

Influence of light on myopia—a review

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Abstract

• In China, the high incidence rate of myopia has become an important factor affecting children's visual health. In the contemporary social environment, prolonged use of electronic products and reduced outdoor activities have become important causes of the development of myopia in children, which reflects the significant influence of light on myopia. This review was performed by searching PubMed data sets including research articles and reviews utilizing the terms "light", "myopia", and "hyperopia reserve", and the review was concluded in October 2024. This article analyzes the impact of light on myopia, including light intensity, light wavelength, light frequency, light distribution, light rhythm, exposure time, and the impact of light exposure on hyperopia reserve, in order to provide new ideas for the prevention, control, and treatment of myopia, and to provide theoretical support for the development of more scientific and effective intervention measures.

• **KEYWORDS:** myopia; light; exposure time; hyperopia reserve

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INTRODUCTION

Myopia refers to a refractive state in which parallel light rays converge in front of the retina after passing through the refractive system of the eye when the human eye is in a state of relaxed accommodation. As one of the countries with the highest prevalence of myopia in children and adolescents, China has a significant increase in myopia cases. According to relevant statistics, by the time students reach high school, the myopia rate exceeds 80%^[1]. Currently, myopia in China is showing an increasing trend with a younger

age of onset. If myopia cannot be effectively controlled, it will not only increase the risk of developing high myopia, but also lead to other vision impairments such as cataracts, retinal detachment, glaucoma, and myopic macular degeneration^[2].

Several studies have consistently pointed out that outdoor activities can effectively control myopia and extended outdoor activity time can significantly reduce the risk of myopia onset^[3-4]. It is generally believed that the positive effects of outdoor activities on myopia are mainly attributed to light exposure^[5]. However, some studies have not found a direct relationship between light exposure and myopia^[6-7]. This discrepancy in findings may be related to the multiple properties of light sources. Therefore, this article explores the influence of light on myopia in terms of light intensity, light wavelength, light frequency, light distribution, light rhythm, exposure time, and its impact on hyperopia reserve, in order to provide protection for the visual health of children and adolescents.

IMPACT OF LIGHT INTENSITY ON MYOPIA

Definition of Light Intensity Light intensity refers to the unit area of visible light received by the luminous flux, the unit is lux (lx). It is used to express the strength of light exposure and the level of environmental brightness.

Impact of Outdoor Light Intensity on Myopia One research pointed out that increasing the time children spend on outdoor activities can effectively reduce the risk of myopia onset, and the protective effect of outdoor activities is related to outdoor light intensity^[4]. Another research compared the preventive effects of different outdoor light intensities and exposure times on myopia, showing that students with less outdoor activity time (125–199min) needed to be exposed to higher light intensity ($\geq 10\ 000$ lx) to effectively prevent myopia, while for students with longer outdoor activity time (>200 min), moderate light intensity (1000–5000 lx) was sufficient to have a preventive effect^[5]. Another study measured environmental light intensity in real-time and found no significant difference in the average daily exposure time between myopic and non-myopic children under lower light intensity (>1000 lx and >2000 lx)^[8]. However, myopic children had shorter exposure times under higher light intensities (>3000 lx and >5000 lx), which indicates that exposure to light intensity >3000 lx is an important factor in preventing myopia in children. These findings collectively suggest that both weaker (≥ 3000 lx) and

stronger (>5000 lx) outdoor light intensities have a significant protective effect against myopia in adolescents.

By comparing choroidal thickness (CT) after two hours of exposure to different light conditions (indoor 350 lx, dark <0.1 lx, outdoor 6000-50 000 lx), it was found that there was a significant decrease in CT in outdoor environment^[9]. Conversely, another study showed that after two hours of exposure to mild (500 lx) or moderate (1000 lx) light intensity environments, adults experienced a shortening of the axial length (AL) of the eye and an increase in CT^[10]. Read *et al*^[11] observed that greater daily light exposure was associated with less axial eye growth in children. The differing results between these studies may be related to variations in experimental design, light intensity, and spectral composition. In order to better understand the effects of light on refractive development, particularly the role of the choroid, further research is needed to explore the short-time and long-term effects of different light intensities on CT and AL.

Current research suggests that outdoor light exposure can shorten the AL of the eye and increase CT, thereby providing protective effects against myopia in adolescents. However, this does not mean that only high-intensity light exposure can prevent myopia. Even in dimly lit environments, such as under a corridor or tree, prolonged outdoor activities can effectively prevent myopia. It is important to note that appropriate sun protection measures should be taken during outdoor activities. Wearing sunglasses and hats can reduce the potential damage caused by direct sunlight to the eyes and skin, thereby reducing the risk of cataracts, macular degeneration, and skin cancer^[12].

Impact of Indoor Light Intensity on Myopia One of the mechanisms through which outdoor activities protect against myopia is by stimulating the retina with strong light, leading to the release of dopamine (DA), which slows down eye growth and controls the development of myopia^[13]. However, since indoor light intensity is weaker, whether increasing indoor light intensity can also promote the release of DA and thus reduce the incidence of myopia remains inconclusive. Hua *et al*^[14] found that increasing classroom lighting from 100 lx to 500 lx significantly reduced the incidence of myopia and AL in the participants. Suh *et al*^[15] similarly supported this view, noting that participants with baseline ALs below the average (<22.7 mm) exhibited greater axial elongation (0.19 mm) in low daylight schools compared to those in high daylight schools (0.15 mm). However, Harb *et al*^[16] reported contradictory findings, stating that although the indoor environment for myopic participants was brighter than for non-myopic participants (217.86 lx vs 182.60 lx), no significant difference between the two groups was found, and average indoor light intensity was not significantly correlated with AL or spherical equivalent (SE). It has even been noted that using multimedia teaching in brightly

lit indoor environments might increase the incidence of myopia in children^[17]. This may be due to prolonged close-up focus on screens, which could adversely affect the refractive development of the eye, even in bright environments.

Although increased outdoor activities and outdoor light exposure have positive effects on preventing myopia, the relationship between indoor light intensity and myopia is still unclear. The nature and duration of indoor activities (such as multimedia teaching) may also be key factors affecting myopia. Most studies tend to suggest that increasing indoor light intensity helps reduce axial elongation and may have a positive effect on preventing myopia. When using light measurement instruments to assess the relationship between myopia and light intensity, various factors need to be considered^[18]. Such as the position of the device, sampling frequency, measurement time, geographic location, and season, all of which can affect the accuracy and reliability of data collection. To overcome these challenges, it is crucial to employ more suitable research instruments, engage in prolonged monitoring, initiate multi-center research initiatives, and enhance participant adherence.

Preventive and Control Measures In an era marked by considerable academic demands and a lack of time for outdoor activities, the classroom has emerged as the central setting for children's daily educational experiences and routines. Consequently, the standard of lighting within the classroom exerts a direct influence on the visual well-being of students. Light emitting diodes (LED) lighting, with its energy-efficient, environmentally friendly nature, superior color rendering index, and spectrum that closely mimics natural light, has gained widespread acceptance and adoption for use in educational settings, outshining traditional incandescent and fluorescent bulbs. Maintaining a desktop illumination level of 400-500 lx using LED lights in elementary school classrooms creates an optimal lighting environment, which not only ensures comfortable visual conditions for students but also aids in reducing eye strain associated with extended periods of study. Animal studies have revealed that chickens subjected to LED lighting exhibit significantly thicker choroidal layers in their eyes compared to those exposed to fluorescent lighting^[19]. Contrarily, a separate study presents a contrasting viewpoint, suggesting that children completing homework under LED lighting conditions have increased AL and SE than those working under traditional incandescent or fluorescent lights, which could imply a potential role of LED lighting in the development of myopia in children^[20]. However, the latter study concentrated solely on the type of lighting without conducting a direct comparison of the three light sources based on specific parameters such as flicker frequency, wavelength, and light intensity.

The research conducted by Li *et al*^[21] and Li *et al*^[22] both highlight the critical role of outdoor activity in the prevention of myopia. In Li *et al*'s^[21] research, the researchers send text messages to parents twice daily, reminding them to ensure their children spend time outdoors. This approach yielded significant outcomes three years post-intervention, with the intervention group exhibiting a notably slower growth rate of the ocular axis (0.30 ± 0.03 mm) compared to the control group (0.35 ± 0.02 mm), and a marked decrease in the incidence of myopia (46.6% vs 65.4%). Li *et al*^[22] adopted a different strategy by disseminating weekly health education content to parents through school, with the aim of encouraging an increase in their children's outdoor activity time. Following a two-year intervention period, their findings revealed a substantially lower prevalence of myopia in the intervention group (19.5%) when contrasted with the control group (24.4%). These studies underscore the pivotal role that outdoor activities play in the prevention of childhood myopia and offer practical, evidence-based interventions that can be readily adopted by parents, educators, and public health officials.

Therefore, maintaining appropriate indoor illumination levels, ranging from 400 to 500 lx, and to augment the duration of outdoor activities for students, both within the school premises and at home, is essential. These strategies serve as potent measures to mitigate the risk of myopia development among the student population, while also enhancing the overall comfort and conduciveness of the educational setting.

IMPACT OF LIGHT WAVELENGTH ON MYOPIA

Definition of Light Wavelength The wavelength of light refers to the length of one complete cycle of a light wave, which is the distance between two consecutive peaks (or troughs) of the wave. In air, the wavelength of visible light ranges from approximately 400 to 700 nm. The spectrum can be further delineated as follows: Violet: 400–450 nm; Blue: 450–495 nm; Green: 495–570 nm; Yellow: 570–590 nm; Orange: 590–620 nm; Red: 620–700 nm.

Impact of Blue Light on Myopia With the increased use of LED and electronic devices rich in blue light, the exposure to blue light in our environment has also increased, making its impact on eye health crucial^[23]. Some animal experiments and preliminary studies suggest that short-term exposure to blue light may be beneficial for the eyes. In guinea pigs, the CT and choroidal blood perfusion (CBP) increased during the first two weeks of blue light exposure, suggesting that blue light may help inhibit the development of myopia, and also this effect is proportional to the duration of exposure^[24]. Thakur *et al*^[25] also reached similar conclusions, noting that short-term exposure to blue light could inhibit axial elongation in the human eye. However, prolonged exposure to blue light may have adverse effects on the eyes. After four weeks of research in guinea

pigs, retinal thickness decreased, and CT and CBP no longer showed an increase^[24]. Additionally, other studies emphasize the importance of the timing of exposure. Nickla *et al*^[26] noted that exposure to low-intensity blue light (<1000 lx) in the morning or evening stimulates eye growth in chicks, while Nickla *et al*^[27] suggested that exposure to blue light at night promotes axial elongation of the eye, with no significant effect in the morning. This suggests that the impact of blue light on the eyes may depend on the timing of exposure.

The inhibitory effect of blue light on myopia may be related to the stimulation of retinal ganglion cell axons in the optic nerve head, which then upregulates retinal DA synthesis^[28-29]. Although there is currently no evidence that blue light exposure at home illumination levels causes retinal toxicity in the human eye, one study found that blue light had significant cytotoxic effects on retinal pigment epithelial cells in pigs^[23,30]. Using lenses that selectively filter out blue light could protect the retina, suggesting that optical measures to reduce blue light exposure might be an effective preventive measure.

These findings indicate that the impact of blue light on eye is multifaceted and closely related to factors such as exposure time, light intensity, and wavelength. Although short-term exposure to blue light may inhibit myopia, given the widespread exposure to blue light in modern life, measures such as children using blue light-blocking glasses, limiting nighttime use of electronic devices, and adjusting device settings to reduce blue light output may be considered to protect eye health.

Impact of Purple Light on Myopia Purple light is a key component of natural sunlight, but in indoor environments, most purple light is blocked by windows. Light sources such as fluorescent lamps, incandescent bulbs, and LEDs generally lack purple light^[31]. Therefore, indoor environments in modern society typically have very little purple light. However, some studies suggest that purple light may have an inhibitory effect on myopia. A study in Japan found that children with myopia who wore glasses that emitted purple light showed significant reductions in AL and increased CT after six months^[32]. A case report also showed that in a child with anisometropic amblyopia, covering the dominant eye and having the amblyopic eye wear purple light-transmitting glasses resulted in improved vision, reduced AL, and increased CT after two years^[33]. Ullah *et al*^[34] also came to a similar conclusion that violet light transmission glasses can shorten axial, reduce spherical equivalent refraction (SER), and improve visual acuity. This suggests that purple light-transmitting glasses might help inhibit axial elongation and control the progression of myopia. One study also found that purple light-transmitting glasses inhibited axial elongation by 21.4% compared to traditional glasses^[35]. In a mouse model, it was found that the inhibitory effect of purple light on myopia was influenced

by the light transmittance, with lenses with high purple light transmittance being the most effective^[36]. These results suggest that purple light may have an inhibitory effect on the development of myopia.

Researchers have suggested that the myopia-controlling effect of purple light might be due to stimulation of retinal ganglion cells expressing *Opn5*, which upregulates early growth response 1 (*EGR-1*) expression in a dose-dependent manner, thereby increasing CT and inhibiting axial elongation^[37]. Compared to blue and green light, purple light might be the most effective wavelength in inhibiting myopia^[38]. Current studies have not observed significant adverse reactions in the retina from purple light exposure, suggesting that purple light exposure for myopia control may be relatively safe.

Current research indicates that purple light may inhibit the progression of myopia. In the future, we can focus on increasing indoor purple light exposure, with targeting the *Opn5* pathway being a potential molecular target for purple light-based myopia treatment. Purple light-transmitting glasses, as a potential tool for myopia prevention and control, are still under investigation for their effectiveness and safety. Continuing research to further understand the long-term impact of purple light on myopia prevention is crucial.

Impact of Green Light on Myopia Thakur *et al*^[25] suggests that exposing human eyes to green light for four sessions of one hour each could significantly increase AL and reduce CT. In animal studies, the response of zebrafish to green light exposure is different from humans, where their AL shortened^[39]. Another animal study indicated that after 8wk of exposure to flickering green light, the refractive error in mice decreased significantly, the AL increased substantially, and there was a marked reduction in the expression of M1 receptors in the retina and sclera, suggesting that M1 receptors may play a causal or protective role in myopia development^[40]. Ji *et al*^[41] even found that green light exposure induces retinal neurodegeneration in mice.

Because the research on the impact of green light on myopia is relatively limited, and there are significant differences in results across different experimental subjects (*e.g.*, human eyes, zebrafish, mice), there is no unified conclusion yet. However, most studies suggest that green light may promote axial elongation, indicating that medium-wavelength light could play a role in advancing myopia.

Impact of Red Light on Myopia Swiatczak and Schaeffel^[42] found that 620 nm red light can reduce AL by 77% in non-myopic eyes and 41% in myopic eyes, suggesting that red light may have a suppressive effect on myopia. Another 2-year randomized controlled trial showed that repeated low-level red light therapy (RLRL) significantly controlled AL and SER progression (75.0% and 75.0% respectively)^[43]. Dong *et al*^[44]

research also reached a similar conclusion that children in the RLRL group showed less myopia progression and axial elongation. Additionally, the potential trend suggests that higher-powered red light could be more effective for myopia control^[45]. Although no adverse events were observed in the aforementioned studies^[43,45-48], one study pointed out that red light therapy poses a risk of retinal photochemical and thermal damage^[49], and there have been cases of temporary vision loss and retinal damage^[50]. Therefore, clinicians should use red light therapy cautiously for treating pediatric myopia until its safety is verified, and also need to closely monitor changes in the fundus after therapy.

A study found that RLRL could increase macular choroidal thickness (mCT) and choroidal blood flow, whereas wearing single-vision spectacles (SVS) led to a reduction in CT^[46]. This finding aligns with animal research, where scleral hypoxia promotes myopia progression, while increased choroidal blood flow can alleviate scleral hypoxia^[51]. Thus, RLRL may control myopia progression by increasing CT and blood flow, which in turn alleviates scleral hypoxia.

Preventive and Control Measures Current research shows that long-term exposure to blue and green light causes axial elongation, reduces choroidal blood flow, and damages the retina. Therefore, measures should be taken to reduce exposure to blue and green light, and protective measures should be adopted when necessary. Red light exposure is thought to shorten AL and increase choroidal blood flow, but reports of retinal damage and photochemical damage following red light therapy suggest that red light treatment should be used cautiously until its safety is confirmed. The effects of purple light on the eyes are similar to red light, and no adverse reactions in the fundus have been observed. Future studies could explore increasing indoor purple light exposure as a preventive measure for myopia.

IMPACT OF LIGHT FREQUENCY ON MYOPIA

Definition of Light Frequency Light frequency refers to the number of oscillations a light wave undergoes per second, and it is used to describe how fast the light wave vibrates, measured in Hertz (Hz).

Impact of Light Frequency on Myopia With the development of modern artificial light sources, colored flickering light has become increasingly common in daily life. Animal studies have found that colored flickering light significantly affects refractive development. Exposing guinea pigs to green flickering light at a frequency of 5Hz for 8wk caused a significant decrease in SE and an increase in AL^[40]. And also the expression of mRNA for the M1 receptor was significantly decreased in retinal and scleral tissues. This suggests that low-frequency green flickering light may promote the progression of myopia in guinea pigs. However, in another

study with chicks, it was found that compared to 400 Hz light, 1 Hz or 10 Hz flickering light prevented choroidal thinning, stimulated DA release in the retina, and related analyses indicated that higher retinal DA levels were associated with thicker choroid^[52].

However, due to ethical and other limitations, there are few studies that focus on the impact of colored flickering light on human eyes. Zhang *et al*^[53] noted that the frequency and color of flickering light affect the variability of the accommodation response in myopic patients, with lower frequencies leading to larger variability. Low-frequency red/blue flickering light resulted in the largest variability. This suggests that flickering light may affect the development of myopia through changes in the accommodation response. She *et al*^[54] indicated that the ERK1/2-MMP-2 pathway may be involved in the remodeling of the posterior sclera (PS) and contribute to the formation of myopia in guinea pigs.

In general, colored flickering light may accelerate the progression of myopia in young individuals. However, due to limitations in research equipment, current studies have only focused on low-frequency flickering light, and the effects of high-frequency flickering light on human eyes require further investigation. Future studies should explore whether M1 receptors and the ERK1/2-MMP-2 pathway play a role in flickering light-induced myopia, as well as the impact of flickering light frequency and color on human myopia development.

Preventive and Control Measures The critical fusion frequency (CFF) is the lowest frequency at which the human eye can distinguish two consecutive stimuli. The CFF range is between 60-90 Hz, meaning when light flickers at or above this frequency, the human eye perceives it as continuous. However, when the light flickers below this frequency, it may cause flicker perception, leading to visual fatigue, which is more significant in individuals with myopia^[53]. Therefore, it is important to protect the eyes from surrounding flickering lights.

IMPACT OF LIGHT DISTRIBUTION ON MYOPIA

Definition of Light Distribution Light distribution refers to the spatial characteristics of light, including its brightness, color, and direction. As light travels through space, it encounters various objects or media that scatter or interfere with the light, resulting in changes in its illumination, direction, and frequency, which in turn forms different light distributions.

Impact of Light Distribution on Myopia In hyperopic eyes, images are focused behind the retina, which generates a “GO” signal that promotes axial elongation. In contrast, in myopic eyes, images are focused in front of the retina, generating a “STOP” signal that helps slow axial elongation. Ward *et al*^[55] found that narrowband long-wavelength light (red light) produces an effect similar to the “STOP” signal in tree shrews and rhesus monkeys, while narrowband medium-wavelength

light (green light) tends to promote myopia^[55-57]. Narrowband short-wavelength light (blue light) causes tree shrews’ eyes to first develop hyperopia and then switch to myopia^[58].

Because the visual system of tree shrews is based on two-color vision, whereas most human visual systems are based on three-color vision, there is some skepticism about whether the results in tree shrews can be directly applied to humans. Despite this, two-color vision is considered the baseline for color perception in all mammals, including primates, while three-color vision developed later in the evolutionary process of primates. Therefore, the effects of narrowband light on the human eye may be somewhat similar to those observed in tree shrews.

Preventive and Control Measures Current research on the impact of light distribution on myopia is mainly conducted using animal models. Given the evolutionary background of the human visual system, it is reasonable to hypothesize that narrowband red light may help delay axial growth, thus counteracting the development of myopia. In contrast, narrowband green light may promote axial elongation, and narrowband blue light may initially slow down but later promote axial growth.

IMPACT OF LIGHT RHYTHM ON MYOPIA

Definition of Circadian Rhythm Circadian rhythm refers to biological activities that follow an approximately 24-hour cycle, including plant photosynthesis, animal feeding, physical activity, sleep, and wakefulness.

Impact of Light Circadian Rhythm on Myopia Growing evidence suggests that the circadian rhythm of light significantly impacts eye growth and the development of refractive errors^[59-60]. Melatonin, a key neurohormone secreted by the pineal gland, regulates circadian rhythms in various organisms. Its synthesis and release are controlled by photosensitive retinal ganglion cells^[61]. Chakraborty *et al*^[62] found that urinary melatonin levels in adults with myopia (29.17±18.67) were significantly lower than in non-myopic adults (42.51±23.97). Additionally, myopic adults exhibited a delay in melatonin secretion by 1h and 12min, suggesting a potential relationship between melatonin levels and myopia. Similar findings have been observed in children, where myopic children showed delayed sleep onset, prolonged sleep latency, and shorter sleep duration^[63].

However, other studies have found no significant correlation between salivary melatonin levels in the morning and refractive error or AL in adolescents^[64]. The relationship between melatonin and myopia remains inconclusive, partly due to differences in the biological fluid samples used in these studies^[65]. It remains unclear whether melatonin’s role occurs before, during, or after the onset of myopia, highlighting the need for further prospective studies to clarify its involvement in myopia development^[66]. Understanding the relationship

between melatonin levels during childhood and the risk of myopia onset or axial growth rate is crucial for elucidating myopia's mechanisms and informing prevention strategies^[64].

Preventive and Control Measures With the rise of modern artificial lighting and increased academic pressures, circadian rhythm disorders have become common among children and adolescents^[67]. Many studies suggest that iterations in light rhythms disrupt the normal secretion and release of melatonin, a hormone critical for regulating sleep and biological clocks. Its abnormality may be associated with the onset and progression of myopia^[68]. Therefore, children and their parents should be encouraged to prioritize sleep, paying particular attention to sleep duration, quality, timing, and efficiency^[69]. Ensuring consistent and high-quality sleep may help mitigate disruptions to circadian rhythms and their potential effects on myopia.

IMPACT OF LIGHT EXPOSURE TIME ON MYOPIA

In the contemporary digital age, electronic devices have become an integral part of daily life. A study in Spain revealed that myopic children spend significantly more time using screens and less time engaging in outdoor activities compared to non-myopic children^[70]. The extensive use of electronic devices has been linked to a decline in children's vision^[71]. Multiple studies have highlighted that increasing outdoor activity time can effectively reduce the prevalence and incidence of myopia^[3,72-73]. And the protective effect of outdoor time on slowing axial elongation is stronger in early adolescence compared to mid-to-late adolescence^[74]. Adolescence is a critical developmental phase during which the activity of hormones such as DA, melatonin, and estradiol is influenced, playing an essential role in mediating the effects of outdoor activities on myopia. Zhang and Deng^[75] summarized that the protective effects of outdoor time against myopia are achieved through four mechanisms: high light intensity promotes DA release, inhibiting axial elongation; Outdoor sunlight (blue light) focuses near the lens, inducing hyperopia; Outdoor time impacts DA concentration and release; Outdoor activities trigger vitamin D synthesis

HYPEROPIA RESERVE

Hyperopia reserve refers to the degree of hyperopia that children's eyes should have before developing normal vision. It is a physiological state of hyperopia that gradually normalizes with growth. Typically, a 3-year-old child has approximately +3.00 D of hyperopia, which decreases with age and disappears after 12y of age.

A study in Israel found that children studying in low indoor light conditions (359 ± 2.64 lx) had lower hyperopia reserves^[76]. Low hyperopia reserve is a risk factor for developing myopia. Chen *et al*^[77] reported that from 2005 to 2021, the prevalence of myopia and pre-myopia significantly increased among Chinese children aged 4–6y. This trend underscores the importance of

regularly monitoring children's hyperopia reserves for effective myopia prevention. The AL/corneal radius of curvature (CRC) ratio is a useful predictive tool for assessing hyperopic reserve in children who cannot undergo cycloplegic refraction^[78].

CONCLUSION

In contemporary educational settings, increasing academic pressures have reduced outdoor activities for children and adolescents, leading to parental concerns about their children's myopia. This paper analyzed the impact of light exposure on myopia and found that myopia can be prevented and controlled by increasing outdoor activities, improving indoor light intensity, moderate exposure to red and purple light, maintaining good sleep habits, and regularly monitoring hyperopic reserve. However, it is also important to implement sun protection during outdoor activities and reduce exposure to blue, green, and low-frequency flickering light.

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