Understanding Blue Light Retinal Damages and the Methods of Prevention

Amelia Lee

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J. Thomas McClintock, Ph.D.
Thesis Chair

____
Ben Kalu, M.D.
Committee Member

____
David Schweitzer, Ph.D.
Assistant Honors Director

____
Date

Abstract

Light emitting diode (LED) lights that comprise television screens, phone displays, laptops, and tablets have been studied by scientists in order to understand the implications of blue light radiation and the effects that it has on the human body—especially the retina of the eye. The retina is comprised of highly metabolic cells, and when those cells are placed under oxidative stress, death occurs causing ocular disease. Additionally, excess blue light exposure causes shifts in biological rhythms that govern patterns of alertness and sleep. Recently scientists began studying the methods of blue light prevention. Some studies show that blue light radiation is not as damaging as researchers once thought, but long-term blue light exposure studies are still necessary to rule out any health concerns.

Understanding Blue Light Retinal Damage and the Methods of Prevention

Introduction

Studies have shown that blue light exposure has a negative impact on health in many ways. From worsening the symptoms of age-related macular degeneration (AMD), disrupting circadian rhythms, and altering sleep patterns, blue light has increased the presence of ocular disease. Because of the ever-increasing use of LED screens, cell phones, and blue light technologies, the effect of blue light exposure is a topic worthy of discussion. This topic is widely debated among health care professionals and scientists, and there are two opposing views regarding blue light exposure and ocular health—both opinions have studies to support their claims, both opinions are rooted in science, and both opinions drastically oppose each other. Is blue light radiation exposure harmful, or is society buying into a fad providing an excuse to wear trendy glasses? Are the harmful effects of blue light exposure relevant enough to raise public healthcare concerns?

While the degree of harm related to blue light exposure is still being debated among scientists, it is generally agreed that blue light exposure plays a vital role in maintaining proper circadian rhythms and creating patterns of alertness. While a certain level of blue light is necessary for proper functioning, excessive amounts of exposure are linked to age-related diseases like AMD, disrupted circadian rhythms, alteration of sleep patterns, and other illnesses. Through research, scientists have identified different ways that blue light exposure can be reduced. Antioxidants, night-shift mode on devices, blue light blocking glasses, and avoidance are all methods that scientists are working to understand and improve, and they all have different degrees of measured effectiveness. Scientists are continuing to research the effectiveness of these methods, and new research continues to observe the effect of blue light on a person's overall health. Understanding the balance of blue light avoidance and exposure is essential to retinal health and circadian rhythm maintenance, and it is critical that this balance is being explained and used to educate the public of the necessity and danger of blue light exposure.

Identification of Blue Light and its Implications

Blue Light

In order to understand how blue light affects the retina and causes disease, scientists must have a sharp understanding of the definition and common sources of blue light. Blue wavelength light—electromagnetic radiation between the wavelengths of 380-780nm—is one of the main causes for age-related blindness, eyesight degeneration, and the progression of genetically inherited ocular diseases (Contin et al., 2015). Blue light is the most intense radiation of the visible spectrum that the human eye can detect (Calvo-Sanz & Tapia-Ayuga, 2020). LED lights and displays typically contain blue light in the 450 to 470 nm range, and this light is higher in energy and shorter in wavelength than most visible light (Heo et al., 2017).

Sources of Blue Light

Because of their high efficiency, small size, and long-lasting power, LED lights have risen in popularity and are replacing incandescent bulbs in homes and in commercial buildings (Tosini et al., 2016). Incandescent bulbs, the primary lighting source before LED light technology, released similar wavelengths of light that the sun naturally releases, thus posing a lesser threat to ocular health (O'Hagan et al., 2016). As prices for LED lighting became lower and lower, they gradually phased out incandescent lighting sources (O'Hagan et al., 2016). Because LEDs are small, compact, energy-efficient, and reliable, many companies use LED lights in liquid crystal displays (LCDs) and lighting fixtures (Tosini et al., 2016).

Modern computer screens, televisions, smart watches, and smartphones contain LED illuminated LCDs, drastically increasing the average amount of blue light a person is exposed to in a lifetime (Tosini et al., 2016). In fact, studies have shown that a person's blue light exposure will only increase as time goes on (Heo et al., 2017). Deng et al. (2019) estimates that the average person spends around 2.5 hours a day on their smartphone in some form or capacity. Blue light can also be emitted from fluorescent light tubes—another popular lighting option that is frequently seen in commercial buildings and public places (Leung et al., 2017). Black lights, fluorescent lights that are created with glass tubes coated in a special material that only emits UV-A and blue wavelength light, are especially strong sources of blue light (Kitchel, 2000). Black lights are commonly used in night clubs, bowling alleys, and roller-skating rinks, and there are high risks associated with long term exposure and direct gazing (Kitchel, 2000). While studies show that blue light is emitted from sources of technology, blue light is also emitted from the sun naturally, and humans are exposed to blue light in everyday settings (Huang et al., 2014).

Natural Human Defense to Blue Light Exposure

The human eye is equipped with a lens that filters light before reaching the retina. The crystalline lens of the eye absorbs wavelengths of light between 300 and 400nm, and pigments in the macula called lutein and zeaxanthin absorb high-energy short wavelength light (Downie, 2017). Because the crystalline lens is able to absorb high energy wavelengths of light, the eye is less likely to develop reactive oxygen species within the retina like lipofuscin (Margrain et al., 2004). This is a natural built-in defense for blue light exposure. As humans age, the crystalline lens becomes cloudy and yellow, decreasing the amount of blue light that reaches the lens. This decrease in daytime blue light exposure could be the cause of sleep issues in older individuals, leading to disturbances in circadian rhythms (Tosini et al., 2016). This supports the idea that blue light is a key component in the maintenance of sleep cycles and circadian rhythms.

While the eye was designed to absorb some blue wavelength light, excessive amounts can cause damage. In order to maintain proper circadian rhythm and achieve optimal retinal health, individuals must balance the amount and timing of blue light exposure. It may seem like new harmful blue light exposures have dawned on society with the progression of technologies and LED screens, but similar spectrums of light are emitted from the sun (O'Hagan et al., 2016). Some scientists argue that humans are incapable of staring at LED screens for long enough to cause retinal damage because it would simply be too uncomfortable (O'Hagan et al., 2016). This theory is demonstrated by the solar eclipse phenomenon—during a solar eclipse, a person can unknowingly damage their retinas by staring at the sun's harsh rays even though it is not uncomfortably bright. Under normal conditions, someone would never stare at the sun for a dangerous amount of time because it would be painful and uncomfortable (O'Hagan et al., 2016). O'Hagan et. al (2016) argues that a person's intrinsic ability to avoid blue light overexposure in a natural setting is innate, so why would that ability not carry over into the realm of technology and LED screens? In addition, the amount of blue light a person is exposed to through screen and technology exposure is not enough of a risk to pose public health concerns (O'Hagan et al., 2016). If LED screens were overexposing a person's eyes to blue light, their body would sense this overexposure and avoid blue light exposure innately.

Benefits of Blue Light Exposure Within Proper Limits

Blue light rules the body's circadian rhythm and internal biological clock by promoting alertness, perceptiveness, and normal daily functioning (Oh et al., 2015; Ouyang et al., 2020). Despite the majority of claims that charge blue light with retinal deterioration and general health issues, blue light is essential in maintaining proper biological rhythms (Leung et al., 2017). Studies have shown that some amount of blue light is required at the appropriate time in order to maintain proper sleep cycles (Tosini et al., 2016). In fact, avoiding blue light during daylight hours could have the same negative effect on circadian rhythms as blue light exposure at night, and it could cause detrimental sleep pattern disruptions (Leung et al., 2017). Without proper exposure to blue light during day light hours, melatonin is not properly inhibited, and a person's degree of alertness and awareness decreases causing lethargy and sleepiness (Leung et al., 2017). Proper blue light exposure is a matter of good timing and balance.

Because of blue light's ability to promote arousal and alertness, environments are often equipped with such lights where optimal functioning is essential—medical buildings, transportation systems, and military operations (Ouyang et al., 2020). In addition, blue light plays an important role in vision, contributing to color discrimination, night vision, and object differentiation (Leung et al., 2017). These factors are especially important in the engineering of blue light blocking glasses. Blue light exposure is also used to treat certain medical conditions like neonatal jaundice because of its ability to lower bilirubin blood concentrations (Ouyang et al., 2020).

Blue light is essential for normal, everyday biological rhythms, but at what point is it considered overexposure? While blue light promotes alertness and attention, how does blue light exposure affect someone who is exposed for long periods of time? What are the long-term consequences of blue light exposure, and how can this improper blue light exposure be avoided? These are the questions scientists have been asking themselves since the dawn of blue light technologies and blue light related retinal harm and biological rhythm dysfunction.

Scientific Basis for Retinal Damage

While the body was designed to function on a clock governed by blue light exposure, improper or excessive blue light exposure can cause damage. The basis for ocular damage due to blue light is the build-up of phototoxic chemicals after light exposure to the retina, but these effects depend on the amount of light exposure and its intensity (Vicente-Tejedor et al., 2018). When the retinal cell wall is exposed to large amounts of blue light at high intensity, phototoxic particles build up and cause oxidative damage (Jaadene et al., 2017). These phototoxic chemicals are called reactive oxygen species (ROS), and blue light increases their production in the retina. One of the most harmful ROS that are expressed within the retina due to blue light exposure is lipofuscin—one of the main risk factors in the development of age-related macular degeneration (Margrain et al., 2004). An excessive amount of ROS in the retina triggers cell apoptosis, and this leads to blindness (Alaimo et al., 2019). In addition, excessive blue light exposure causes severe damage to retinal tissues—photoreceptors and retinal pigment epithelium cells are damaged, and because of this, retinal ganglion cells, the cells that transduce electrical signals from the retinal to the brain, are also killed (Huang et al., 2014). Retinal damage due to blue light exposure is based on the buildup of ROS and the tissue's inability to metabolize and remove these before compounds cause damage.

Mechanisms of Blue Light Damage

The retina is composed of two different kinds of cells that transduce images to the visual center of the brain. Photoreceptors, composed of rods and cones, convert photons to light signals that can be relayed to the nervous system. Retinal pigment epithelium cells (RPE cells) work alongside photoreceptor cells to maintain the proper cell environment for retinal functioning. RPE cells control physiological functions like growth factor release, antioxidant control and secretion, and homeostatic regulation of the blood-retinal barrier (Ouyang et al., 2020). Numerous studies have shown that excessive blue light exposure damages both photoreceptor and RPE cells (Ouyang et al., 2020).

Tosini et al. (2016) has identified three mechanisms of light-induced retinal damage—photochemical, photomechanical, and photothermal. Photochemical retinal damage involves periods of short and intense blue light exposure to the retinal pigment epithelium or long periods of less intense exposure to the outer parts of photoreceptor cells (Tosini et al., 2016). This mechanism is characterized by the buildup of ROS, primarily lipofuscin, and oxidative damages to the retina (Tosini et al., 2016). In addition, the buildup of ROS within the cell causes increased inflammation and death of photoreceptors (Ouyang et al., 2020). Photomechanical damage occurs when the retinal pigment epithelium captures energy rapidly and damages photoreceptor cells (Tosini et al., 2016). Finally, the mechanism of photothermal damage occurs when the retinal cells experience a significant raise in temperature when exposed to large amounts of blue light energy (Tosini et al., 2016).

In addition to these three mechanisms identified by Tosini et al., there are two other mechanism classifications called Noell (Class I) and Ham (Class II) damage (Lawrenson et al., 2017). These mechanisms are distinguished by the differences in duration and length of exposure (Lawrenson et al., 2017). The mechanism classified as Noell damage is characterized by lower intensity blue light exposures over longer periods of time (Lawrenson et al., 2017). This includes photoreceptor damage caused by long exposures to fluorescent lights (Lawrenson et al., 2017). Ham damage, on the other hand, is characterized by short high intensity exposures to blue light (Lawrenson et al., 2017). Ham damage is known to cause more intense damage, especially at the retinal pigment epithelium (RPE) level (Lawrenson et al., 2017). Both of these mechanisms are based on the formation of ROS and the accumulation within retinal cells.

Current research suggests that all three of these mechanisms increase retinal inflammation, damage DNA, and damage mitochondria within retinal tissues (Ouyang et al., 2020). The production of ROS increases the activity of chemokines and cytokines, producing an inflammatory immune response that damages the blood-retinal barrier, RPE blood vessels, and causes photoreceptor death (Narimatsu et al., 2015; Ouyang et al., 2020). Blue light causes single and double-strand breaks in DNA, and these damages accumulate in retinal cell tissues overtime (Ouyang et al., 2020). DNA damage decreases retinal metabolism integrity, and this causes a cycle of increased ROS production (Ouyang et al., 2020). Both inflammation and DNA mutation cause mitochondrial damage in retinal tissues; in fact, studies have shown that mitochondria are the main target of ROS (Moreira & Oliveira, 2011). Because the retina is such a metabolically active tissue in the body, tremendous amounts of oxygen are demanded from the tissue, and cells contain many mitochondria (Tao et al., 2019). In fact, metabolic rates in retinal tissues are some of the highest in the body, and photoreceptor cells require 3-4 times the amount of oxygen than other retinal or nervous system cells (Tao et al., 2019). Excessive blue light exposure to retinal cells decreases ATP levels and cause mitochondrial apoptosis (Ouyang et al., 2020).

By studying LED lights and the damage caused in rat retinal tissue, Jaadene et al., (2017) discovered that high energy blue light disrupted tight junctions in the retina, increased cell size, and disorganized the actin cytoskeleton within the cell. This triggered unfolded protein response within the cell and autophagy. Other studies have connected LED light exposure and mitochondrial damages—many age-related diseases, including age-related macular degeneration (AMD), are associated with mitochondrial damage (Alaimo et al., 2019). Huang et. al (2014) studied rat retinas following long-term blue light exposure. In alignment with other studies published, his team found that blue light exposure induced severe mitochondrial damage and decrease of normal functioning, excessive overproduction of ROS, exaggerated immune responses, and a biological response to blue light induced DNA damage (Huang et al., 2014).

Eventually, all of these factors and cellular stresses cause retinal cells to undergo apoptosis (Huang et al., 2014). Apoptosis occurs in retinal cells by the pathways involved in Bcl-2, Bax, and caspase-2 signaling pathways when there is prolonged blue light exposure (Huang et al., 2014). Scientists are still studying the mechanisms of blue light damage, and these advances help researchers develop treatments for AMD and other age-related ocular diseases.

Examples of Blue Light Damage and Scientific Research

Blue light is known to cause health issues relating to the eye, but excessive blue light exposure—especially at night—can also cause sleep and psychiatric disorders that eventually lead to obesity, diabetes, and cancer (Oh et al., 2015). While ocular damage from blue light radiation exposure is a primary concern, overall health can be affected by blue light exposure, and scientists are still trying to understand the interconnected mechanisms that cause these issues.

Age-Related Macular Degeneration and Retinal Damage

Age-related ocular diseases are the leading cause of blindness and reduced vision in Americans aged 40 years and older (Centers for Disease Control and Prevention [CDC], 2020). There are over 300,000 new cases of AMD diagnosed annually, and it is the leading cause of blindness in the American elderly population (Hollyfield, 2010). In fact, AMD accounts for almost half of blind registrations in the developed world, and there is no practical prevention method or treatment option for most patients (Margrain et al., 2004). AMD affects almost 10 million Americans (Ambati & Fowler, 2012). In order to put this into perspective, consider the 12 million Americans living with cancer and compare AMD’s prevalence (Ambati & Fowler, 2012).

AMD is characterized by the loss of central vision and damage to the macula because of degeneration of the RPE (Alaimo et al., 2019). There are two kinds of AMD—wet and dry. The two types of AMD are distinguished by the presence or absence of blood vessels in the retinal tissues (Ambati & Fowler, 2012). Dry AMD is a chronic disease that has mild symptoms and occasionally causes severe blindness (Ambati & Fowler, 2012). Dry AMD progresses slowly, but left untreated, dry AMD becomes wet AMD and leads to central vision impairment; in fact, dry AMD can be considered a risk factor for the development of wet AMD (Ambati & Fowler, 2012). Wet AMD is primarily characterized by choroidal neovascularization. Choroidal neovascularization occurs when immature blood vessels overtake the retina from the choroid and leak excess fluid into the retina (Ambati & Fowler, 2012). Unlike dry AMD, wet AMD can quickly deteriorate a person’s vision and cause blindness (Ambati & Fowler, 2012).

The causes of AMD are unknown, but risk factors have been identified, and they are actively being studied by scientists today (Singh et al., 2019). The common risk factors for AMD include ageing, tobacco use, oxidative stress caused by blue light exposure, and genetic predisposition (Singh et al., 2019). There are many different factors that contribute to the onset and progression of AMD in patients, causing difficulty for scientists to fully understand the link between blue light exposure and AMD (Tosini et al., 2016). While studies have shown that blue light exposure is a factor in the development of AMD, much is still unknown about how much blue light exposure contributes to the progression of vision loss and what kinds of sources are most dangerous (Algvere et al., 2006).

Studies have shown that AMD affects populations over 50 years old, but with the increased use of LED screens and blue light exposure, scientists are unsure of blue light’s effects on AMD progression and onset. There is concern that increased blue light exposure will cause AMD symptoms to progress earlier and more quickly in patients (Alaimo et al., 2019). Because blue light technology has become more prevalent in the last 40 years and there are no long-term studies testing the effects of blue light exposure on AMD, generations of people might develop AMD more quickly as aging occurs.

One of the risk factors for the development of AMD is inflammation and an exaggerated immune response. While inflammation serves the body in times of stress by responding to pathogens or foreign materials, prolonged inflammation leads to chronic health issues (Kauppinen et al., 2016). Blue light exposure, the accumulation of ROS within the retina, and increasing retinal dysfunction due to AMD are all detected by pathogen recognition receptors (PRRs) in the immune system, and this triggers the activation of cytokines and chemokines in nearby tissues (Kauppinen et al., 2016). In addition, lipofuscin and drusen accumulation, two of the main ROS byproducts of blue light induced AMD, are pro-inflammatory molecules that also stimulate increased and prolonged inflammatory responses (Liu et al., 2013).

AMD progression is a vicious cycle of blue light exposure, increased ROS production, increased inflammatory response, decreased ability to degenerate harmful ROS species due to inflammation, age-related decreased immune function, and vision loss. AMD is a difficult disease to treat and prevent because it is so closely intertwined with immune function and aging. Aging has a negative effect on immune function, and these immune changes have a negative effect on the retina and its ability to fight drusen build-up and prevent AMD symptoms.

Alteration of Circadian Rhythms

Many organisms—including humans—function on a sleep-wake cycle called the circadian rhythm. Circadian rhythms are governed by the presence or absence of blue light, and they allow organisms to maintain a necessary cycle of work and rest (Oh et al., 2015). Circadian rhythms ensure that during the hours of 2 a.m. and 4 a.m. the pineal gland synthesizes an adequate amount of melatonin and re-sets the 24-hour biological clock (Pauley, 2004). Melatonin rules the “dark phase” of the circadian rhythm, and when secreted at night melatonin causes sleepiness and preparation for bed (Esaki et al., 2016). When the retina is exposed to blue light, retinal ganglion cells interact with the brain to control melatonin levels. Blue light exposure suppresses melatonin secretion and interferes with an organism’s biological schedule. In fact, any artificial light source that emits blue light affects the retina in the same way that natural sources of blue light would, tricking the brain into thinking that a new “day” has begun (Oh et al., 2015).

Other studies have linked melatonin suppression caused by late night blue light exposure to higher incidences of breast and colorectal cancers (Pauley, 2004). In the industrial world, there is a three to five times higher rate of breast cancer than in the developing world, with night-shift workers have a much higher chance of developing colorectal cancer (Pauley, 2004). Pauley’s (2004) study found that melatonin might be a breast cancer growth inhibitor, and low levels of melatonin due to late night blue light exposure might be the cause for higher rates of breast cancer in industrial workers.

Many of the illnesses caused by improper blue light exposure are intertwined and interdependent on each other, and they all stem from improper blue light exposure and circadian rhythm alteration and interference. One current blue light study has discovered that age-related macular degeneration (AMD), a disease characterized by progressive central vision loss, age, and blue light exposure, greatly alters a person’s circadian rhythm (Tosini et al., 2016). AMD symptoms influence circadian rhythms, and this further contributes to the symptoms of AMD—excessive blue light exposure creates a cycle of circadian rhythm disruption, illness, and further circadian rhythm disruption. In addition, circadian rhythm disruption causes sleep disturbances, and these disturbances also contribute to the progression of disease. If scientists can better understand the effect that blue light has on these biological rhythms, research may be able to correct disturbances in sleep patterns and circadian rhythms, and retinal health—as well as overall health—will improve.

Alteration of Sleep Patterns

Blue light has become an integral part of modern society, but the harmful effects of blue light on the retina and on personal sleep patterns are still being studied. When a person is unable to fall asleep easily or wake up at conventional times, doctors diagnose individuals with delayed sleep phase disorder (Esaki et al., 2016). According to Figueiro et al. (2017), almost 29% of adults get less than six hours of sleep on a typical weeknight. In Watson et. al’s (2015) Joint Consensus Statement released by the American Academy of Sleep Medicine and Sleep Research, the minimal amount of sleep recommended by experts is seven hours. With the obvious discrepancy between the recommended amount of sleep and the actual amount of sleep many people are getting, sleep research efforts have focused on increasing sleep quality and identifying elements that disrupt sleep patterns. Understanding the true effects of blue light on sleep patterns is important because poor sleep quality can lead to other complications and diseases such as depression, immune dysfunction, hormone dysfunction, anxiety, diabetes, obesity, cardiovascular disease, and certain kinds of cancers (Nagare et al., 2019; Watson et al., 2015). In addition, poor sleep quality can cause increased risk for injury and safety-related performance issues (Figueiro et al., 2017).

Sleep cycles are governed by circadian rhythms, and circadian rhythms are maximally sensitive to blue light exposure (Nagare et al., 2019). There is a correlation between blue light exposure before bed and disturbances in sleep cycle rhythms, often leading to fatigue, restlessness, and poor sleep quality (Jniene et al., 2019). In fact, scientists have discovered that smartphone use at night alters circadian rhythms and decreases melatonin secretion (Oh et al., 2015).

In a 2017 study, scientists tested people after exposure to blue light emitted by smartphones at night by analyzing their melatonin levels, cortisol levels, body temperature, and level of calmness (Heo et al. 2017). Two kinds of LEDs were tested—one that mimicked blue light (but in reality, was an LED without blue light) and an LED with blue light. Groups were exposed to each LED for a week with a washout week in between. It was shown that adults expressed decreased sleepiness before bed when exposed to the blue light LEDs. This study further proves that blue light has a negative effect on sleep patterns, and smartphone use before bed prevents good rest (Heo et al., 2017). Other studies have tested the duration of exposure before bed and how that can affect sleep patterns. Wood et al. (2013), discovered that blue light exposure from an iPad at full brightness before bed had minimal effects after one hour of exposure, but that after two hours of exposure melatonin levels began to drop.

In another recent study, scientists studied the differences between eight different LED screens—two AMOLED screens, two IPS-NEO screens, two IPS-LCD screens, one screen with IPS-LED, and one screen with IPS IGZO (Calvo-Sanz & Tapia-Ayuga, 2020). These screens were manufactured by Blackberry, Oneplus, Huawei, Apple, Asus, and Vernee (Calvo-Sanz & Tapia-Ayuga, 2020). This experiment analyzed and observed the amounts of blue light emitted from different screen manufacturers and found that each screen emitted unique amounts of blue light (Calvo-Sanz & Tapia-Ayuga, 2020). This research was valuable in determining the kind of LED screen that was least harmful to sleep quality, but further research could be conducted that tests the effects of each LED screen on the retina over time. This research is the basis for the studies behind the invention of a retina-safe LED screen that emits limited amounts of harmful blue light.

Blue Light Radiation Damage Prevention Methods

The most obvious way to reduce the amount of blue light exposure is simple—avoidance. But in a technologically advanced world, how does someone simply avoid blue light when it seeps out of the pores of our own homes, communities, and world? LED light provide light displays for television screens, a major form of entertainment, and cell phones, a major avenue of communication and news from around the world. LED light also illuminates homes and buildings sustainably and comfortably. There are many new methods of prevention that exist. Some of these methods are more exploratory; antioxidants, for example, are still being tested for efficacy, and new products are being developed that would integrate the ROS neutralizing powers of these compounds so they can be used in medicinal forms. Other methods are simple ways to reduce the amount of blue light emitted from devices and irradiated to a person's retina.

Antioxidants

One of the most damaging by-products of blue light retinal exposure is the formation of ROS. Fortunately, antioxidants are compounds that can stop oxidative chain reactions and delay oxidative damages by neutralizing reactive oxygen species in body tissues (Gülçin, 2010). In a study conducted by Bapary et al. (2019), there was a direct correlation between antioxidants and a decrease in ROS, further emphasizing the hypothesis that antioxidants have ROS reducing powers. Retinal cells are able to produce enzymatic and non-enzymatic antioxidants on their own, and these antioxidants act as a mechanism of defense against harmful reactive oxygen species (Margrain et al., 2004). As a person ages, their ability to produce antioxidants and neutralize reactive oxygen species declines, leaving the elderly susceptible to reactive oxygen species build-up and severe oxidative damage to the retina (Margrain et al., 2004). Older generations are unable to create antioxidants independently, so antioxidant therapy is an effective and beneficial treatment for older patients (Margrain et al., 2004).

The effect of cranberry juice antioxidants on a macular lesions were tested by measuring the phenolic compounds present in cranberry juice, the antioxidant capacity, and reducing power by HPLC analysis using a mouse CRP-19 cell line (Chang et al., 2017). While the scientists were able to determine the antioxidant properties and limits of cranberry juice, they were unable to identify the exact mechanism by which the phenolic compounds were able to interact with the retinal cell wall. Antioxidant treatment is effective in decreasing the effects of blue light exposure in the retina, but other methods have been proven to be more effective and successful.

Night Shift Modes on Devices

There are many factors that influence the amount of blue light emitted from screen technologies including program code, the mobile operating system, and screen engineering (Calvo-Sanz & Tapia-Ayuga, 2020). A study testing the efficacy of a program released by apple called “night-shift” mode settings on iPads showed that melatonin levels were still suppressed even when the color gradient was shifted to warmer tones (Nagare et al., 2019). In other words, even with the “night shift” mode was activated on devices, negative effects on sleep patterns and decreased melatonin levels were observed in participants. Melatonin suppression did not significantly change between the two modes (Nagare et al., 2019). In order to avoid the decrease of melatonin production, research suggests that it is more effective to turn down the brightness setting on laptops in addition to turning on “night shift” instead of solely relying on the “night-shift” setting (Nagare et al., 2019). These technologies are being studied further in order to create new screens that emit the minimum amount of blue light, but researchers have found that software controlled blue light reduction has a minimal effect on reducing blue light exposure and melatonin suppression (Calvo-Sanz & Tapia-Ayuga, 2020).

Blue Light Blocking Glasses

Many companies have developed blue light filtering glasses that claim to have a positive effect on sleep and decrease eye strain. While these lenses should be effective based on laboratory results, it is still debated among scientists if these lenses work effectively or not (Downie, 2017). The sudden spike in blue-light glasses' popularity has increased ocular health awareness and introduced conversations about blue light exposure, but some scientists believe that blue-light filtering glasses are ineffective.

Theory of Design

In theory, blue light blocking glasses will reduce the amount of blue wavelength light hitting the retina and reduce the formation of ROS (Margrain et al., 2004). Many companies coat lenses with filtering materials that reduce the amount of blue light that reaches the eye, but it is challenging to create a lens that filters an adequate amount of blue light while still maintaining the visual integrity of the lens (Leung et al., 2017). Other approaches include coating lenses with a brown/yellow tint that will absorb blue light as it passes through the lens (Leung et al., 2017).

Debate of Effectiveness

In theory, blue light blocking glasses should reduce the amount of blue light that reaches the retina and reduce blue light overexposure by reducing the amount of blue light wavelengths that pass through the lens. Interestingly enough, some studies argue that blocking blue light exposure with lenses could have a negative effect on circadian rhythms and biological clocks (Margrain et al., 2004). These arguments are supported by the idea that normal blue light exposure is essential in alertness and the reset of circadian rhythms, and that the complete removal or drastic reduction of blue light would inhibit biological clock function. While this argument could theoretically be true, there is also argument that the effects of blue light blocking lenses would not be so drastic (Margrain et al., 2004).

While there are numerous studies that connect blue light exposure to ocular disease and circadian rhythm disruption, there are just as many studies that test the effectiveness of blue light blocking glasses and find that there are minimal improvements to ocular or retinal health (Singh et al., 2019). Lawrenson et al. (2017), for example, conducted a study that tested the effects of blue light blocking glasses and found that there were no significant changes or improvements in participant's levels of eye strain or sleep quality. Participants were asked to wear blue light blocking glasses for a period of time and record their observations. Subjective results from participants were compared to a group that wore clear lenses, and their results were inconclusive. There were no observable discrepancies between the participants and the control group (Lawrenson et al., 2017).

Another study conducted by Leung et al. (2017), tested five different blue light blocking lenses and measured their ability to block blue light transmission and reduce melatonin suppression. While the lenses were very successful in reducing the amount of blue light transmission through the lens, there was only a very small decrease in melatonin suppression efficiency (Leung et al., 2017). With that being said, participants in the study reported improved vision while viewing a computer screen and decreased sensitivity to light (Leung et al., 2017). The disadvantages of blue light glasses have been considered and identified. The main concerns blue light blocking lenses pose are the alteration of circadian rhythms due to improper timing of blue light blocking, color perception alterations, and decrease in night vision (Lawrenson et al., 2017). The theory and the methodology of blue light glasses are there, but how effective are they really, and how do they actually affect the people who wear them?

Cultural Impact

In developed countries, media and marketing have a direct impact on culture—particularly health and wellness. Numerous marketing campaigns for blue light glasses have emerged since the dawn of blue light technology, and many claim that blue light blocking lenses can alleviate ocular discomfort, reduce eye strain, improve sleep quality, and provide a barrier against blue light retinal exposure and reduce phototoxicity (Singh et al., 2019). While these marketing campaigns are true to a certain degree, there is a lack of public educational support surrounding these claims. For example, studies have shown that in some scenarios blue light can cause retinal damage, ocular strain, sleep disturbances, aging, and certain kinds of cancers, but blue light also has positive effects on daily rhythms and alertness, and these ideas are left behind in the dark—figuratively and literally (Singh et al., 2019). Instead of educating the public on the importance of balanced blue light exposure and avoiding blue light exposure at night, companies are advertising blue light blocking glasses' ability to prevent retinal damages and alleviate eye strain. This causes blue light exposure to be seen in a negative light (again—both figuratively and literally), persuading people to purchase blue light lenses based on the idea that they will dramatically save their retinas from unprecedented ocular damage.

Systematic literature reviews studying the effectiveness of blue light blocking glasses show no evidence of blue light blocking lenses' ability to scientifically alleviate eyestrain, improve a person's quality of sleep, or protect the retina from oxidative damage (Lawrenson et al., 2017). In order to obtain this data, researchers need to conduct high quality clinical studies that can experimentally observe and explain the mechanisms that media campaigns are promising to customers. These high-quality studies are currently lacking in scientific literature

(Lawrenson et al., 2017). Lawrenson et al. (2017) also makes a very interesting point regarding subjective clinical studies that test the effectiveness of blue light glasses. Often times when a participant is asked to describe their level of ocular discomfort after completing a task on a computer screen, their reported discomfort could come from many different places. The participant could have an uncorrected refractive error that is causing this underlying discomfort, or the patient could have an oculomotor issue that has been left unaddressed (Lawrenson et al., 2017). Discomfort caused by blue light exposure versus other ocular issues can be difficult to separate, and subjective studies leave room for false data and misinterpretation.

Current Blue Light Research and Further Study

While scientists understand the general risk factors involved in blue light exposure and retinal damage, there are many gaps in knowledge concerning the exact mechanism that causes this damage (Huang et al., 2014). It is understood that ROS production leads to mitochondrial damage and DNA mutations, but scientists still do not understand the exact methods of this damage and are still looking for more information about how blue light is toxic to retinal cells. Integrated mechanisms of retinal damage connecting blue light exposure, ROS production, and apoptosis are still being sought after (Huang et al., 2014).

Nagare et al. (2019) observed the difference between blue light induced melatonin suppression in adolescents and adults and found that melatonin suppression in adolescents is almost 15% higher than adults when exposed to LED screens before bed. This is an area of research that could be explored more thoroughly, and long-term comprehensive studies evaluating the effects of blue light on developing adolescent retinas could be of great value to the scientific community. Because many of the negative implications surrounding blue light exposure affect older populations, there are few studies that observe the effects of blue light on children and adolescents exclusively, and long-term awareness would provide helpful information regarding appropriate screen exposure.

While there are many new and exciting blue light damage prevention methods, scientists admit that blue light blocking lenses are vastly understudied (Singh et al., 2019). There are few long-term studies conducted on the effects of blue light exposure and the effectiveness of wearing blue light blocking lenses. While scientists have been working hard to develop preventative and restorative methods for blue light damage and the associated diseases and symptoms, the most effective way to avoid blue light retinal damage is to simply avoid blue light at night.

Discussion and Conclusion

As the world advances technologically, healthcare professionals and researchers must advance as well. With new technologies come new hazards, and it is important for scientists to identify these hazards and research their effects. LED lights have given society the opportunity to work at all hours of the day, and it has increased productivity across the board. But what is the price for this productivity? Scientists have identified blue wavelength light and studied its implications. While it has negative effects on age-related disease progression, circadian rhythms, and sleep patterns, blue light is an essential part of a person’s biological clock, and it is important to receive blue light exposure from natural sources during the day. Blue light aids in alertness and proper circadian rhythms, but there are known mechanisms of damage that affect the retina and lead to ROS overproduction and phototoxic chemical buildup.

These mechanisms are still being actively studied by scientists, but the current photochemical, photomechanical, and photothermal theories of retinal damage are acceptable, and they account for many of the biological processes that generally explain drusen and lipofuscin buildup. Oxidative stress and the buildup of ROS account for many of the complications seen in the retina when overexposed to blue light. ROS accumulation is largely responsible for AMD and other signs of retinal aging. In addition to ROS buildup, the alteration of circadian rhythms and sleep patterns proves to be one of the more concerning implications of blue light exposure. Circadian rhythms are strongly influenced by the presence or absence of blue light, and the timing of blue light exposure plays a huge role in maintaining proper biological rhythms. In fact, correct timing of blue light exposure is an essential part of cultivating a healthy circadian rhythm. Studies show that it is just as essential as avoiding blue light overexposure. Proper blue light exposure is the foundation for a healthy circadian rhythm, a healthy circadian rhythm is the foundation for healthy sleep cycles, and adequate sleep is the foundation for overall health and the avoidance of chronic and short-term illnesses like depression, anxiety, hormonal imbalances, cardiovascular disease, and cancer.

The prevention methods discussed in this review are diverse—antioxidants provide defense against ROS buildup and decrease oxidative stress placed upon retinal cells. This method is more experimental, and it does not prevent blue light exposure. Antioxidants just “clean up” the aftermath of free radical formation. “Night shift” modes on computers, phones, and laptops, theoretically reduce the amount of blue light being emitted from devices illuminated by LED screens, but studies show that these modes are largely ineffective. The same is true for blue light blocking glasses. While the amount of blue light that reaches the retina is effectively reduced, melatonin secretion is still only inhibited slightly. All of these methods discussed above are effective in their own way, but the most effective way of reducing blue light exposure is pure avoidance.

Blue light technology is relatively new—computers and tablets have made their way into everyday culture within the past forty years, so long-term implications of regular, increased blue light exposure must be further studied in order to fully grasp the associated health consequences. Long-term clinical studies of retinal tissues and the progression of age-related diseases like AMD are necessary in understanding the actual effects of blue light exposure over long periods of time. Even though blue light glasses might be moderately ineffective, there is some benefit to protecting retinal tissues from excess blue light exposure, especially until long-term studies are released that analyze blue light exposure and ocular health.

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