VILNIUS UNIVERSITY

MEDICAL FACULTY

The Final thesis

Eyeglass Lens Coatings (Anti-reflective, Blue Light Blocking). Literature Review

Student: **Oleksiy Petrenko, VI year, 4 group**

Institute of Health Sciences, Department of Optometry

Supervisor Assoc. prof. dr. Saulius Galgauskas

Consultant (if applicable) ______________

The Head of Department/Clinic Assoc. prof. dr. Saulius Galgauskas

2023

Email of the student: oleskiy.petrenko@mf.stud.vu.lt

SUMMARY

This thesis explores the advancements in eyewear technology, particularly the development of advanced coatings and materials for eyewear, and their impact on the optical industry. The study includes a systematic search of the Medline database, primarily through PubMed, to investigate the effects of different coatings on eyeglasses. The findings indicate that antireflective coatings, sol-gel coatings, and ophthalmic lens coatings have significantly improved vision by reducing reflection, increasing thermal resistivity, and enhancing mechanical durability. High wrap frames and high base curve lenses have been found to be effective in preventing UV radiation, while coatings with low UV reflectance can provide adequate protection. Blue-light filtering lenses have been shown to reduce blue light transmission with minimal impact on visual performance, but their effectiveness in reducing digital eye strain is still a topic of debate. The study concludes that advancements in eyewear technology have significantly improved the quality and effectiveness of eyeglasses, and ongoing research aims to further improve eye protection and visual performance.

KEYWORDS

Eyeglasses, ophthalmic lens coating, lens coating, blue light blocking, antireflective coatings, antireflection coating, ultraviolet, UV, circadian rhythm, damage.

INTRODUCTION

Eyeglass lenses can be treated with a variety of coatings that improve their durability and functionality. These coatings can serve different purposes and are available for all types of glasses, including single vision, bifocal, and progressive lenses. There are four main types of coatings that can be applied to eyeglass lenses, including anti-reflective, anti-fog, UV protection, and scratch-resistant coatings.

Anti-reflective coating, for example, is designed to reduce glare and improve vision by eliminating reflections on the surface of eyeglass lenses. This makes it easier to maintain eye contact and prevents eyestrain. Moreover, the coatings enable more light to pass through the lenses, which improves your ability to see small patterns and letters. These coatings are particularly beneficial for individuals who are sensitive to glare from headlights and other sources of light while driving at night.

Scratch-resistant coating is another common type of lens coating that makes the lens more resistant to scratching, helping to keep it in good condition and providing sharp vision. Most lenses today have a built-in scratch-resistant coating.

Anti-fog coating is designed to eliminate condensation on the lens, which can prevent fogging during temperature changes or physical activity. This type of coating can be particularly useful for individuals who frequently move between different environments.

Finally, UV protection. The coating is crucial in blocking ultraviolet rays from reaching the eyes, which can cause various eye diseases and conditions such as inflammation, sunburn, cataracts, and eye cancers. Polycarbonate and high-index plastics have 100% UV protection built-in. (1) Exposure to UV light can increase the risk of eye diseases and conditions, which can be reduced by wearing sunglasses, particularly for those who spend a lot of time outdoors under the sun or near water and mountains. (2)

LITERATURE SEARCH STRATEGY

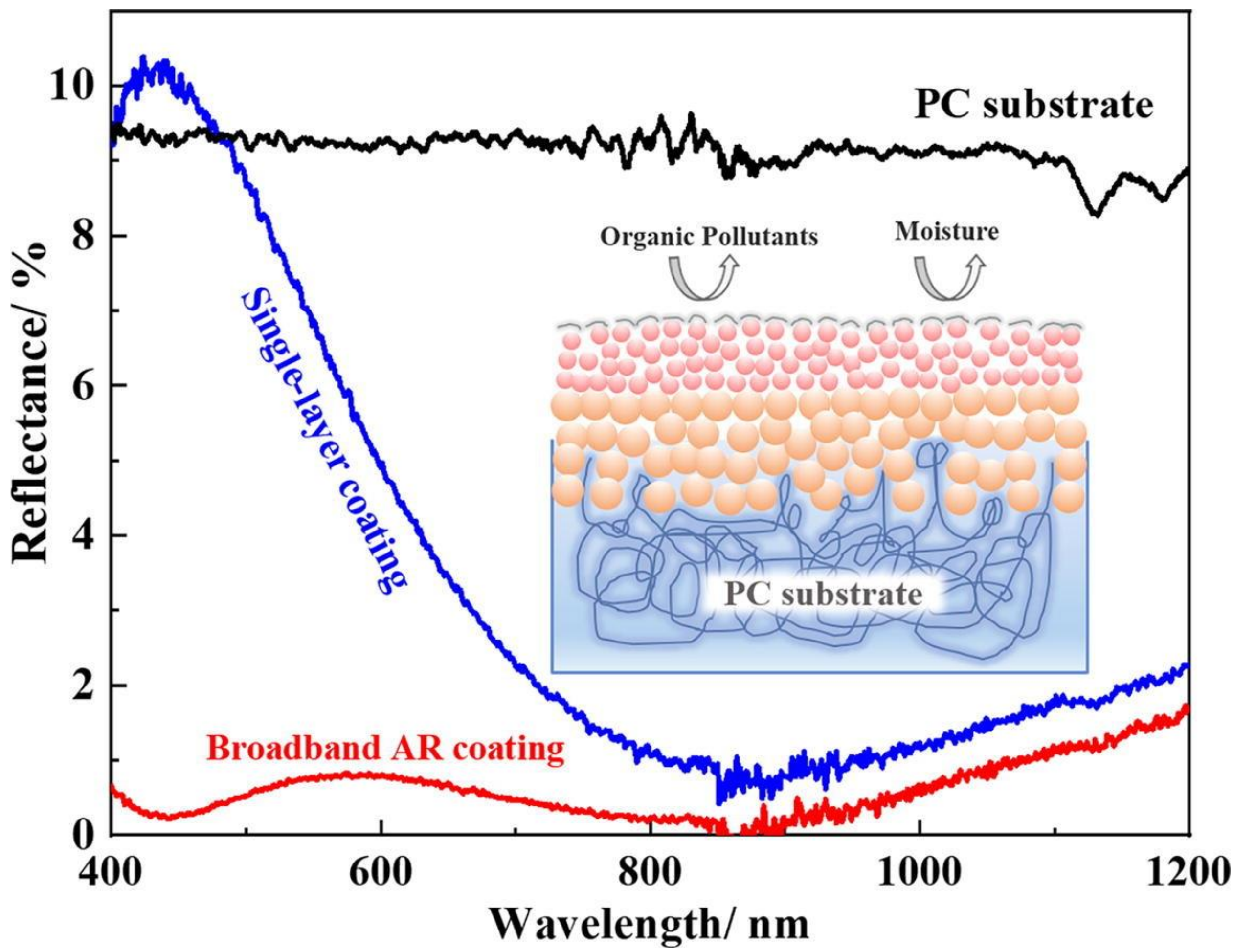
In order to thoroughly investigate the impact of coatings on eyeglasses, a systematic search of the Medline database was carried out primarily through PubMed, a comprehensive scientific literature source. However, due to the limited number of articles found, references from other sources such as the American Academy of Ophthalmology, ScienceDirect webpage, and several third-party websites were also considered. The oldest article found in the references dates back to 2006, with the majority published between 2006 and 2023. Specific keywords such as eyeglasses, coatings, lens, lens coatings, blue blocking lenses, and antireflective lenses were used to ensure all relevant studies and reports were included, given the scarcity of research on this topic. Publications of all levels were considered to gather as much relevant information as possible. The articles analyzed were written in English. The goal of this systematic search was to collect comprehensive information about the effects of different coatings on eyeglasses.

OVERWIEW OF LENS COATINGS

Antireflection Coatings and Their Applications in Optical Systems and Industrial Sectors

Antireflection (AR) coatings are essential for reducing reflection in optical systems, particularly for lenses and glasses with a high refractive index, which reflect more light. These coatings work by producing two sets of reflections that interfere destructively, allowing more light to reach the eyes and improving vision. The coating is usually made up of thin dielectric layers of materials like SiO_2, Al_2O_3, Y_2O_3, or MgF_2. (3) Besides lenses and glasses, antireflection coatings also have many applications in optoelectronic devices such as LEDs, solar cells, and displays. Advances in nanophotonics and nanofabrication have enabled the development of miniaturized and ultrathin antireflective coatings that could improve the performance of these devices. However, the cost and mechanical robustness of plasmonic- and metasurface-based AR coatings remain obstacles to their real-world application. (4)

The use of optical plastics such as polycarbonate (PC) in optical components has gained popularity due to their superior properties compared to traditional optical glasses. However, just like glass, plastic surfaces also suffer from unwanted light reflection, leading to decreased performance. Therefore, AR coatings are essential for optical plastic components. Sol-gel coating methods have shown promise in producing effective AR coatings for PC substrates. Despite this, there are challenges in improving the mechanical properties and environmental stability of sol-gel AR coatings. To overcome these challenges, a triple-layer AR coating with graded refractive index was designed and prepared for PC substrate using chloroform vapor treatment. The importance of surface free energy and surface morphology for environmental stability was also highlighted, and a treatment using vapor treatment of water and hexamethyldisilazane (HMDS) was described to improve contamination resistance. (5)



(5) Graphical abstract

In addition to the use of sol-gel coatings for antireflection purposes, they also have a wide range of applications in other industrial sectors due to their superior optical, mechanical, and functional properties. Eyewear, such as hard coats and antireflective coatings, are some of the areas where sol-gel coatings find extensive use. As touch screen devices continue to gain popularity, there is an increasing demand for transparent functional coatings like anti-glare, anti-fingerprint, and anti-static coatings, which require mechanical durability. Sol-gel coatings have been found to be useful in meeting these requirements. The ease of manufacturing, application, and curing of the coating material makes them even more attractive for industrial applications. (6)

Anti-reflection coatings play a crucial role in the optical industry, especially in eyewear. However, traditional anti-reflective coatings have been known to suffer from poor scratch resistance and high scratch visibility, which can limit their use in applications that require high mechanical durability. In response to this challenge, new anti-reflective coatings with extremely high scratch resistance have been developed using reactive sputtering processes that are scalable for industrial applications. These coatings have a surface reflectance below 0.7%, low colour shifts, and have shown excellent scratch resistance that exceed commercial chemically strengthened glasses. (7)

Advances in Ophthalmic Lens Coatings for Anti-Reflection Properties

The development of ophthalmic lens coatings is a significant advancement in the optical industry. To achieve ultrathin coatings with anti-reflective proficiency over a wide wavelength range, thermal resistivity, and mechanical durability, various scientific techniques have been employed. However, each type of coating has its own limitations. Monolayer AR coatings, for example, only reduce reflectance at a specific wavelength and lose efficiency as the angle of light incidence varies. Fabricating porous nanostructures by adjusting the refractive index of the coating through porosity has been suggested as a solution to this issue. Double and multilayer AR coatings are also used, with the former using a top layer with a lower refractive index than the bottom layer near the substrate. Bilayer AR coatings, known as V or W shape coatings, cannot achieve AR efficiency over a wide spectrum region. Despite this, many research groups have successfully developed bilayer AR coatings following this principle. (8)

Recent developments in the optical industry have focused on creating advanced coatings that offer antireflection and antifogging properties. One promising method involves layer-by-layer deposition of mesoporous silica nanoparticles and poly (diallyldimethylammonium chloride) to create coatings that are both substrate-independent and offer a maximum transmittance of 99.9% in the visible spectral range. The coatings can be applied to a variety of substrates, including polycarbonate and Columbia resin CR-39, which are commonly used in eyewear. (9) Meanwhile, a study has examined the interface and optical characteristics of CR-39 AR-coated eyeglasses. The study found that hard-coated and single-sided AR-coated eyeglasses had smooth and homogeneous surfaces, while double-sided AR-coated glasses had defects of 200-250 nm that did not affect vision. The eyeglasses with AR coating on both sides had high transmittance, low absorption, and good spectrum transmittance. (10)

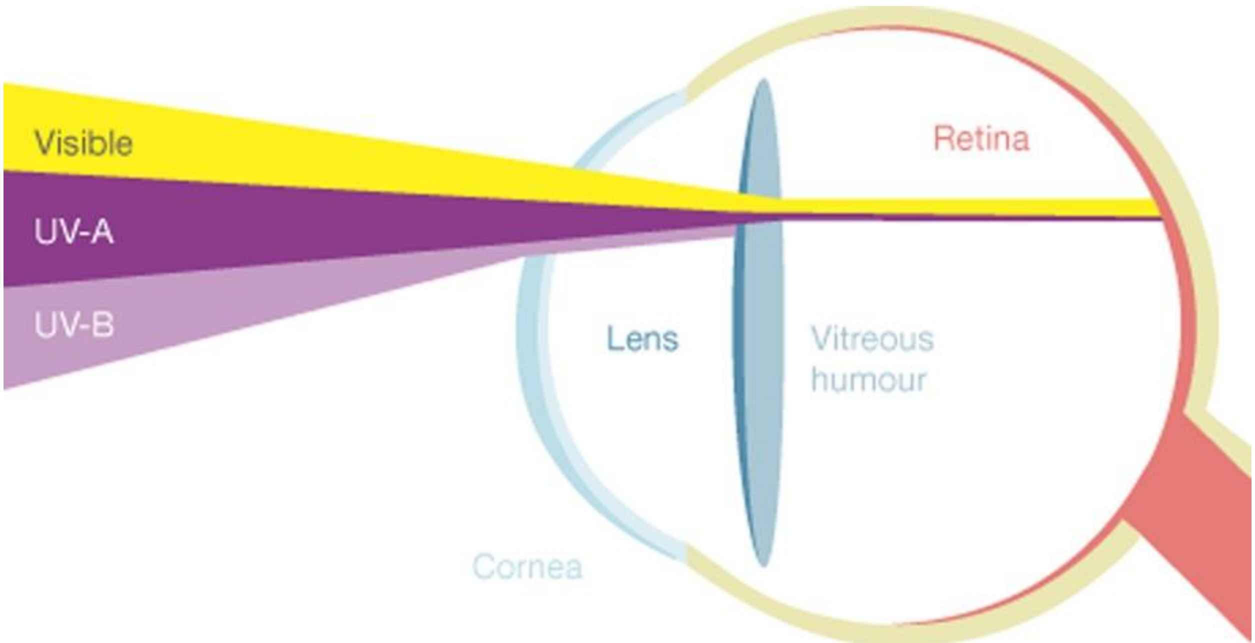
Researchers are continually seeking to improve the performance of eyeglasses through the development of new coatings and materials. One promising area of research involves biomimetic nanostructures inspired by the unique nanostructure of moth eyes. The moth-eye nanostructure is ideal for anti-reflective coatings, as it minimizes reflection and maximizes light transmission. Some companies have already started using this technology in their eyeglasses, creating the moth-eye-like nanostructures on the lens surface using a process called nanoimprint lithography. This has been shown to reduce glare and reflections, resulting in clearer vision for the wearer. However, it is important to note that this technology is still relatively new and may not be widely available or affordable. Additionally, the effectiveness of the anti-reflective coating may depend on various factors, such as the angle of incident light and the quality of the coating, making it unsuitable for everyone and in all situations. (11) (12)

The Importance of UV Protection in Eyewear and the Role of Coatings and Lens Materials

While AR coatings can be effective in reducing reflections and improving visual clarity, they have not typically been designed to address UV reflectance. This can result in harmful levels of UV radiation being reflected back into the wearer's eyes, particularly in sunny environments.

To address this issue, researchers have explored different lens materials and eyewear designs to provide adequate protection from UV radiation. One study evaluated the transmittance and reflectance properties of various clear and tinted lens materials, finding that high wrap frames and high base curve lenses can be effective in preventing UV radiation from reaching the eye. This suggests that eyewear design can play a crucial role in protecting the eyes from harmful UV radiation. (13)

This is important because the nasal area of the eye is particularly vulnerable to UV damage, which can contribute to the development of conditions such as pinguecula and pterygia. However, coatings on lenses can also impact their functionality and contribute to the total UV burden on the eyes. While coatings on both sides of lenses can reduce reflection in the visible range and improve transmission and contrast, some antireflective coatings can increase UV reflection compared to no coating at all. This means that even lenses that block 100% of UV transmission may not offer complete UV protection due to the reflection from the back face of the coated lenses. Thus, when evaluating the effectiveness of sun-protection measures, it's crucial to consider both transmittance and reflectance to comprehensively assess the eye-protecting properties of these measures. It's important to note that coatings can still be useful in reducing visible light reflections and improving contrast, but it's crucial to choose coatings that also have low UV reflectance to provide adequate protection from harmful UV radiation. (14)

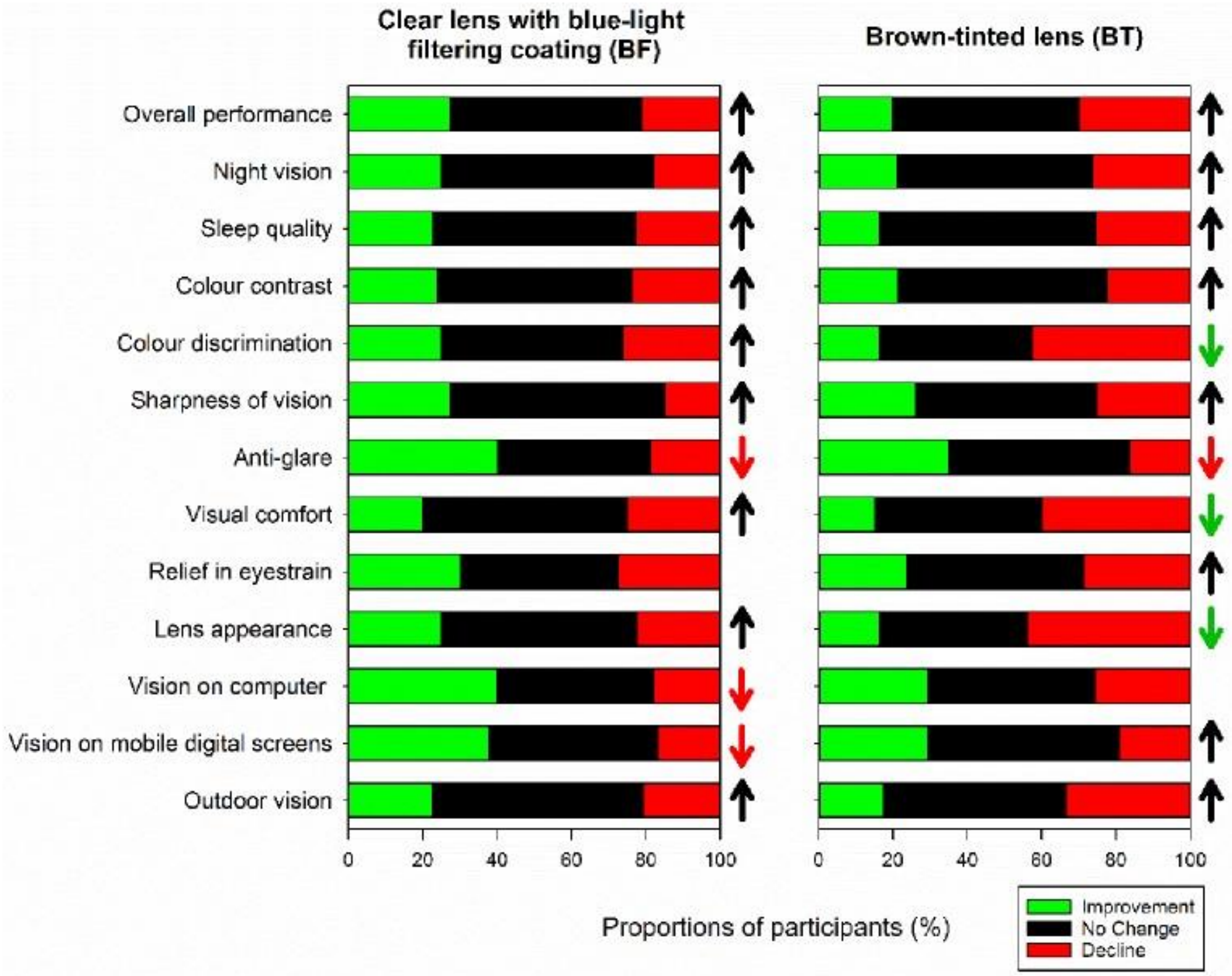


(14)

Another aspect to consider is the effect of UV radiation on the impact resistance of different ophthalmic lens materials. A study conducted a ballistic impact test to assess the impact resistance of various lens substrates and coating treatments, including scratch-resistant and antireflection coatings, after prolonged exposure to UV radiation. The results showed that the impact resistance of the tested lens substrates commonly used for occupational eye protectors significantly decreased after exposure to UV radiation. The study recommends replacing protective lenses that have been regularly exposed to high levels of UV radiation, even if there is no visible damage or wear and tear, to ensure optimal impact protection. Specifically, the study found that coated lenses exhibited reductions in fracture velocity ranging from 3.5 to 4.8 m/s after UV radiation exposure. This suggests that the impact resistance of protective lenses may be compromised over time with UV radiation exposure, underscoring the importance of regular replacement of lenses to ensure adequate protection. (15)

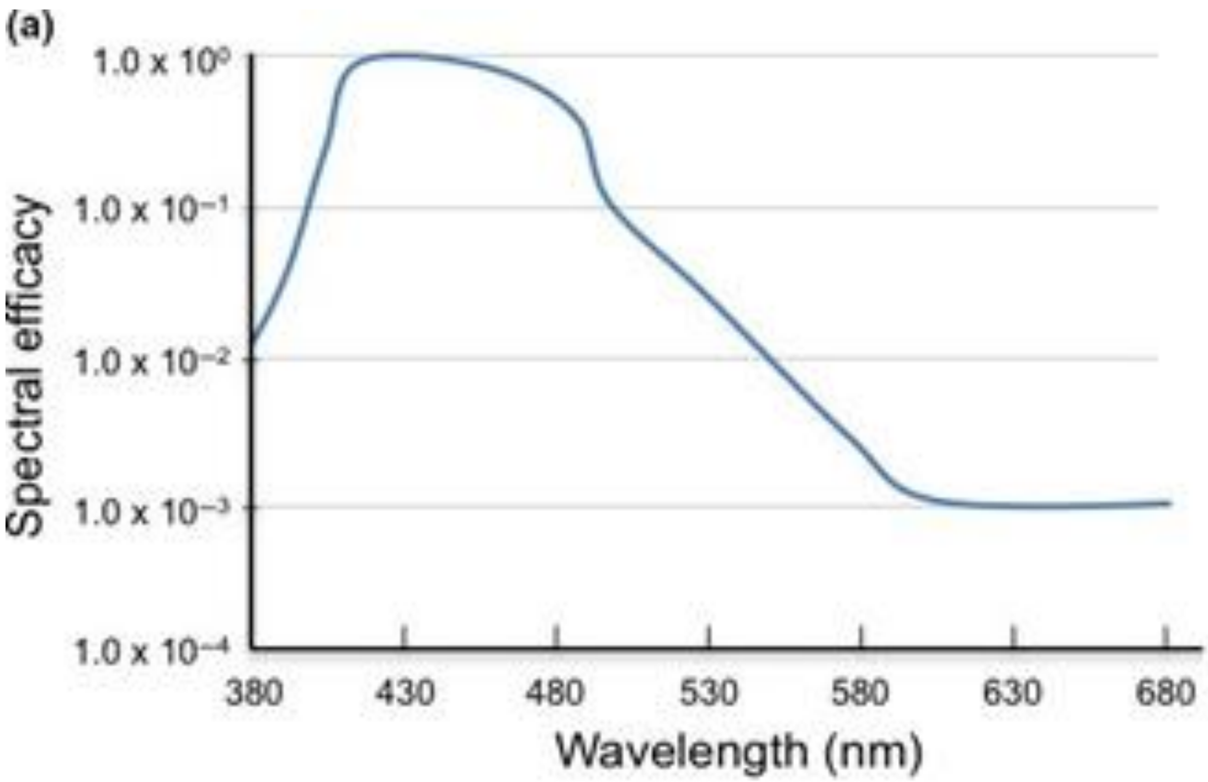
The Protective Efficacy of Blue-Light Filtering Lenses

Blue light blocking glasses are designed to protect our eyes from the harmful effects of blue light, which is emitted by digital screens, LED lights, fluorescent lamps and other artificial sources of light. Overexposure to blue light can be phototoxic and has been implicated in several eye diseases, including age-related macular degeneration (AMD). However, blue light is essential for normal night vision and circadian rhythms. To evaluate the protective efficacy of blue-light filtering lenses against blue-light hazard, a study was conducted which included spectacle and intraocular lenses. The study found that all five blue-light filtering lenses chosen in the study reduced blue light transmission while maintaining sufficient visible light for twilight and night driving. In fact, laboratory studies have confirmed that reducing blue-light transmission through a blue-light filter by 50% could reduce approximately 80% of photochemical damage to the retina. The study used established standards to calculate the theoretical protective efficacy of these lenses, which revealed that blue-light filtering spectacle lenses theoretically reduced 10.6% to 23.6% of the potential phototoxicity by blocking the hazardous radiation between 400 to 500 nm. These lenses are non-invasive, easy to prescribe and handle, and can serve as a useful protective measure against blue-light hazard. (16)



(16)

While one concern of using blue-light filters is that they can attenuate scotopic sensitivity and melatonin suppression, the study found that the lenses slightly attenuate these by only 2.4% to 7.5% and 5.8% to 15.0%, respectively. Additionally, the study evaluated the impact of blue-light filtering lenses on visual performance and found that they did not significantly affect contrast sensitivity with and without glare or colour vision of the wearers. In fact, a clear lens with a blue-filtering coating was found to provide better anti-glare performance and improved vision for computer and mobile digital screens for more than one-third of the wearers. Therefore, the study suggests that blue-light filtering lenses can help protect against blue-light hazard without significantly affecting visual performance, and the data from the study can serve as a framework for future lens design. (17)



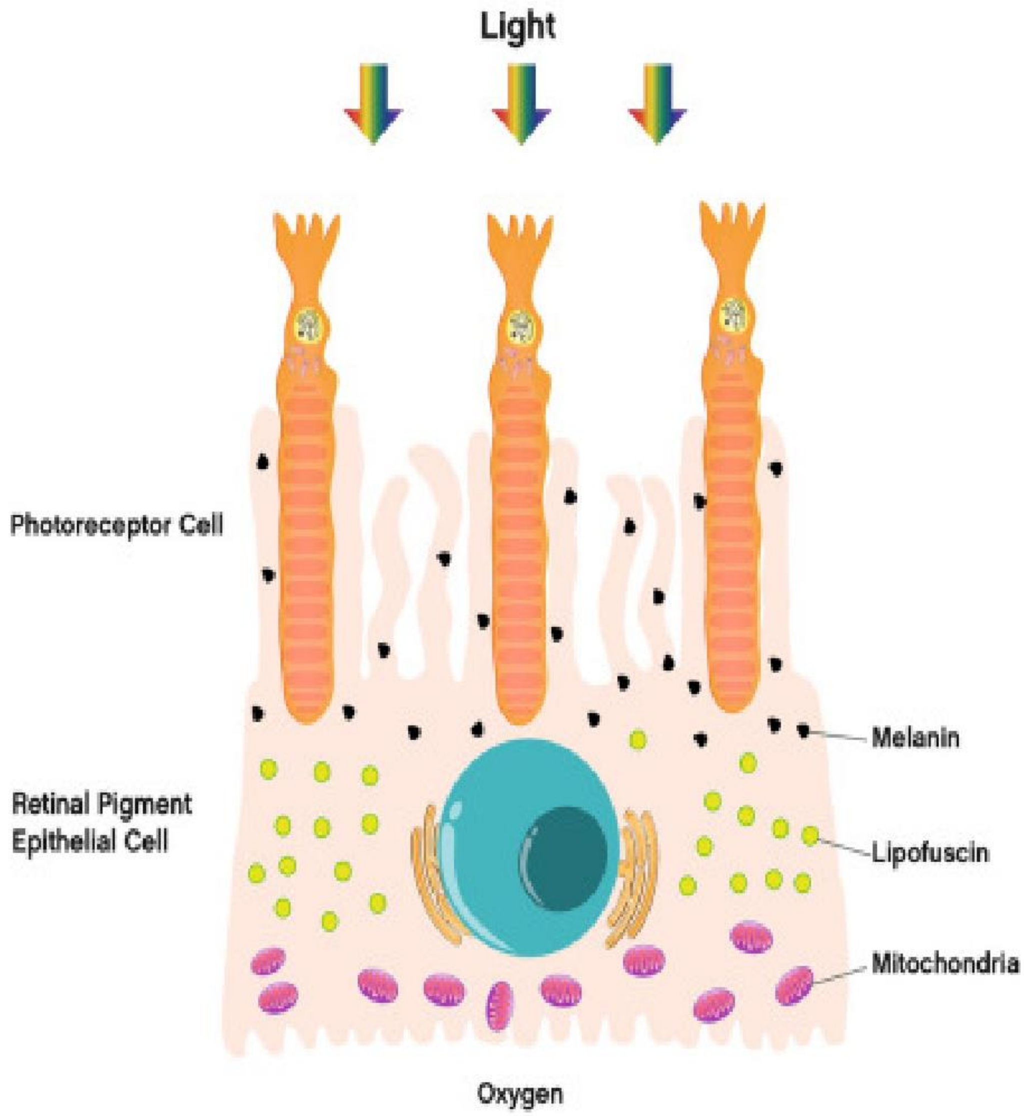
(17)

The Effects of Blue Light on the Eyes and Retina

The previous paragraph highlighted the importance of blue light in regulating nonvisual functions and the potential risks associated with blue light exposure. This section will further explore the effects of blue light on the eyes and the retina. When light enters the eye, it passes through various transparent media, including the cornea, lens, and vitreous humor, before reaching the retina. The retina contains photosensitive cells, such as rods and cones, which convert light into electrical signals that are sent to the brain. Blue light, in particular, plays a significant role in regulating the body's circadian rhythm through specialized cells in the retina called melanopsin-expressing retinal ganglion cells.

However, exposure to excessive blue light can have harmful effects on the eyes and the retina. Blue light and ultraviolet light have been linked to cataracts and retinal damage, respectively.

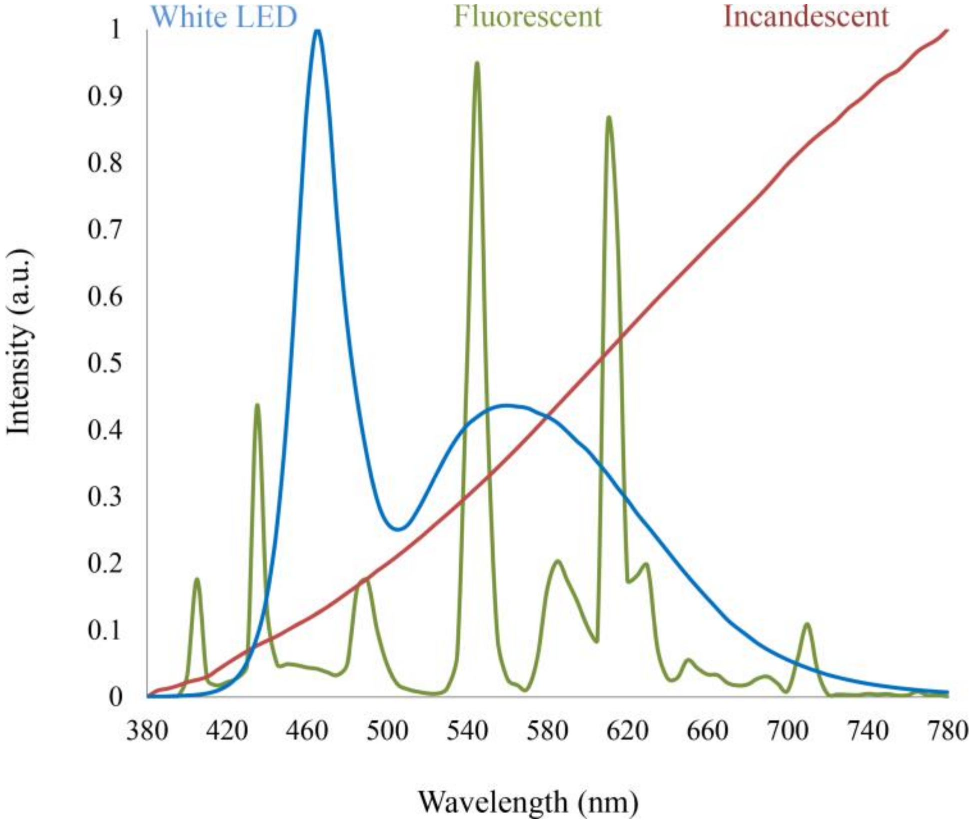
The retina is especially vulnerable to damage from blue light, which can cause oxidative stress, inflammation, and cell apoptosis. Studies have shown that excessive exposure to blue light with wavelengths between 400 and 500 nm can lead to severe photochemical injury of the retina, resulting in the loss of photoreceptors and lipid peroxidation. There are still ongoing studies to determine the exact mechanisms of blue light damage to the retina. (18)



(18)

The ocular surface, which includes the tear film, corneal epithelial tissue, and conjunctival tissue, is the first barrier against irradiant energy and is susceptible to light hazard and abnormalities. Research has shown that blue light exposure can cause damage to the cornea, leading to oxidative stress, inflammation, and cell apoptosis. Long-term exposure to blue light can also cause oxidative damage and apoptosis to the cornea, resulting in dry eye disease. Conjunctival cells are more vulnerable to blue light exposure than corneal cells due to the lack of antioxidative defense mechanisms. Additionally, the conjunctiva contains various immune cells and is the first site of eye inflammation, making it sensitive to inflammation caused by blue light exposure. Overall, exposure to blue light with short wavelengths can cause oxidative stress, increase the expression of inflammatory factors, decrease cell viability, and cause dry eye. (19)

Exposure to blue light, particularly in the visible range of 390-600 nm, can induce light-induced damage on the retina through photomechanical, photothermal, and photochemical mechanisms. Photochemical damage, caused by exposure to high-intensity light, is the most common and can lead to oxidative damage by increasing the production of reactive oxygen species (ROS). Short exposure to blue light can induce damage to the retinal pigment epithelium (RPE), while longer exposure can damage the outer segment of the photoreceptors. Blue light is more effective in regenerating bleached rhodopsin via a photochemical reaction called photoreversal of bleaching, leading to the accumulation and build-up of lipofuscin in the RPE, which can impair its ability to provide nutrients to the photoreceptors and affect photoreceptor viability. Recent studies have also shown that even low levels of blue light exposure can damage photoreceptors and RPE cells. (20) Studies have further shown that short-wavelength radiation, particularly blue light with an excitation peak at 440 nm, can induce photochemical damage and apoptotic cell death in the retina. High-energy blue light and ultraviolet-A radiation can strike the retina in non-phakic eyes following cataract surgery, potentially increasing the risk for the development of AMD and other retinal pathologies. While there is some evidence to suggest that chronic exposure to blue light may be a factor in the development of AMD, the real risk for humans is difficult to assess due to individual susceptibility and limited use of light therapy. (21)



(20)

Effectiveness and Consequences of Blue-Blocking Lenses for Digital Eye Strain and Computer Vision Syndrome

The use of blue-blocking lenses is a popular topic of discussion in optometry, as they are marketed to alleviate eyestrain, discomfort, and possibly protect against retinal phototoxicity caused by blue light. However, the effectiveness of these lenses is not supported by high-quality clinical trial evidence, according to a systematic review. Some low-quality studies suggest that blue-blocking lenses may improve eyestrain or eye fatigue, but the evidence is not statistically significant or clinically meaningful. Furthermore, computer vision syndrome has multiple potential causes, and the role of blue light in these symptoms is difficult to determine. (22)

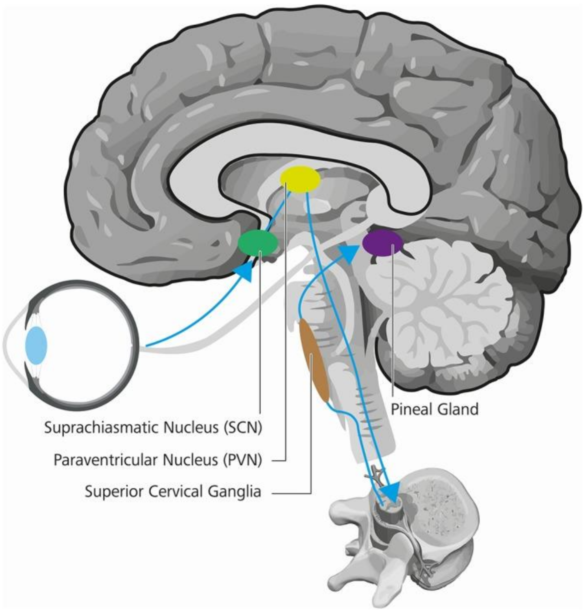
One study investigated the effect of blue-blocking lenses on colour contrast sensitivity in normal individuals under low and high contrast stimulus conditions. The study found that blue-blocking lenses with lower transmittance profiles led to greater reductions in colour contrast sensitivity, specifically for blue colours at low contrasts. Optometrists should be aware of these consequences when prescribing blue-blocking lenses for individuals who work in environments in which blue light is prevalent. (23)

Another text discusses the three mechanisms that cause computer vision syndrome, including the extraocular, accommodative, and ocular surface mechanisms. Reduced blink rate, which is caused by prolonged computer usage, is one of the primary causes of computer vision syndrome. The ocular surface mechanism causes symptoms such as dryness of the eyes and redness, while the accommodative mechanism causes vision-related symptoms such as blurred vision and double vision. (24)

Overall, blue-blocking lenses may help reduce the symptoms of digital eye strain, but their effectiveness is not yet supported by high-quality clinical trial evidence. Optometrists need to be aware of the unintended consequences of blue-blocking lenses on visual behaviour, particularly for the detection of colour, and consider the multiple potential causes of computer vision syndrome when recommending blue-blocking lenses for their patients. Further research is needed to determine the effectiveness of blue-blocking lenses in alleviating eyestrain and discomfort and protecting against retinal phototoxicity.

The Impact of Blue Light Exposure on Circadian Rhythm and Health: The Role of Blue-Blocking Glasses

Exposure to blue light during the day is important for organism vitality, but exposure to low levels of blue light during the night or before bedtime can disrupt circadian rhythm, which can have severe health implications. Specialized cells in the human eye, known as intrinsically photosensitive retinal ganglion cells (ipRGCs), are responsive to blue light and transmit signals to the suprachiasmatic nucleus (SCN) in the brain, which is responsible for regulating the body's circadian rhythm. To maintain a healthy circadian system, it is recommended to have proper, bright artificial lighting with a more blue-weighted spectrum during the daytime and a reduction of the same blue portion during the night and evening hours. Blue light blocking glasses and lenses can effectively attenuate LED-induced melatonin suppression and reduce sleep disturbances. (25)



(25)

Furthermore, studies have shown that blue-blocking glasses can be effective in reducing sleep onset latency and may be a high-yield intervention to study for bipolar disorder. A systematic review of 29 experimental publications also supports the use of blue-blocking glasses for improving sleep, particularly for patients with sleep disorders, jet lag, or variable shift work schedules. Blue-blocking glasses are a viable intervention to recommend to patients with insomnia or a delayed sleep phase. Additionally, reducing the blue portion of artificial light during nighttime hours could protect shift workers against disorders such as cancer and cardiovascular disorders. It is important to consider the optimal spectral requirements of both conscious and unconscious photo-reception when selecting solutions. (26)

Studies have investigated the effectiveness of blue-blocking glasses in improving sleep and mood disorders. Blue-blocking glasses reduce activation of retinal cells most sensitive to blue light, leading to an increase in melatonin and improved sleep. Research has found that wearing blue light-blocking amber glasses in individuals with delayed sleep phase disorder (DSPD) can advance sleep onset time by 132 minutes after two weeks of use. However, the change in dim light melatonin onset (DLMO) value was not statistically significant. (27) In patients with major depressive disorder (MDD) with sleep onset insomnia, wearing blue-blocking glasses in the evening may improve sleep quality, although not significantly compared to a placebo group. Nevertheless, half of the BB group showed a clear improvement in sleep quality, and there was a trend towards a shift to morning type in the BB group. However, 40% of participants reported discomfort from wearing the glasses, which were only available in one size, suggesting a need for further research with larger sample sizes and size-adjustable glasses. Overall, blue-blocking glasses are a viable intervention for patients with insomnia or a delayed sleep phase and may be a high-yield intervention to study for bipolar disorder, although further research is needed to confirm these findings in larger patient cohorts. (28)

CONCLUSION

In conclusion, the development of advanced coatings and materials for eyewear has significantly improved the optical industry, providing solutions to issues such as reflection, fogging, UV radiation, and blue light exposure. Antireflective coatings have been found to be effective in reducing reflection and improving vision, and sol-gel coatings have been developed with superior optical and mechanical properties. Ophthalmic lens coatings have been developed with anti-reflective proficiency over a wide wavelength range, thermal resistivity, and mechanical durability. High wrap frames and high base curve lenses have been found to be effective in preventing UV radiation from reaching the eye, while coatings with low UV reflectance can provide adequate protection. Blue-light filtering lenses have been found to be effective in reducing blue light transmission while maintaining sufficient visible light, with minimal impact on visual performance. However, the effectiveness of blue-blocking lenses in reducing digital eye strain is still a topic of debate and requires further research. Overall, advancements in eyewear technology have significantly improved the quality and effectiveness of eyeglasses, and ongoing research aims to further improve eye protection and visual performance.

REFERENCES

1. (Delfaro, How to Choose Eyeglasses for Vision Correction, 2020); Available from: https://www.aao.org/eye-health/glasses-contacts/glasses
2. (Turbert, The Sun, UV Light and Your Eyes , 2020); Available from: https://www.aao.org/eye-health/tips-prevention/sun
3. (Dhara, Chemical Solution Synthesis for Materials Design and Thin Film Device Applications, 2021); Available from: https://www.sciencedirect.com/topics/materials-science/antireflection-coating
4. Keshavarz Hedayati M, Elbahri M. Antireflective Coatings: Conventional Stacking Layers and Ultrathin Plasmonic Metasurfaces, A Mini-Review. *Materials (Basel)*. 2016;9(6):497. Published 2016 Jun 21. doi:10.3390/ma9060497; Available from: https://pubmed.ncbi.nlm.nih.gov/28773620/
5. Zhang, Chen et al. "Embedding constructed refractive index graded antireflective coating with high abrasion resistance and environmental stability for polycarbonate glass." *Journal of colloid and interface science* vol. 608,Pt 1 (2022): 13-21. doi:10.1016/j.jcis.2021.09.152; Available from: https://pubmed.ncbi.nlm.nih.gov/34626961/
6. Lu S, Shao J, Wu F. Industrial applications of sol-gel derived coatings [published online ahead of print, 2022 Dec 2]. *J Solgel Sci Technol*. 2022;1-11. doi:10.1007/s10971-022-05988-6; Available from: https://pubmed.ncbi.nlm.nih.gov/36475095/
7. Paulson CA, Price JJ, Koch KW, et al. Industrial-grade anti-reflection coatings with extreme scratch resistance. *Opt Lett*. 2019;44(24):5977-5980. doi:10.1364/OL.44.005977; Available from: https://pubmed.ncbi.nlm.nih.gov/32628197/
8. (Zhang, Antireflective Coatings Processing Techniques, Applications and Future Perspective, 2017); Available from: https://www.rroij.com/open-access/a-mini-review-antireflective-coatings-processingtechniques-applications-and-future-perspective-2321-6212-1000192.php?aid=86329#41
9. ***J. Mater. Chem.***, 2010,**20**, 6125-6130; Available from: https://pubs.rsc.org/en/content/articlelanding/2010/jm/c0jm00792g/unauth
10. (Mutlu, Analysis of the Anti-Reflection Coated Eyeglass Used in Turkey, 2021); Available from: https://www.researchgate.net/publication/355119614_Analysis_of_the_Anti-Reflection_Coated_Eyeglass_Used_in_Turkey
11. Seekamp, J. (2003). Optical Applications of Nanoimprint Lithography. In: Sotomayor Torres, C.M. (eds) Alternative Lithography. Nanostructure Science and Technology. Springer, Boston, MA. Available from: https://link.springer.com/chapter/10.1007/978-1-4419-9204-8_15
12. Chan LW, Morse DE, Gordon MJ. Moth eye-inspired anti-reflective surfaces for improved IR optical systems & visible LEDs fabricated with colloidal lithography and etching. *Bioinspir Biomim*. 2018;13(4):041001. Published 2018 May 8. doi:10.1088/1748-3190/aab738; Available from: https://pubmed.ncbi.nlm.nih.gov/29547135/

13. Citek K. Anti-reflective coatings reflect ultraviolet radiation. *Optometry*. 2008;79(3):143-148. doi:10.1016/j.optm.2007.08.019; Available from: https://pubmed.ncbi.nlm.nih.gov/18302957/
14. Krutmann J, Béhar-Cohen F, Baillet G, et al. Towards standardization of UV eye protection: what can be learned from photodermatology?. *Photodermatol Photoimmunol Photomed*. 2014;30(2-3):128-136. doi:10.1111/phpp.12089; Available from: https://pubmed.ncbi.nlm.nih.gov/24303877/
15. Chou BR, Dain SJ, Cheng BB. Effect of Ultraviolet Exposure on Impact Resistance of Ophthalmic Lenses. *Optom Vis Sci*. 2015;92(12):1154-1160. doi:10.1097/OPX.0000000000000730; Available from: https://pubmed.ncbi.nlm.nih.gov/26540475/
16. Leung TW, Li RW, Kee CS. Blue-Light Filtering Spectacle Lenses: Optical and Clinical Performances. *PLoS One*. 2017;12(1):e0169114. Published 2017 Jan 3. doi:10.1371/journal.pone.0169114; Available from: https://pubmed.ncbi.nlm.nih.gov/28045969/
17. Downie LE. Blue-light filtering ophthalmic lenses: to prescribe, or not to prescribe?. *Ophthalmic Physiol Opt*. 2017;37(6):640-643. doi:10.1111/opo.12414; Available from: https://pubmed.ncbi.nlm.nih.gov/29044667/
18. Cougnard-Gregoire A, Merle BMJ, Aslam T, et al. Blue Light Exposure: Ocular Hazards and Prevention-A Narrative Review. *Ophthalmol Ther*. 2023;12(2):755-788. doi:10.1007/s40123-023-00675-3; Available from: https://pubmed.ncbi.nlm.nih.gov/36808601/
19. Ouyang X, Yang J, Hong Z, Wu Y, Xie Y, Wang G. Mechanisms of blue light-induced eye hazard and protective measures: a review. *Biomed Pharmacother*. 2020;130:110577. doi:10.1016/j.biopha.2020.110577; Available from: https://pubmed.ncbi.nlm.nih.gov/32763817/
20. Tosini G, Ferguson I, Tsubota K. Effects of blue light on the circadian system and eye physiology. *Mol Vis*. 2016;22:61-72. Published 2016 Jan 24. Available from: https://pubmed.ncbi.nlm.nih.gov/26900325/
21. Algvere PV, Marshall J, Seregard S. Age-related maculopathy and the impact of blue light hazard. *Acta Ophthalmol Scand*. 2006;84(1):4-15. doi:10.1111/j.1600-0420.2005.00627.x; Available from: https://pubmed.ncbi.nlm.nih.gov/16445433/
22. Alzahran HS, Roy M, Honson V, Khuu SK. Effect of blue-blocking lenses on colour contrast sensitivity. *Clin Exp Optom*. 2021;104(2):207-214. doi:10.1111/cxo.13135; Available from: https://pubmed.ncbi.nlm.nih.gov/32830377/
23. Lawrenson JG, Hull CC, Downie LE. The effect of blue-light blocking spectacle lenses on visual performance, macular health and the sleep-wake cycle: a systematic review of the literature. *Ophthalmic Physiol Opt*. 2017;37(6):644-654. doi:10.1111/opo.12406; Available from: https://pubmed.ncbi.nlm.nih.gov/29044670/

24. Kaur K, Gurnani B, Nayak S, et al. Digital Eye Strain- A Comprehensive Review. *Ophthalmol Ther*. 2022;11(5):1655-1680. doi:10.1007/s40123-022-00540-9; Available from: https://pubmed.ncbi.nlm.nih.gov/35809192/
25. Wahl S, Engelhardt M, Schaupp P, Lappe C, Ivanov IV. The inner clock-Blue light sets the human rhythm. *J Biophotonics*. 2019;12(12):e201900102. doi:10.1002/jbio.201900102; Available from: https://pubmed.ncbi.nlm.nih.gov/31433569/
26. Hester L, Dang D, Barker CJ, et al. Evening wear of blue-blocking glasses for sleep and mood disorders: a systematic review. *Chronobiol Int*. 2021;38(10):1375-1383. doi:10.1080/07420528.2021.1930029; Available from: https://pubmed.ncbi.nlm.nih.gov/34030534/
27. Esaki Y, Kitajima T, Ito Y, et al. Wearing blue light-blocking glasses in the evening advances circadian rhythms in the patients with delayed sleep phase disorder: An open-label trial. *Chronobiol Int*. 2016;33(8):1037-1044. doi:10.1080/07420528.2016.1194289; Available from: https://pubmed.ncbi.nlm.nih.gov/27322730/
28. Esaki Y, Kitajima T, Takeuchi I, et al. Effect of blue-blocking glasses in major depressive disorder with sleep onset insomnia: A randomized, double-blind, placebo-controlled study. *Chronobiol Int*. 2017;34(6):753-761. doi:10.1080/07420528.2017.1318893; Available from: https://pubmed.ncbi.nlm.nih.gov/28488943/