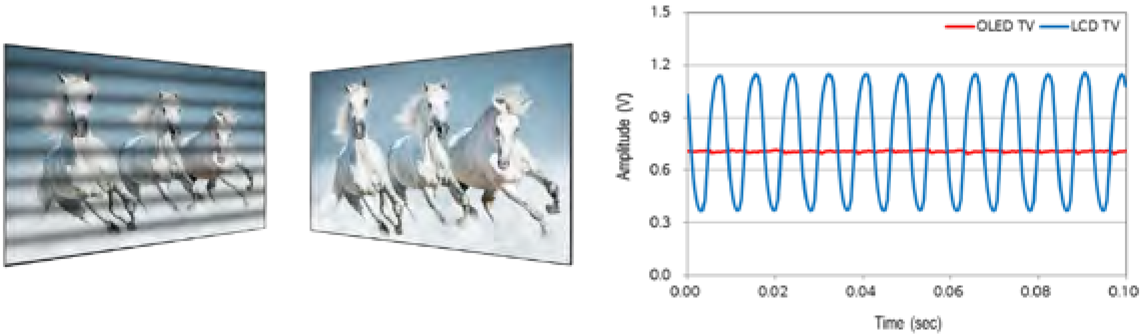
Through the UL verification, OLED TV was certified to satisfy not only the blue light standard but also ultraviolet and infrared standards. The UL-certified blue light is graded by multiplying the radiant energy between 300 and 700 nm by the Hazard Function. An OLED TV was evaluated at 50% compared to LCD TV (Figure 25-1).

Flicker Also Effects Eye Comfort

Flicker refers to a phenomenon that can cause eye fatigue due to the rapid but sometimes noticeable switching of pixels on a screen. See Figure 25-4 for a comparison of flicker.

Flicker is largely divided into visible flicker and invisible flicker. For the first time in the TV industry, OLED TV has been certified free of not only visible flicker but also invisible flicker through TÜV and UL. TÜV certification follows JEITA standards for visible flickers, and TÜV self-assessment method for invisible flickers.[10] On the other hand, UL follows the ISO international standard[11] for the visible flicker and the IEEE standard for the invisible flicker.[12] OLED TV satisfies all standards of TÜV and UL and is certified as “flicker free”.

Figure 25-4. Flicker can be measured as waveforms and can have a visible effect on picture quality.



Excess Glare Effects Eye Comfort

In March 2021, OLED TV received “Discomfort glare free” certification through UL. Discomfort glare is a concept defined by CIE (Commission Internationale de l’Eclairage), and refers to glare that has no effect on visual acuity but may cause discomfort due to brightness. For example, when watching a TV that is too bright in a dark bedroom, it corresponds to discomfort to the eyes or glare that is uncomfortable for a person. Contrary to the conventional perception that a brighter TV shows better picture quality, a TV that is too bright may cause eye strain.

As a method of evaluating glare, the UGR concept defined by the CIE was used. The UGR calculation includes factors such as background illuminance (illuminance for watching TV), display luminance, viewing distance, display size, and reflectance.[13] UL certification is given when the calculated UGR value satisfies the glare limit of 22 or less.[14-15]

All OLED TV models obtained UL certification, satisfying all UGR tolerance standards for glare evaluation in various viewing environments, which are general household illuminance values.

UGR Calculation:

$$UGR = 8 \times \log_{10} \frac{0.25}{L_b} \sum_{i=1}^{n} \frac{L^2_{s,i}\omega_{s,i}}{P^2}$$

OLED TVs Can Keep Us Healthier and Engaged

OLED TV is the only TV currently on the market with all three certifications for low blue light emissions, flicker and glare.

Television viewing improves the lives of people by giving them news and entertainment plus exposure to sights and sounds beyond what they might experience directly. With a global trend of increased use of display screens for work and play, and an upward trend of daily screentime that has accelerated due to the pandemic, we need technology that is sensitive to health concerns. By embracing the concerns of the health care community and actively working with standards organizations and expert services such as TÜV Rheinland, Eyesafe and UL, TV makers can deliver both a captivating experience and one that offers improved eye comfort.

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▶ **eyesafe.com/research**

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Products With Blue Light Protection

Global brands are responding to consumer concern about exposure to high-energy blue light with products that meet industry-leading requirements for low blue light emissions, designed for human health.

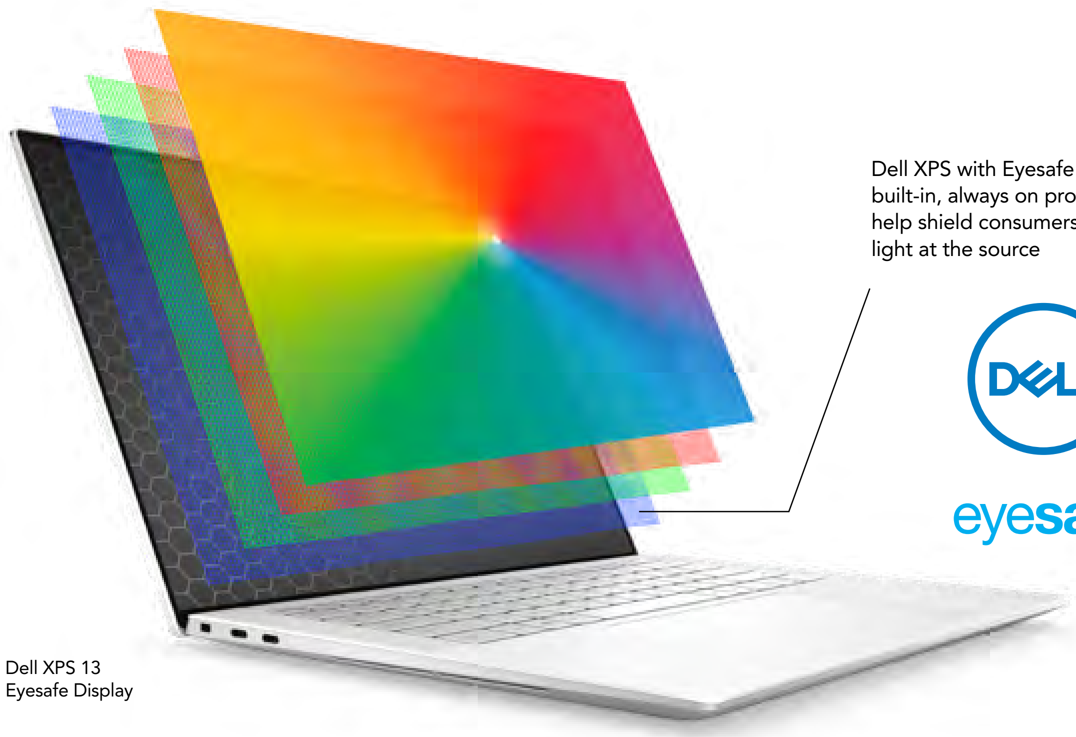
Dell Elevates the PC Experience with Flawlessly Designed XPS with Eyesafe

Dell was the world's first PC manufacturer to adopt Eyesafe and has since expanded it as the low blue light brand of choice for the XPS line of premium laptops.

The XPS line is Dell's most awarded line of devices celebrated for its best-in-class technologies, exceptional build and materials, and ability to blend both power and beauty.

Dell is taking that commitment one step further with Eyesafe, helping reduce high-energy blue light emissions while maintaining color performance and luminance.

Dell XPS meets Eyesafe® Requirements for blue light emissions, toxicity and color. The standards were developed with the guidance of a world-class team of eye doctors, engineers and scientists with decades of experience in electronics, display materials, and light management.

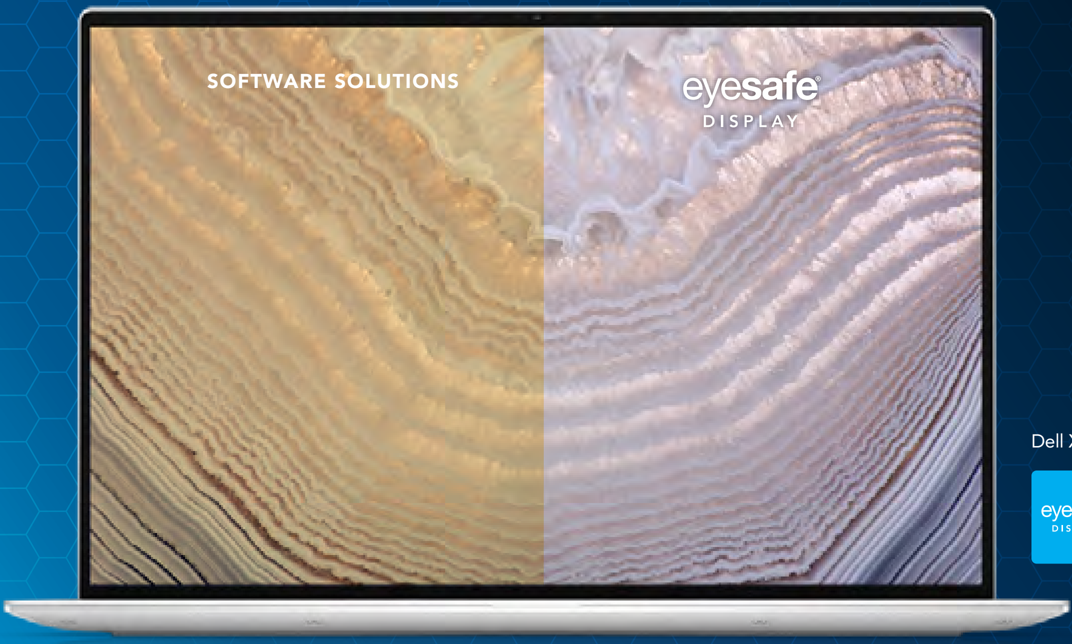


Dell XPS with Eyesafe Display offers built-in, always on protection to help shield consumers from blue light at the source

DELL

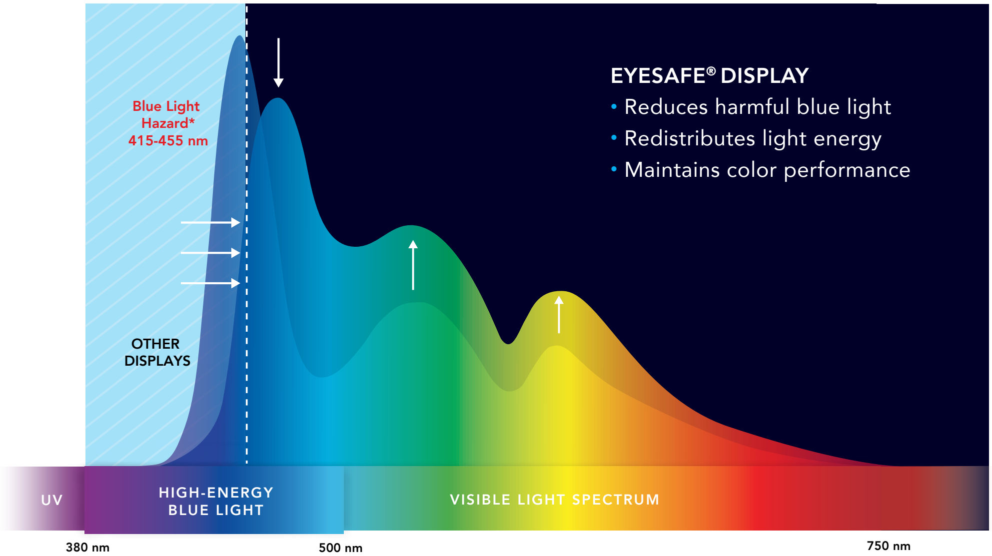
eyesafe®

Dell XPS 13
Eyesafe Display



Dell XPS 13

Compared to software solutions, which may impact color gamut, Dell XPS with Eyesafe® Display redesigns light at the hardware level, providing always-on protection.



* *Source: American National Standards Institute (ANSI) Z80.3 Table*

XPS LAPTOPS

Dell XPS 13 Laptop

13.4-inch laptop that's precision cut for a flawless finish in a small size. Designed with premium materials like carbon fiber, machined aluminum and Gorilla Glass, its durable, yet lightweight design offers InfinityEdge display for an immersive viewing experience, pinpoint accurate resolution and high color gamut and contrast ratio for vivid, bright and accurate color.

Dell XPS 13

Dell XPS 15

The 15.6-inch InfinityEdge display has an incredible 92.9% screen-to-body ratio with 100% Adobe RGB color. It delivers brilliance that makes your creations as vivid as your imagination with choice of 4K+ 100% Adobe RGB color or 3.5K OLED options provide vivid, bright and accurate color. It is precision cut to achieve a flawless finish in durable, lightweight design.

Dell XPS 15

Dell XPS 17

This is the most powerful XPS laptop ever, featuring a 17-inch InfinityEdge display with 11th Gen Intel® Core™ processors, up to NVIDIA® GeForce RTX™ 3060 graphics and a studio-quality display. Pinpoint accurate resolution and 100% Adobe RGB color gamut provide vivid, bright and accurate color. It is precision cut to achieve a flawless finish in durable, lightweight design.

Dell XPS 17

eyesafe.com/products

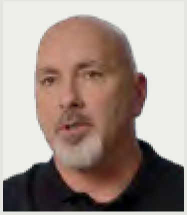
Dell and UnitedHealthcare Collaborate to Incentivize Healthier Screen Time

Starting in January 2022, UnitedHealthcare members will be eligible to receive discounts on qualifying Eyesafe® Display Dell XPS laptops. UnitedHealthcare is investing in new ways to help children and adults across the country reduce their exposure to blue light and support their overall eye health.

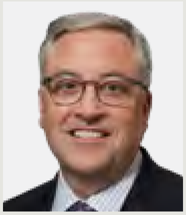
Learn more:
eyesafe.com/uhc

DELL eyesafe® United Healthcare

"XPS is all about industry leadership. We chartered a path in 2019 to make all XPS notebooks Eyesafe, and now we are collaborating with UnitedHealthcare and Eyesafe to bring XPS to UnitedHealthcare members."



Donnie Oliphant, Senior Director XPS Product Group, Dell Technologies



John Ryan, CEO, UnitedHealthcare Vision

"UnitedHealthcare and Dell are coming together to provide Dell XPS with Eyesafe product solutions at preferred pricing to UnitedHealthcare members. This is an industry first, and there has never been a more important time for members to be considering their exposure to high-energy blue light."

EYESAFE® CERTIFIED OLED TV

OLED Shines with Low Blue Light Beautiful Color

Increased screen time on digital devices may cause negative effects on our eyes. Eyesafe Certified OLED can be a solution to our extended screen time. Large amounts of high-energy visible blue light exposed to the eye may negatively affect ocular health. Eyesafe Certified OLED manages light at the source, selectively reduces blue light without compromising image quality and color.

- The Highest Standard for Low Blue Light
- Optimal Color Integrity
- Developed with Doctors
- Promotes Eye Health and Better Sleep

LG Display

World's First Eyesafe® Certified OLED TV Display

In late 2021, LG Display, the world's largest manufacturer of OLED television panels, announced a first-of-its kind partnership with Eyesafe. Together, they look to establish OLED as the world's most effective technology for eye comfort.

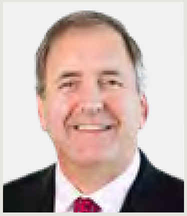
LG Display has committed to certify all of its OLED TV displays to meet Eyesafe® Requirements for low emission of blue light and optimal color performance. The certification was conducted by leading independent testing and certification firm TÜV Rheinland.

SooYoung Yoon,
Chief Technology
Officer, LG Display

"We are so proud to be the first manufacturer to certify our TV displays as Eyesafe – the recognized leader in screen time safety, blue light mitigation, and optimal color performance across consumer electronics."

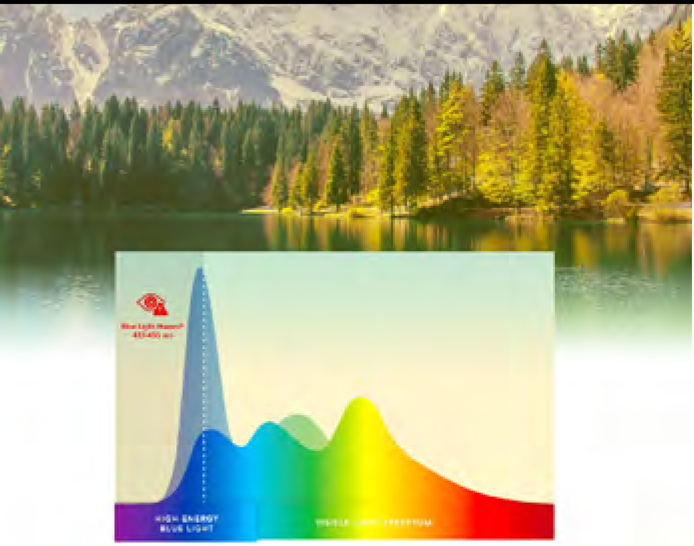
KJ Kim,
Vice President of TV Sales
Group at LG Display

"LG Display is an industry innovator, and that's why we partnered with Eyesafe to introduce LG Display's OLED, designed to have low blue light for improved eye comfort and better sleep."

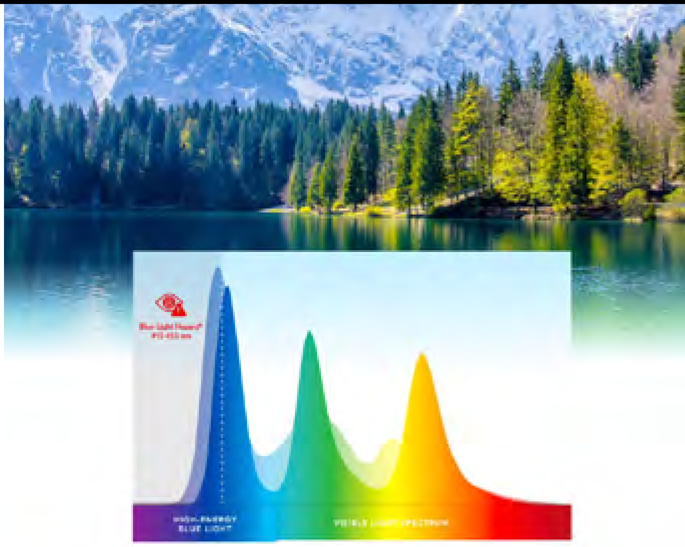


Dr. Vance
Thompson, MD

"Eyesafe Certified OLED is what TV should be – designed with human health at the forefront."



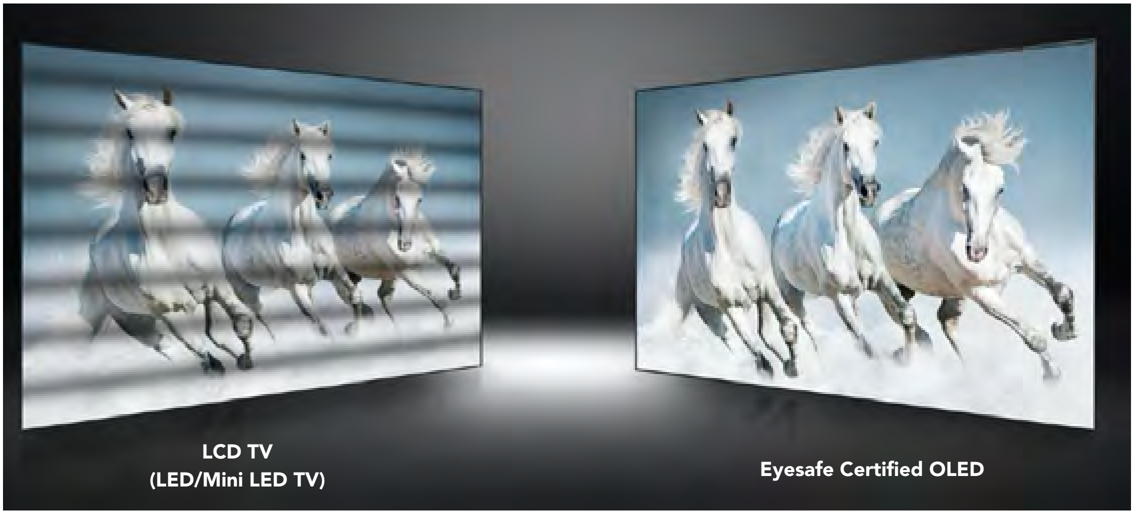
Other Solutions



Eyesafe Certified OLED

Reduced High-energy Blue Light with Optimal Color Integrity

Other filters and common software solutions adjust the blue light by shifting your screen to warmer hues. Eyesafe Certified OLED reduces high-energy blue light, while maintaining color performance and luminance.



Flicker Free, Glare Free

OLED minimizes eye strain by eliminating flicker that can't be detected by the naked eye and glare that disrupts your viewing experience.

What makes Eyesafe® Certified OLED better than a typical LCD TV?

OLED pixels emit their own light, eliminating the need for a backlight which distorts colors, screen flicker and light bleed. The result is a more comfortable experience with optimal color integrity.

Looks Good, Does Good.

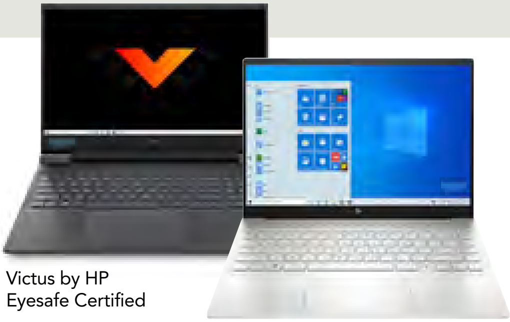
HP is leading the consumer electronics industry with the most Eyesafe® Certified models in-market. In recognition of its commitment to consumer wellbeing, HP was honored with the 2021 Global Leadership and Achievement in Screentime Safety (GLASS) Award at Blue Light Summit 2021.

HP offers a wide array of high-powered Eyesafe Certified laptops and monitors designed for business, creators and gamers. The first HP notebook with Eyesafe, HP Spectre laptops combine mighty processing power with exceptional adaptability to create the perfect solution for almost any need.

The world's first Eyesafe tablet* has arrived with low blue light peace of mind. With a sleek 11-inch screen, this multitasker operates seamlessly in portrait and landscape modes. It has 13MP camera that rotates 235° for high-quality photos and video calling, plus a keyboard and pen built into its design.

*Based on detachable PCs and tablets with Eyesafe® Certification as of November 12, 2021. See https://eyesafe.com/products/ for more details.

HP 11 inch Tablet PC Eyesafe Certified



Victus by HP Eyesafe Certified

HP ENVY Eyesafe Certified

HP X-Series are built for gaming, providing an immersive experience with vivid color and super-fast refresh rate. **HP M-Series monitors** are an affordable choice to handle everyday needs, made with eco-friendly materials.

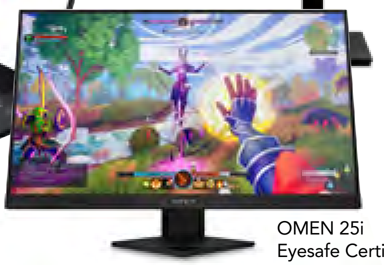
HP M32f FHD Eyesafe Certified

HP X32 QHD HDR Eyesafe Certified

HP ENVY laptops offer pro-grade performance so creators can edit photos, videos and broadcasts with ease. **Victus by HP** gaming laptops have all the features to handle gaming and everyday needs.

OMEN by HP gaming laptops and monitors combine high-performance graphics, processing power, and a blazing-fast refresh rate with a sleek design.

OMEN by HP Laptop Eyesafe Certified



OMEN 25i Eyesafe Certified

eyesafe.com/hp

Stefan Engel VP/GM Visuals Global Business, Lenovo at Blue Light Summit 2021

Zhaochun Ma, Executive Director, Lenovo Consumer & SMB Notebook Development Center in the Intelligent Devices Group at Blue Light Summit 2021

"Lenovo is committed to eye health and safety in the design of our product solutions," said Engel. "Natural low blue light is an innovative feature that we've championed for years. Now faced with increased levels of screen time, more customers are ready to talk about what can be done to reduce their blue light exposure as it's never too late or too early to start protecting your eyes."

"The Eyesafe mark has emerged as the gold standard across the consumer electronics industry when it comes to low blue light filtration," said Ma. "We want to give Lenovo PC users peace of mind to be able to enjoy the vivid colors and low blue light of their display without worrying about the health impacts of excessive blue light exposure."

New Lenovo Eyesafe® Certified monitors and laptops minimize potentially toxic blue light without color distortion for gaming, learning, working and more.

ThinkVision P40w-20 Eyesafe Certified

Yoga Slim 7 Pro (14") Eyesafe Certified

Lenovo G24e-20 Eyesafe Certified

eyesafe.com/lenovo

Acer Eyesafe® Certified Monitors

Acer monitors feature the latest technologies and are available in a wide variety of styles and sizes, ensuring that there is something for everyone, whether they're crunching numbers in the office or cranking out matches in a video game. Some of our monitors boast certifications from Eyesafe, making them an excellent option for those looking for the most comfortable viewing experience possible.

Predator Gaming Monitors

Predator gaming monitors are high-performance displays with innovative technologies designed for hardcore gamers. The Eyesafe Certified monitors have lower blue light emissions compared to standard gaming monitors, helping gamers to perform their best—without compromising on display color.

Predator XB323QK NV
Eyesafe Certified

Nitro Series Gaming Monitors

Acer Nitro gaming monitors strive to make gaming more accessible to a wider variety of players. Eyesafe Certified options help make sure that when players step into their next adventure, they're starting off on the right foot, equipped to more comfortably enjoy their favorite games in true-to-life color.

Nitro XV282K KV
Eyesafe Certified

eyesafe.com/acer

GIGABYTE Eyesafe® Certified Gaming Monitors

Extreme gaming performance with low blue light.

With expertise encompassing consumer, business, gaming, and cloud systems, GIGABYTE established its reputation as a leader in the industry with award-winning products including motherboards, graphics cards, laptops, mini PCs, and other PC components and accessories. In 2021, GIGABYTE achieved Eyesafe® Certification on several of its gaming monitors, including its high-end AORUS brand.

GIGABYTE gaming monitors offer the most extreme gaming experience in UHD 4K, with 144Hz refresh rate and 1ms GTG for the most fluid gaming experience and awesome picture quality. GIGABYTE monitors bring out the best performance of your gaming and multimedia experience.

AORUS FI32U Gaming Monitor
Eyesafe Certified

M28U Gaming Monitor
Eyesafe Certified

M32Q/ M32U Gaming Monitor
Eyesafe Certified

AORUS FI32Q Gaming Monitor
Eyesafe Certified

eyesafe.com/gigabyte

BenQ Eyesafe® Certified Displays

BenQ's advanced consumer monitors and education interactive displays provide maximum protection against eye strain. Two G Series monitors and the RP03 series interactive displays have achieved Eyesafe® Certification for low blue light and color performance.

G Series Monitors

BenQ's G Series monitors promote a more comfortable method of working and learning. Each monitor features a customizable height adjustment system, a built-in noise-canceling microphone, as well as a pre-installed Care Mode and Reading Mode for optimal user comfort.

27" Eye-Care Monitor (GW2785)
Eyesafe Certified

24" Eye-Care IPS Monitor (GW2485)
Eyesafe Certified

Interactive Displays for Education

The RP03 series interactive displays for education offer a hands-on learning approach for both in-classroom and remote learning environments. Its interactive abilities and versatile screen sharing features enhance the learning experience and boost student understanding.

BenQ 75" Interactive Display for Education
Eyesafe Certified

eyesafe.com/products

MSI Eyesafe® Certified Monitors

With stunning high resolution and Smart Gaming AI pairing abilities, MSI's Optix MAG monitors are an excellent choice for users looking for a fluid, high-quality gaming experience. With two of MSI's Optix MAG products earning Eyesafe® Certification, can now enjoy a high-performance, immersive gaming display with reduced blue light emissions and uncompromised color.

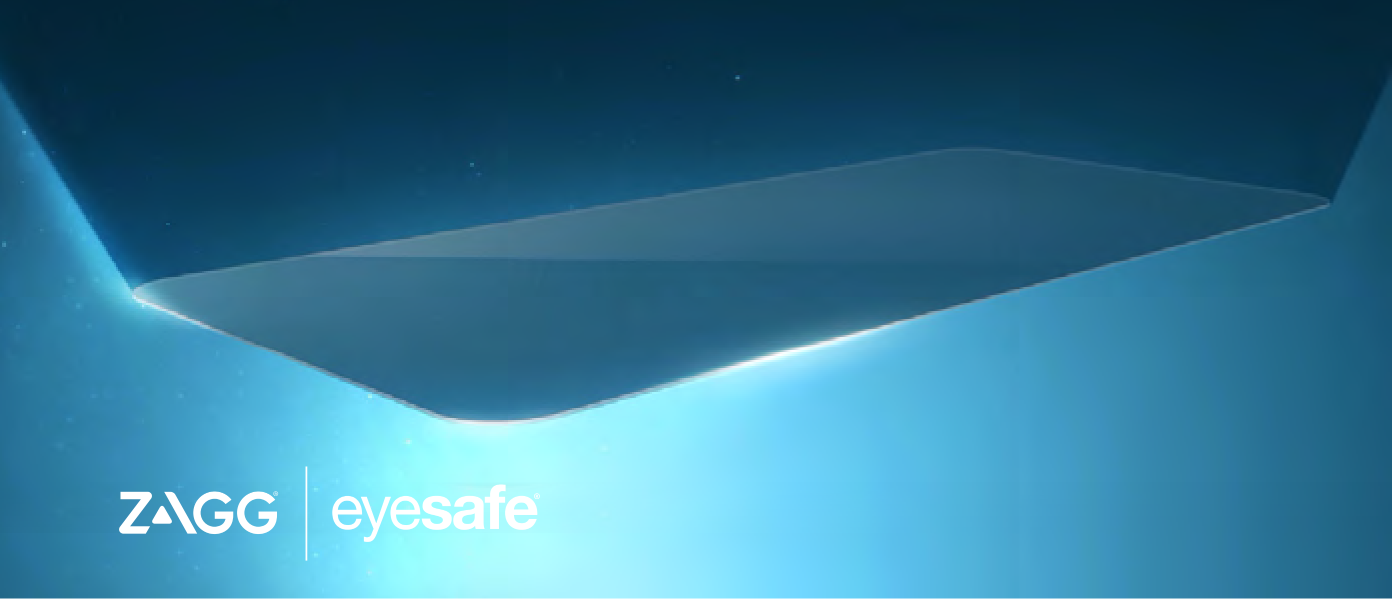
MSI's Optix MAG monitors provide the ultimate gaming adventure with their UHD 4k resolution, IPS grade panel, and AMD FreeSync™ technology. The monitors supply crisp, vivid visuals, as well as customizable color palettes for an unmatched gaming experience.

MSI Optix MAG281URV
Eyesafe Certified

MSI Optix MAG281URF
Eyesafe Certified

eyesafe.com/products

Protect Your Eyes and Your Device, Better.



The first major electronics accessory brand to see the need to protect against high-energy blue light, ZAGG leads by integrating Eyesafe technology in the #1 best-selling screen protection product, InvisibleShield.

Together, ZAGG products with Eyesafe® patented technology protects millions of screens and helps millions of eyes every day. ZAGG and Eyesafe set the bar for blue light reduction without compromising color quality. Our technology is developed with doctors, backed by science, and designed for health. With award-winning innovations in total protection from rugged cases to the strongest screen protection designed for eyes, ZAGG protects, better.

10M+ Sold Globally

#1 Trusted Best Selling Screen Protection in the US

Award-winning blue light screen protection

Developed with doctors, industry-leading standards for blue light set the bar

ZAGG InvisibleShield screen protection with Eyesafe® patented technology is developed with eye doctors to promote eye health and reduce peak toxic levels of high-energy blue light. Certified by TÜV Rheinland, global leader in independent product verification.

eyesafe 40

Eyesafe patented technology filters 40% of peak toxic blue light at (435-440 nm)

DEVELOPED WITH EYE DOCTORS

TÜV Rheinland®

Precisely Right.

No yellow tint

The Eyesafe® layer filters peak toxic blue light right at the source: your device screen. Unlike a Night Mode setting, VisionGuard with Eyesafe technology maintains the superior color performance of your screen, with no yellow tint.

"With ZAGG InvisibleShield screen protection on millions of devices today, and millions more to come, we are in a unique position to truly do something meaningful about blue light. We can filter light that's known to be most harmful right at the source – your device screen – where our products are already preventing scratches and impacts. Protecting against the negative effects of screen time and high-energy light are all a part of our mission to protect better." – Chris Ahern CEO, ZAGG

Glass Elite VisionGuard®

Maximum strength tempered glass screen protection with blue light filtration.

- Protective Eyesafe® technology
- Our strongest glass screen protection
- Contains anti-microbial treatment
- ClearPrint® Technology
- Easy Application
- Lifetime Warranty

Glass XTR

Our most advanced screen protector ever with full screen coverage and reinforced with D3O technology.

- Protective Eyesafe® technology
- Reinforced with D3O®
- Engineered for maximum touch sensitivity
- Full-screen coverage
- Advanced nano-coated treatment
- Contains anti-microbial treatment
- ClearPrint® Technology

GlassFusion VisionGuard+ with D3O

- Over 20% stronger than the original
- Reinforced with D3O®
- Protective Eyesafe® technology
- Contains anti-microbial treatment
- Flexible protection with a glass-like feel
- Smudge resistant
- Fingerprint scanner compatible

eyesafe 40

Eyesafe patented technology filters 40% of peak toxic blue light at 435-440nm, reducing the effects of overexposure to high-energy blue light.

eyesafe 40

"Given that eyes are still developing through the teenage years, blue light protection is important for children's eyes."

– Sheri Rowen, MD World-recognized ophthalmologist and Eyesafe Vision Health Advisory Board member

FIND MORE ZAGG EYESAFE SOLUTIONS:
https://www.zagg.com/en_us/invisibleshield/visionguard-screen-protection

Eyesafe Blue Light Screen Filters are designed with health in mind.

Consumer electronics companies are embracing blue light protection, developing and certifying a dizzying array of new laptops, monitors and TV displays to meet the industry leading low blue light and color standards. But what about all the existing smartphones, tablets, laptops and monitors? Clearly, the biggest potential risk for blue light exposure is with existing devices.

Eyesafe Blue Light Screen Filters are designed to fit legacy devices, effectively reducing blue light emissions at the source. They are an inexpensive, practical solution to address rising screen time and blue light exposure for employers, educators and governmental bodies.

Eyesafe Blue Light Screen Filters do more than protect the glass

Most screen protectors are designed with a primary purpose of protecting your device from damage, but they don't protect you from blue light exposure.

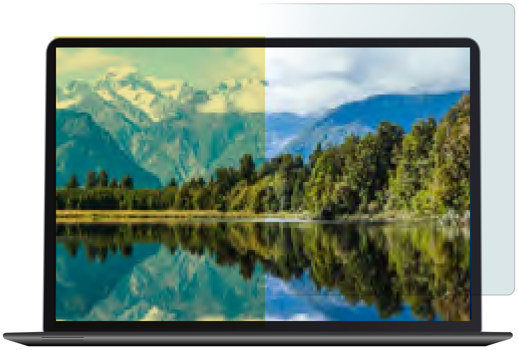
Eyesafe Blue Light Screen Filters provide industry standard device protection from scratches, drops, smudges and glare, with the added benefit of filtering out blue light emissions.

The advantages of Eyesafe Filters include:

- Developed with eye doctors
- Always-on, advanced blue light protection
- Maintains vivid screen color and brightness
- Quick install
- Scratch resistance
- Certified by TÜV Rheinland

Patented. Tested. Certified.

Eyesafe Blue Light Screen Filters are patented and verified to manage high-energy blue light emissions while maintaining the vivid color of your screen. Typical software solutions reduce blue light by turning your screen yellow; Eyesafe maintains color integrity.



OTHER SOLUTIONS EYESAFE®

Developed with Doctors

Guided by a group of leading optometrists and ophthalmologists from across the globe, Eyesafe Filters integrate advanced, patented technology based on optical testing and research.

Eyesafe Filters were developed by a world-class team of eye doctors, engineers, and scientists with decades of experience in electronics, display materials, light management, optometry and ophthalmology.

eyesafe.com/filters

Employee Well-Being and Productivity

Employees spend significantly large amounts of time on digital devices, including laptops, monitors and phones, to complete their tasks and connect with co-workers.

With many employees working remotely or in a hybrid environment, screen time has become a critical component of the job. Employees are exposed to increasing levels of intense blue light on a near-constant basis, which has employers looking for solutions.

As a means to enhance their benefits package, improve retention, increase worker productivity or overall wellbeing, many employers are now considering blue light screen filters.

Initial survey data of employees shows promise, with potential benefits ranging from eye comfort to better sleep.[1]

81% of employers identified reduced blue light emission as critical or highly important in improving productivity.[2]

57% of employees believe blue light education and solutions are important in a comprehensive benefits package.[1]

Student Learning and Wellness

Children may be more vulnerable to blue light exposure because their eyes are still developing. With the onset of COVID-19, the average time spent online doubled for children, from ~3 hours pre-pandemic to ~6 today. More than a quarter of children spend 8+ hours online.[3]

The increased usage of, and access to, digital devices by young children and adolescents may lead to sleep disruption and decreased educational performance, ability to retain information and impacts to social-emotional learning.

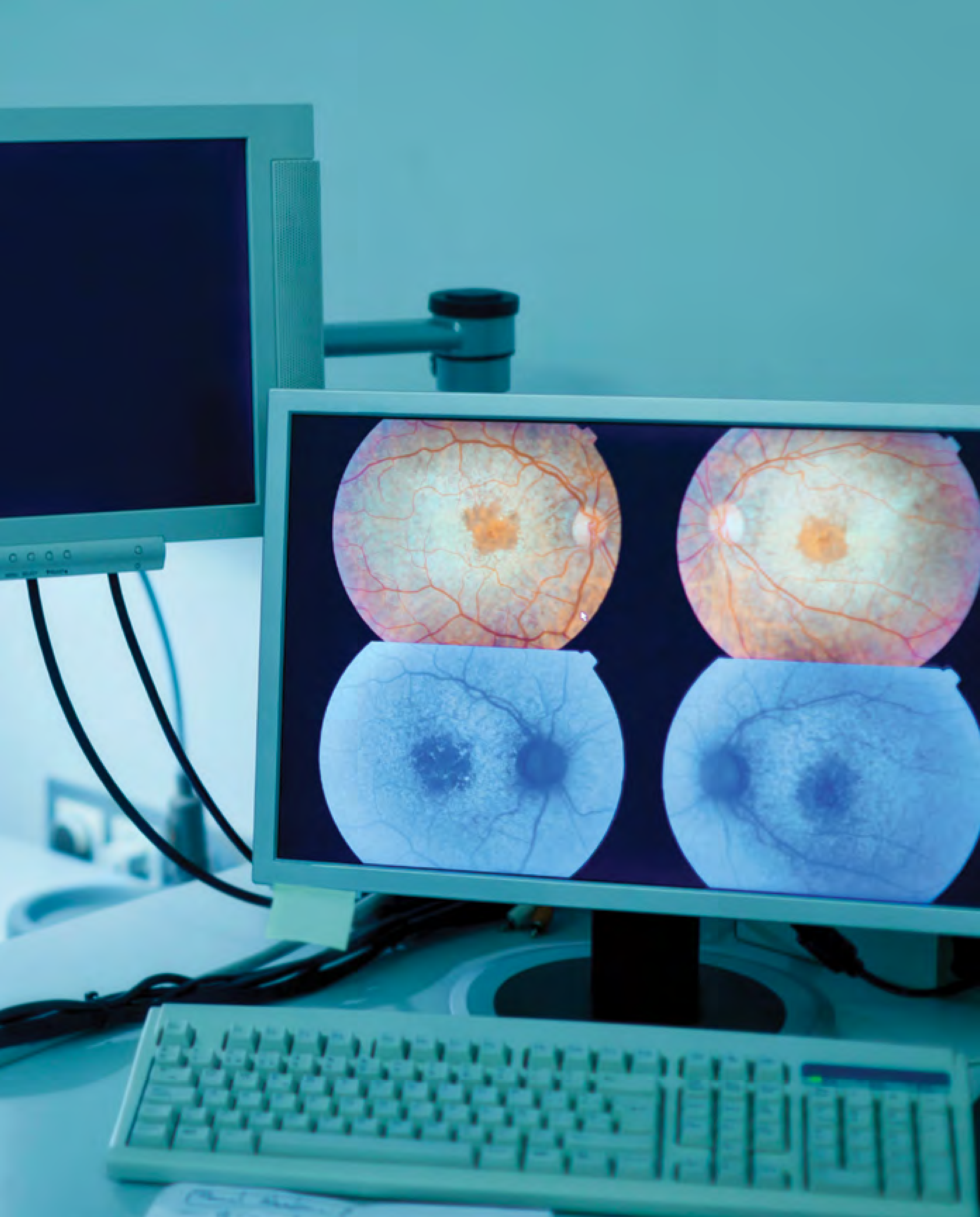
Eyesafe Blue Light Screen Filters for Chromebooks are an effective option to protect students from potentially harmful blue light exposure.

93% of parents and 96% of educators are concerned about the impact of prolonged screen time and blue light exposure on children's eyes.[4]

Eyesafe® Filters are designed to provide protection from blue light to compensate for the natural filtration otherwise not present in children's eyes.

References

1. Screen Time Survey 2022, 535 employees in US, Jan. 2022
2. Study conducted by Forrester Consulting on behalf of Dell, June 2019
3. *Survey Shows Parents Alarmed as Kids' Screen Time Skyrockets During COVID-19 Crisis*, https://parents-together.org/survey-shows-parents-alarmed-as-kids-screen-time-skyrockets-during-covid-19-crisis
4. Screen Time Survey of Parents and Educators, https://eyesafe.com/parent-educator-survey-results

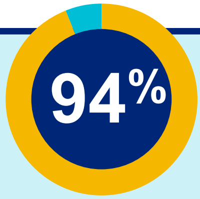


Resources and Selected Research

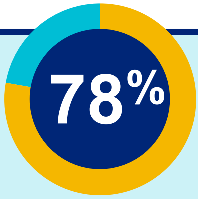
Screen Time 2020 Overview

As many people spend more time on digital devices due to COVID-19, some eye care professionals and employers are becoming increasingly concerned about the potential health impacts of increased exposure to blue light.

13+ hours are spent on screens per day since COVID-19 emerged.[1]



of eye doctors are concerned.



of employers are concerned.

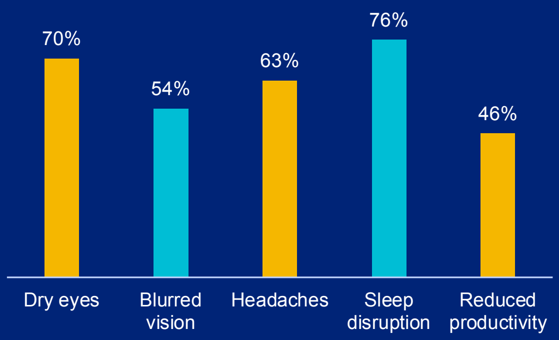
By offering blue light protective solutions, eye care providers believe the expected benefits most often cited include:

- **Sleep improvement (71%)**
- **Improve eye and vision care (69%)**
- **Greater satisfaction with their overall care (56%)**
- **Morale and mood increase (45%)**

Over 77% **of employers want a specific insurance or benefit plan covering impacts of screen time.**

Nearly 8 in 10 **eye care professionals estimate that blue light is impacting not only patients' eyes but their overall physical and mental health.**

Symptoms most cited by eye care professionals as a result of excessive blue light exposure from digital devices include:



Employers and eye care professionals both identified the light sources presenting the most potential health issues for employees and patients:

- **Phones**
- **Notebook/desktop computers**

United Healthcare | eyesafe

Source: Employer and Eye Care Provider Screen Time Survey 2020

[1] Eyesafe, 2020, https://eyesafe.com/covid-19-screen-time-spike-to-over-13-hours-per-day

Screen Time 2020 Report

Eyesafe and UnitedHealthcare Vision collaborated to conduct a survey to assess the opinions of employers and eye care professionals related to the potential health issues associated with the use of digital devices and excessive exposure to blue light.

Employer Results Summary

71% surveyed estimate employees spend at least 3 hours a day looking at device screens and nearly 10% estimate employees are on screens at least 12 hours a day.

78% are “somewhat” to “very concerned” about the impact of digital device screen time on their and employees’ eyes and heath and nearly half are “very concerned” and “concerned”.

Light sources identified as presenting the most potential health issues are phones (51%) and notebook/desktop computers (55%). Sunlight identified as the blue light source of least concern (25%).

Symptoms most cited as a result of excessive blue light exposure from digital devices include: 1) headaches (63%), 2) blurred vision (55%), 3) dry eyes (50%), 4) sleep disruption (36%), and 5) reduced productivity at work (32%).

62% of respondents estimate 50% of employees or less are impacted by blue light-related symptoms and 12% estimate all employees are impacted.

78% of respondents identified an insured vision benefit that includes solutions for employee screen exposure to computer device screens and blue light as “very attractive” to “somewhat attractive”.

30% of respondents identified that blue light education and prevention is “very important to our overall wellness culture and we are or have plans to address”.

Eye exams ranked as the most important insured vision benefit by 69% of respondents.

Blue light protective solutions ranked as most important benefit enhancement by 53% of respondents.

By offering blue light protective solutions to employees, benefits most cited include: 1) improved eye and vision care (73%), 2) attention improvement (53%), and 3) greater satisfaction with their benefit package (49%).

67% of employers reported interest in sharing with employees health and safety information about blue light.

Screen Time 2020 Report https://eyesafe.com/uhc/

Eye Care Provider Results Summary

94% of eye care professionals surveyed are "very concerned" to "somewhat concerned" about the impact of digital device screen time on their patient's eyes.

Light sources identified as presenting the most potential health issues are phones (65%) and notebook/desktop computers (61%). Television identified as the blue light source of least concern (12%).

Symptoms most cited as a result of excessive blue light exposure from digital devices include: 1) sleep disruption (76%), 2) dry eyes (70%), 3) headaches (63%), 4) blurred vision (54%), and 5) reduced productivity at work (46%).

83% of respondents estimate that up to 75% of patients are impacted by blue light-related symptoms.

67% of respondents agree that employers should be providing blue light protective solutions for employees.

80% of respondents estimate that given the current climate and growth in screen usage, blue light is impacting patients' eyes and overall health.

72% of eye care professionals surveyed agree that blue light education and prevention is "important" or "very important" to address in the workplace or benefits package.

83% of respondents agree that an insured vision benefit that includes solutions for employee exposure to computer device blue light as "very important" to "somewhat important".

By offering blue light protective solutions, expected benefits most cited include: 1) sleep improvement (71%), 2) improved eye and vision care (69%), 3) greater satisfaction with their overall care (56%), and 4) morale and mood increase (45%).

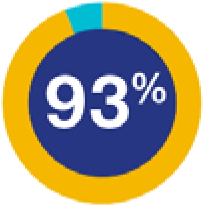
Information identified as most helpful to share with patients includes: 1) research on blue light and screen time (77%), 2) product solutions for blue light and screen time (70%), and 3) potential health risks (65%).

In a range of 1-10 with 1 "not often" and 10 "often", the topic of screen time and blue light was identified to come up as an average of 5.5.

In a range of 1-10 with 1 "not knowledgeable" and 10 "very knowledgeable", the level of knowledge on screen time and blue light product solutions is 6.4.

Screen Time 2020 Report https://eyesafe.com/uhc/

Eyesafe and UnitedHealthcare Vision conducted a separate survey to assess the opinions of parents and educators related to the potential health issues associated with the use of digital devices and excessive exposure to blue light.



of parents are concerned[2]

Screen Time Survey of Parents & Educators, 2020

As many young people return to school and remote learning becomes more common, parents should remember that good eye health is important for everyone. This is especially true for students, as 80% of what children learn is through their eyes.[1]

of educators are concerned[2]

Highlights of the Screen Time Survey of Parents and Educators:

93% of parents and 96% of educators are "very concerned" to "somewhat concerned" about the impact of digital device screen time on children's eyes.

The most common symptoms of excessive blue light exposure from digital devices for children are headaches (67%), blurred vision (56%) and dry eyes (49%).

A vision insurance plan that includes blue light protective solutions was ranked No. 1 by 62% of teachers in the survey.

The benefits teachers most expect from blue light protection include attention improvement for students (64%), improved peace of mind for educators (58%) and sleep improvement for students (54%) .

[1] https://www.covd.org/page/learning

[2] Screen Time Survey of Parents & Educators Results https://eyesafe.com/parent-educator-survey-results/

Full survey results, tools for Parents and Educators, Vision Care Providers, and Employers can be found at eyesafe.com/uhc

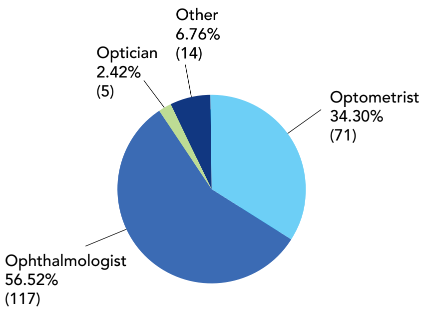
How Eye Care Professionals View the Issue of Blue Light

EXCLUSIVE SURVEY OF OVER 200 EYE CARE PROFESSIONALS

As a part of its continuous education mission, the Eyesafe Vision Health Advisory Board recently conducted a survey of eye doctors on the subject of digital device use and blue light. The 2019 survey, summarized below, offers a baseline of professional opinion regarding the subject.

RESPONDENTS

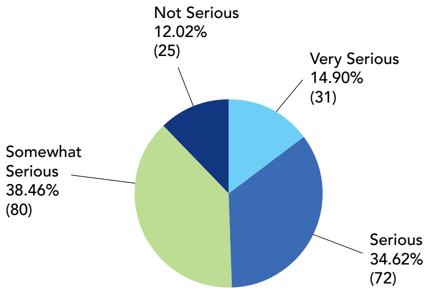
1. Your profession?



Majority of survey respondents are certified doctors, with a combined total of 4,124 years of experience.

CONCERN

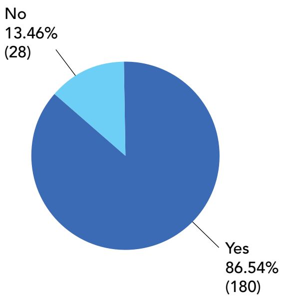
2. How serious of an issue do you believe exposure to high-energy visible blue light from digital devices is?



Exposure can be a serious issue. 88% of doctors surveyed consider it somewhat serious to very serious.

BELIEFS

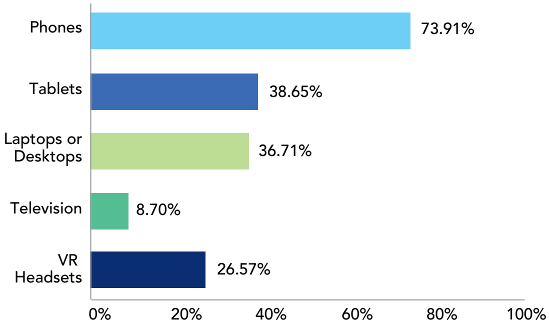
3. Are you concerned about potential eye health problems from blue light emitted by digital devices?



86% of doctors surveyed believe that blue light emitted by digital devices is a major area of concern.

DEVICES

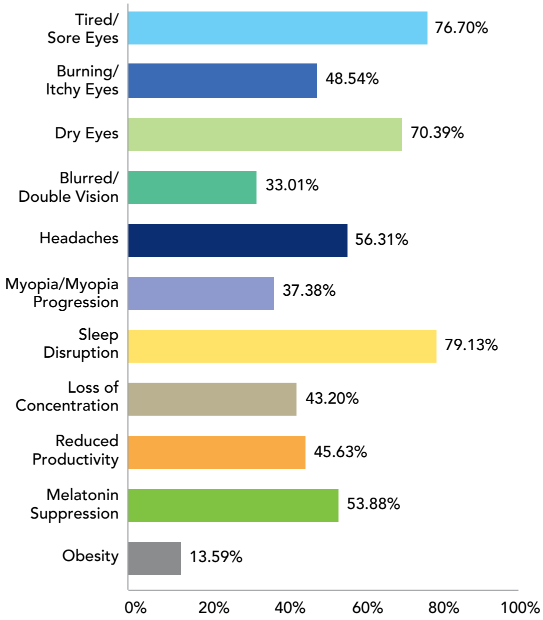
4. Which of the following devices do you think present the most potential health issues from blue light?



Smartphones are seven times the potential health concern as TVs, according to doctors surveyed.

SYMPTOMS

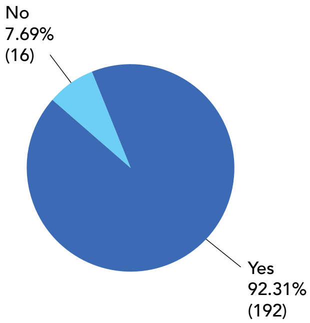
5. Which of the following do you believe are symptoms of excessive blue light exposure from digital devices? (Check all that apply.)



70% of doctors surveyed believe that excessive exposure creates symptoms of tired/sore eyes, dry eyes and sleep disruption.

SOLUTIONS

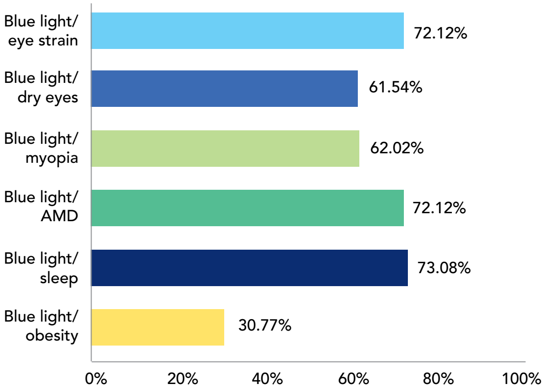
6. Do you believe digital device manufacturers should be providing blue light-attenuating solutions?



Over 90% of doctors surveyed think that device makers need to provide solutions.

RESEARCH

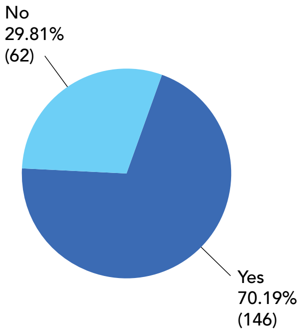
8. Which of the following topics do you believe require additional research? (Check all that apply.)



Most agree that more research is needed on blue light exposure from digital devices.

REGULATION

7. Do you believe government regulations should be proposed to limit the amount of blue light emitted by digital devices?



Most doctors surveyed favor *regulatory action* on health and safety of digital devices.

Survey conducted May-August 2019 by Vision Health Advisory Board. Survey respondents were entered to win a $200 Amazon gift card and Dell Eyesafe Notebook Computer.

Key finding: 81% of employers say blue light emission as critical or highly important in improving productivity

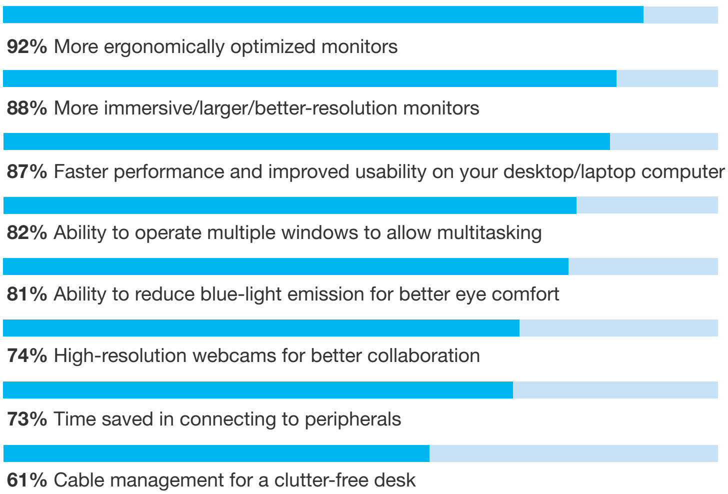
A study conducted by Forrester Consulting on behalf of Dell in June 2019 surveyed 450 employers (150), employees (150) and healthcare professionals/office planners (150) in China, the UK, and the US. Employee and employer survey participants were from medium businesses, commercial and large enterprises.

"The front of screen experience of monitors impacts productivity. Size and resolution, color accuracy, and reduction in blue-light emission from monitors are important features to consider in improving the productivity of the workforce. With this in mind, 67% of employers consider wide color coverage, accuracy, and calibration to be high priorities in their consideration of monitor investments. Eighty-eight percent of employees believe better resolution and more immersive monitors improve productivity, while 81% believe reduced blue-light emission enables this further.... Healthcare professionals recognize the importance of front of screen experience on well-being. Sixty-eight percent of healthcare professionals validate that providing customizable color and resolution of monitors that are easy on the eyes would have a high or critical impact on the overall workplace, specifically in creating a positive well-being for employees. Sixty-six percent of employees think that reducing blue-light emissions from monitors for better eye comfort would have the same effect; employers agree that reducing blue-light emissions improves well-being (67%), especially in markets like the UK (70%) and worldwide commercial (72%) and enterprise companies (78%)."

Survey Question: How important are the following factors of your hardware and devices in improving your productivity?

Base: 150 professionals across China, the UK, and the US Note: Not all responses are shown, showing percentage of employees considering the above features 'critical' or 'highly important'

Source: A commissioned study conducted by Forrester Consulting on behalf of Dell, June 2019. Whitepaper: Exploring The Role of Monitors in Improving Employee Experience



Glossary

20/20 vision	The term 20/20 denotes the Snellen visual acuity system. The top number is the viewing distance between the patient and the eye chart. The other refers to the line readable on the eye chart. In the United States, this distance typically is 20 feet; in other countries, it is 6 meters. Reading the 20/20 line on the eye chart is considered "normal acuity".
A2E	N-retinyl-N-retinylidene ethanolamine (A2E) retinoid, which is thought to be a cytotoxic component for RPE, is the best-characterized component of lipofuscin so far.
Accommodation	Mechanism by which the eye adjusts its optical power, by changing the shape of the crystalline lens, to maintain a clear image or focus on the retina.
Acute toxicity	High intensity light over a short period of time (thermal destruction of retina's cells and cells death by necrosis).
AMD or ARMD	Age-related macular degeneration - Macular degeneration is a deterioration of the macula, portion of the retina responsible for visual acuity. Symptoms are disturbances of vision or loss in the center of the field of vision. There are two types of AMD, dry and wet. In dry macular degeneration, the center of the retina deteriorates. With wet macular degeneration, leaky blood vessels grow under the retina.
AMOLED	Active Matrix Organic Light Emitting Diode is a display technology with OLEDs are deposited in a matrix arrangement on a thin film transistor (TFT) that energizes them. The advantage is a thinner display that can be flexible.
ANSI	American National Standards Institute www.ansi.org.
Anti-VEGF	Anti–vascular endothelial growth factor therapy, also known as anti-VEGF therapy or anti-VEGF medication, is the use of medications that block vascular endothelial growth factor. This is done in the treatment of certain cancers and in age-related macular degeneration.
Apoptosis	The death of cells that occurs as a normal and controlled part of an organism's growth or development.
Arc-eye	Also called welder's flash, is an inflammation of the cornea, caused by ultraviolet radiation from the arc during welding. Cf. Photokeratitis.
Asthenopia	Eye strain, eye condition that manifests through nonspecific symptoms such as fatigue, pain in or around the eyes, blurred vision, headache, and occasional double vision.
Blue light	High-energy visible (HEV) light rays with wavelengths ranging from 380-500 nm. Blue light is a natural component of sunlight and also is emitted by the screens of electronic devices (computers, tablets and phones) and LED light bulbs.
Blue light filter	Filter decreasing the amount of blue light reaching the eye.
Blue light hazard function	The Blue Light Hazard function weights the more intense bands of the blue light spectrum from 380-500 nm.

Blue Light Ratio (BLR)	Based on the Blue Light Hazard Function, the ratio of emissions at 415-455 nm divided by total blue emmissions (400-500 nm)
Blue Light Toxicity Factor (BLTF)	A measure of potential toxicity using the full scaling factors from ANSI Z87.1-2020.
Cataract	Clouding of the crystalline lens. Cataracts are a very common aging ailment, reducing the transmission of light to the retina. Cataract surgery involves removing the cloudy lens and replacing it with an artificial lens.
CCT	Correlated Color Temperature is the color temperature of the display, in degrees Kelvin.
CFLs	CFLs are compact fluorescent lamps emitting light from a mix of phosphors inside the bulb, designed to replace incandescent lamps.
Chromaticity	Projection of a color into a two-dimensional space that ignores brightness.
Chromaticity diagram	A horseshoe-shaped graph, where the color space has been set into two dimensions; delimiting the range of colors the human eye can perceive, but also showing the ranges of colors (gamuts) that different devices can (or cannot) display.
CIE	International Commission on Illumination (usually abbreviated CIE for its French name Commission Internationale de l'Eclairage). International authority on light, illumination, color, and color spaces.
Circadian rhythm	A natural, internal process that regulates the daily sleep-wake cycle and repeats roughly every 24 hours.
Color balance	The global adjustment of red, green, and blue light intensity in a display to achieve ambient white (neutral color).
Color sensing	Detection of colors based on the RGB scale (Red, Green, Blue).
Color space	A color space is a specific organization of colors, allowing for reproducible representations of color, by attributing to each color a set of space coordinates unique to this color.
Colorimetry	Science of the measurement of colors perceived by the human eye.
CRT	A cathode-ray tube (CRT) is a display device that consists of a vacuum tube containing one or more electron guns and a phosphorescent screen.
Crystalline lens	The crystalline lens is a transparent biconvex lens, which by changing its shape, refracts and maintains the light focused on the retina.

China Video Industry Association (CVIA)	Founded in 1988, CVIA is an industry association and standards making body, made up of video, TV, recording, consumer electronics and gaming companies, with representatives of the Ministry of Industry and Information Technology of the People's Republic of China.
D65	CIE Standard Illuminant D65 representing "natural" light.
Digital eye strain	Also known as computer vision syndrome, a group of eye and vision-related symptoms linked to time spent on digital displays.
Dry eye	A condition where there is an insufficient quantity or quality of tears on the surface of the eye to keep the eyes healthy, comfortable, and/or seeing clearly.
Endocrine disruptor	Chemical product interfering with the endocrine system, which secretes hormones and other products regulating the activities of the body's cells and organs.
Eyesafe®	Eyesafe® technology selectively reduces blue light while maintaining color across the visible spectrum.
Eyesafe® DTX	Eyesafe patent-protected technologies that address blue light emissions in digital displays.
Eyesafe Vision Health Advisory Board	This group includes leaders in ophthalmology and optometry, advocating for public health, and assisting in the development of technology and industry standards for blue light protection.
Full Width Half Maximum (FWHM)	The full width at half maximum is a parameter commonly used to describe the width of a "bump" on a curve or function. It is measured between those points on the y-axis which are half the maximum amplitude.
Gamut	Set of colors that can be represented by a display.
Glaucoma	A leading cause of blindness, glaucoma is a disease that damages the optic nerve. It is usually associated with abnormal high pressure in the eye.
Harmful blue light	The "harmful" blue light spectrum according to the blue light hazard Function, ANSI and ICNIRP Guidelines is 415-455 nm.
HEV light	High-energy visible (HEV) light is an alternative phrase used to describe blue light.
Hyperopia	Also known as farsightedness, is a common type of refractive error where distant objects may be seen more clearly than objects that are near. It occurs when the shape of the eye causes the image to be focused beyond the retina instead of on the retina.
ICNIRP	International Commission on Non-Ionizing Radiation Protection (ICNIRP), an international commission specialized in non-ionizing radiation protection.
Illuminance	Corresponding to the amount of luminous flux per unit area.

IOL	Abbreviation for "intraocular lens" (used in cataract surgery).
ipRGCs	Abbreviation of intrinsically photosensitive retinal ganglion cells, also called photosensitive retinal ganglion cells, or melanopsin-containing retinal ganglion cells, located in the retina of the mammalian eye, they absorb around 460-480 nm. They are mediators of non-image-forming physiological responses to light such as pupil constriction and circadian photoentrainment.
Irradiance	The radiant flux (power) received by a surface per unit area. The SI unit of irradiance is the watt per square meter (W/m^2).
Karolinska Sleepiness Scale (KSS)	Scale used to study sleepiness in various contexts.
Keratitis	Inflammation of the clear tissue on the front of the eye (cornea).
L-cones	L-cones are retinal light receptors that are sensitive to longer wavelengths, red light range - absorption 570 nm.
LED	Light-emitting diode (LED) is a semiconductor device that emits light when submitted to an electric current.
LED-backlit LCD	A flat panel display where the images are rendered by liquid crystal diodes (LCDs) and illuminated from the back and sides by a series of LEDs.
Lipofuscin	A pigmented material composed of a mixture of lipids, proteins and fluorescent compounds, including a derivative of vitamin A. Accumulation of lipofuscin in retinal pigment epithelial (RPE) cells in the eye is a sign of oxidative stress and possible retinal disease.
Luminance	Photometric measure of the intensity of light emitted from a surface per unit area in a given direction, expressed in cd/m^2: candela per square meter.
M-cones	M-cones are retinal light receptors that are sensitive to medium wavelengths, green light range - absorption 540 nm.
Melanopsin	Type of photopigment belonging to a larger family of light-sensitive retinal proteins called opsins and encoded by the gene Opn4.
Melatonin	Hormone secreted by the pineal gland in the brain and involved in the regulation of circadian rhythm. Also called the "sleep hormone."
Myopia	Myopia or nearsightedness is a common vision condition where near objects are seen clearly while objects farther away are blurry. It occurs when the shape of the eye causes the image to be focused in front of the retina instead of on the retina.

Non-image forming (NIF)	Referring to neural pathways from eyes to brain that link to nonvisual receptors.
Nit	The Nit is the unit of luminance and is defined as a candela per square meter. The unit could be written as cd/m^2 or lm/m^2sr. It is most often used to characterize the "brightness" of flat emitting or reflecting surfaces.
OLED	Organic LEDs are made of a layer of organic electroluminescent material, the semiconductor is of organic type, either a polymer or a small molecule.
Oxidative stress	Imbalance between reactive oxygen species (free radicals) and antioxidant defenses. Reactive oxygen species or ROS, are known to cause cells damage.
Photobiological safety	Safety perspective on the effects of ultraviolet, visible and infrared radiation on living organisms and tissues.
Photokeratitis	Photokeratitis is a painful eye condition occuring upon overexposure to ultraviolet (UV) rays, either from the sun or from a man-made source. It affects the surface of the cornea and the conjunctiva, the clear tissue covering the white part of the eye and the inside of the eyelids. Snow blindness is a form of photokeratitis caused by UV rays reflected off ice and snow.
Photopic vision	Photopic vision is the vision of the eye under well-lit conditions (luminance level 10 to 108 cd/m^2). In humans and many other animals, photopic vision allows color perception, mediated by cone cells, and a significantly higher visual acuity and temporal resolution than available with scotopic (low-light) vision.
Phototoxicity	Phototoxicity is an acute light-induced response, a type of photosensitivity.
Pingueculae	A yellowish growth that can develop atop a portion of the white part of the eye (sclera); often associated with chronic exposure to UV radiation.
Presbyopia	The normal, age-related loss of near focusing ability caused by thickening and loss of flexibility of the crystalline lens in the eye. Usually treated with multifocal eyeglass lenses or reading glasses.
Radiance Protection Factor (RPF®)	An Eyesafe trademarked rating system to help the end-user identify and compare devices and their respective blue light emissions at a specific brightness level.
Refractive error	Vision problem caused by light failing to come to a clear focus on the retina. Common refractive errors are nearsightedness, farsightedness and astigmatism.
Retinal epithelium	Pigmented layer of the retina also called Retinal Pigmented Epithelium (RPE): a monolayer of cells located between the choroid and the retinal, assuming many essential functions such as light absorption, epithelial transport, spatial ion buffering, visual cycle, phagocytosis, secretion and immune modulation.

Retinopathy	Retinopathy means disease of the retina, there are several types of retinopathy all involving disease of the small retinal blood vessels.
ROS	Reactive Oxidative Species: chemically reactive chemical species often containing oxygen radical, highly reactive.
RPE	See "Retinal epithelium."
RPF	The RPF® (Radiance Protection Factor) identifies the amount of blue light filtered with the Eyesafe® technology.
S-cones	S-cones are retinal light receptors that are sensitive to short wavelengths, blue light range - absorption 445-450 nm.
Scotopic	Relative to vision in dim light, believed to involve principally the rods of the retina.
Sicca syndrome	A complex autoimmune disease characterized by the combination of dry eyes, dry mouth and connective tissue disease such as rheumatoid arthritis, lupus, scleroderma or polymyositis. Also called Sjogren's syndrome.
Suprachiasmatic nucleus (SCN)	Small region of the brain in the hypothalamus, situated directly above the optic chiasm, responsible for controlling circadian rhythms.
Trachoma	Bacterial infection affecting the eye, causing a roughening of the inner surface of the eyelids. It is contagious and if untreated can lead to blindness.
TÜV	TÜV Rheinland is a global product testing and certification company based in Cologne, Germany.
TÜV blue light standard	The TÜV blue light filtration standard for accessory glass, co-developed with the Eyesafe® Vision Health Advisory Board, is the first standard to take into account the toxicity scaling. The standard brings transparency to customers and identifies the RPF value including color accuracy (CCT) and Luminance.
UL	Underwriters Laboratories (UL) is a global safety certification company based in Northbrook, Illinois.
Vergence	Movement of the eyes in opposite directions (as in convergence or divergence) to keep the image of an object on corresponding retinal points for clear, comfortable, binocular vision.
Visual Analogue Mood Scale (VAMS)	A standardized approach to measuring eight specific mood states.

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