Blue light and health: A review of blue light and its structural and functional effects on children's brains and neural development

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Abstract

Light is essential to all life and is pivotal to humans' visual perception abilities. Without light, biological functioning would not be possible. Blue light, a higher-energy light with a shorter wavelength, makes up almost one-third of all visible light and is particularly known for its positive effects on cognitive function, mood regulation, and the body's circadian rhythms. Recently, blue light has also been recognized as detrimental to the body's health and there has been increased concern about the long-term effects of exposure to blue light during specific time periods in the day. These effects may include a loss of hormone secretion, retinal damage, disturbances in the body's circadian rhythms, and more. Here, these impacts will be discussed in three distinct sections: circadian rhythms/melatonin secretion, retinal cells and visual perception, and other ramifications on human health. This paper will additionally address the advantages and disadvantages of blue light and specific physiological and psychological effects on the brain. This review will focus predominantly on children and their neural development. Structural and possible functional effects that blue light has on the brain will also be mentioned with a particular emphasis on children. The objective of this paper is to recognize these effects and possibly find a correlation between such exposure and the development of specific health issues later in children's lives. Using evidence from multiple studies and attributable data, this paper will provide an objective analysis that expands on current findings and provides insight into the lesser-known effects of blue light. Finally, possible recommendations and preventative measures that may arise due to these effects will also be discussed.

Understanding blue light

Blue light is part of the visible light spectrum, meaning is perceivable to the human eye. Composed of one-third of all visible light, blue light vibrates within the 400-500 nanometer range and is characterized by its high energy level and short wavelength. Blue light is just one of the different spectral components of any given light (Leid, 2019). Blue light is emitted through many sources, including sunlight (most prominent), digital screens, light-emitting diodes (LEDs), and fluorescent lighting (Coats et al., 2020). Scientists have been interested in the effects of blue light for decades and have found many positive effects that this part of the visible light spectrum provides. Such positive effects include an active role in melatonin suppression, circadian rhythm entertainment, alertness, cognitive performance, overall well-being, and additional benefits (Cajochen et al., 2011; Engelhardt et al., 2019). However, there has been growing evidence suggesting that blue light may have more negative effects than positive. These negative effects include implications on overall sleep quality, retinal damage, and even disruptions in circadian phase and cycle durations (Engelhardt et al., 2019). Additionally, it has been shown that blue light may even have detrimental effects on the cardiovascular system, and can increase the risk for mental disorders including psychiatric illnesses as well (Engelhardt et al., 2019).

In terms of the brain and neural development, there have been multiple contrasting studies in regard to the effect of blue light. Some have suggested that brain activation in certain regions increases when exposed to blue light thus changing the course of its neural development as well. Alkozei and colleagues (2016) have found that the prefrontal cortex is one of these regions. The prefrontal cortex functions to regulate our thoughts, actions, and emotions by forming connections with other regions in the brain. Other scientific studies have suggested that some neural areas are silenced or have no effect from blue light exposure. More research is necessary to come to a more complete understanding of these regions. This paper will address the profound effects of blue light on the human body as well as its implications on neural development/progression.

Blue light on health

Impact on circadian rhythms and melatonin suppression

Circadian rhythms are the 24-hour cycles that are part of the body's internal clock. The circadian rhythm serves to carry out necessary biological processes in the body. For background, melatonin is secreted by the pineal gland and helps regulate circadian rhythm (i.e., cycles of alertness and sleepiness) and synchronize the sleep-wake cycle. Blue light, as a result of its short wavelength, is considered the strongest regulator of the circadian system (Wahl et al., 2019). It is important to understand that this does not mean that excess blue light correlates to a healthier amount of sleep. In fact, sometimes it conveys the exact opposite. The timing of blue-light exposure and level of intensity play a vital part in the amount of melatonin suppressed and the number of sleep-wake disruptions that result because of the disturbed sleep (**Figure 1**). To be more specific, blue light inhibits the amount of melatonin suppressed by the brain, which encourages wakefulness and can be disruptive to the sleep-wake cycle (Wahl et al., 2019). This is precisely the reason why chronic exposure to blue-enriched light directly before bedtime may have serious implications on sleep quality, circadian phase, and cycle durations (Wahl et al., 2019). Conversely, undergoing blue light exposure during the day suppresses melatonin secretion, and leads to less sleepiness (i.e., more wakefulness) during the day.

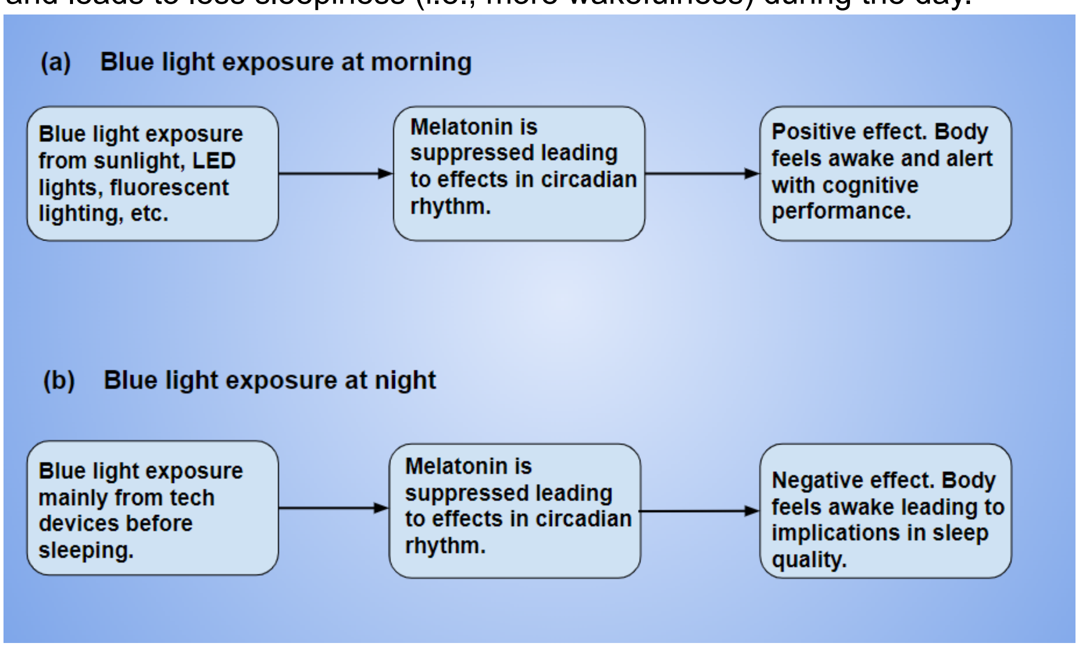

Figure 1. Blue light exposure and its effect on melatonin suppression depending on the time of day. (a) Blue light exposure in the morning and (b) blue light exposure at night.Information derived from Wahl et and colleagues (2019).

Impact on retinal cells and visual perception

Blue light can be harmful to eye tissue because of its high energy level and short wavelength characteristics. More specifically, high energy short wave blue light between 415-455 nanometers is the most harmful (Zhou et al., 2018). Due to the increasing popularity and use of technological devices, the effects of blue light are becoming more prominent in humans becoming a prevalent concern. Blue light causes detrimental effects on many structures in the eyes. This includes the cornea, lens, and retina (**Figure 2**). The cornea is the first structure that light encounters when passing through the eye, so it is afflicted first. Niwano and colleagues (2014) found that blue light exposure to developing corneal epithelial cells is detrimental, and can lead to dry eyes and loss of stability/stability of the tear film, which is the thin fluid layer that protects outer mucosal surfaces of the eye. Blue light also has a negative effect on the lens and has been implicated in the development of cataracts (Zhou et al., 2018). Multiple studies have shown that blue light may induce the production of reactive oxygen species (ROS) in the mitochondria of lens epithelial cells, which may increase the development of cataracts (Zhao et al., 2018). Indeed, the lens does function as a structural boundary in limiting the transmission of blue light to the retina, but this protective effect can also lead to a decrease in transparency or color change of the lens, leading to cataract formation as well (Zhao et al., 2018). In the case that the lens does not block blue light transmission appropriately, the blue light can contact the retina and cause retinal photochemical damage.

Currently, the effects of blue light on the retina and possible negative effects are still being studied and reviewed but there is reason to state that blue light causes adverse effects on retinal cells in people of all ages and can lead to age-related macular degeneration. Moreover, these alterations can cause the onset of many eye disorders such as the development of dry eye disease, glaucoma, and keratitis (Ouyang et al., 2020). Accordingly, there have been many preventative measures for eye-related effects of blue light which will be stated later in the paper.

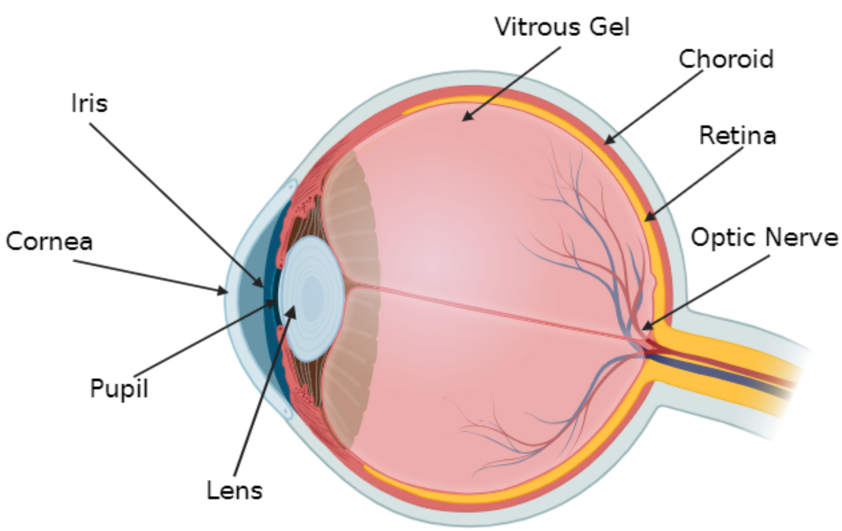

Figure 2. Basic anatomy of the human eye. Image adapted from Eye Health Nepal (2021) and created with Biorender.

Blue light and other ramifications on human health

Most attribute blue light to disruptions in the circadian rhythm cycle and problems related to the eye, but there are considerably more ramifications on human health that are still being researched and reviewed today. In fact, there have been studies that have shown that ultraviolet light can decrease overall blood pressure by releasing nitric oxide from the skin (Stern et al., 2018). Stern and colleagues (2020) conducted an experiment in which healthy male subjects were exposed (i.e., through lighting) to monochromatic blue light or blue light with a filter foil for approximately 30 minutes. Along with other benefits, the blue light exposure significantly decreased systolic blood pressure and increased heart rate compared to the control individuals. The blue light exposure also significantly increased forearm blood flow, and flow-mediated dilation while also decreasing pulse wave velocity and forearm vascular resistance. This suggests that blue light therapy may be promising for those with vascular issues or diseases. As seen, we can observe possible advancements in cardiac research and therapy. This is still a growing body of work and more research is needed to reach a more thorough understanding of these alternate effects of blue light on the body. There have additionally been significant increases in alertness, information processing, and cognitive performance in those who are exposed to blue light as opposed to those who are not; this can be attributed to blue light's impact on circadian rhythm and its effect of "waking up" the exposed individuals (**Figure 1**). Overall, these ramifications need to be studied in a more detailed manner in order to come to a more compelling conclusion.

Impact on children's brains and future implications in neural development

Brain maturation and mental health

Excessive amounts of blue-enriched light can have disruptive effects on the circadian rhythm of humans at night (Cajochen et al., 2011). These effects can lead to a lack of sleep ultimately causing unnecessary effects on behavior and mental health (Engelhardt et al., 2019). Kocevska and colleagues (2016) conducted a prospective cohort study that assessed the association between childhood sleep disturbances and brain morphology at various ages (2 months, 1.5, 2, 3, and 6 years old). The results revealed that sleep disturbances from age two onwards are associated with smaller gray matter volumes in the brain. This reveals that sleep disturbance trajectories in children may interfere with children's neural development and brain maturation. Specifically, this means that sleep disturbances can interfere with – and potentially delay – the maturational processes of the brain, and a thinner prefrontal cortex (Kocevska et al., 2017). Ultimately, these effects can also translate to mental health difficulties. Insufficient and poor-quality sleep is associated with worse mood and emotion regulation, as well as an increased likelihood of developing a mood or anxiety disorder, and a heightened risk of suicidal ideation in children and adolescents (Short et al., 2019). It is important to note that these early years of life are foundational in neural development and pave the way for future developmental changes, so disruptions can lead to a lack of brain maturation and neural development (Short et al., 2019). It is also worth mentioning that more research on the consequences of sleep loss on mental health has been conducted in adults, so more studies of children specifically are needed in this area.

Learning problems and disorders

The disruption of the circadian rhythm cycle can also have implications on children's ability to learn and may even lead to learning problems and disorders (Javary et al., 2020). These correlations could be positive or negative depending on the nature of the sleep schedule (Curcio et al., 2006). Nonetheless, prior research has manipulated sleep in individuals to observe neurocognitive and behavioral consequences such as learning and overall school performance. One such study has suggested that sleep loss is frequently associated with poor declarative and procedural learning in students and that restricted sleep, mainly meaning less than recommended, can lead to a worsening in neurocognitive and academic performance (Curcio et al., 2006). Importantly, sleep modifications such as sleeping during different parts of the day, or less/more amounts of sleep per day than is ideal (i.e., 8-10 hours per night) can have mixed effects over the course of the child's life. Javary and colleagues (2020) conducted a related study that analyzed sleep pattern modifications (i.e., 45-minute reduction in sleep) on learning basic concepts such as mathematical operations/applications in elementary children. The results of this study indicated that sleep pattern modification can reduce students' math-learning disorder. That is, children saw an increase in academic performance and a reduction of learning disorder from the manipulation (dependent on each student) of sleep. This increase in performance may prove to be promising enough to examine and modify the sleep pattern (optimal range of sleeping hours differed between various students in the study) of students with a math learning disorder so as to mitigate learning problems in the school setting. Ultimately, sleep patterns are vital in children and can drastically affect their academic performance as well.

Blue light recommendations and preventative measures

As discussed in previous sections, blue light has various effects on the human body. These effects can be categorized as positive or negative depending on the time of exposure during the day (Wahl et al., 2019; **Figure 1**). This is a growing concern, especially with the rise of technological usage in adults and children. In order to protect the human body from the possible negative effects of blue light exposure, there are specific recommendations and preventative measures that may be utilized to decrease exposure to excessive blue light. One such product is blue-light blocking glasses, which can block from 20% to 100% of blue light from reaching the eyes depending on the type of lenses used. Esaki and colleagues (2016) conducted a study that measured the effect of blue-light-blocking amber glasses on subjects with delayed sleep disorder (DSPD), which is when individuals experience sleep patterns that are two or more hours delayed from a typical sleep pattern. Dim-light melatonin onset was measured after sleep cycles and it was concluded that the blue-light blocking glasses advanced circadian rhythms in the patients with delayed sleep phase disorder. This means blue-light blocking glasses enhanced individuals' ability to sleep, which therefore affected circadian rhythm in a positive manner (Figure. 1). These findings have also been similar with patients that do not have DSPD. Burkhart and Phelps (2009) conducted a randomized study that measured the effect of blue-light-blocking amber glasses and UV-light-blocking yellow-tinted glasses for three hours prior to sleep. The results indicated that sleep quality in the blue-blocking amber lens group experienced significant improvement in sleep quality relative to those who wore glasses that only blocked ultraviolet light. In addition, those who wore the blue-blocking glasses also experienced an improvement in mood. As seen, these blue-light-blocking amber glasses may show promise.

Another device that can show promise is blue-light filtering intraocular lenses (IOLs), which are tiny surgically implanted lenses designed to filter short-wave (blue) light from reaching the eye. Davison and colleagues (2011) evaluated the potential risks and benefits of these intraocular lenses. It was found that these blue-light filtering IOLs allowed individuals to experience an overall better quality of vision, reduced glare disability, and protection from retinal phototoxicity and its potential risk of age-related macular degeneration. These possible preventative measures should be leveraged in addition to basic lifestyle habits that promote healthy sleep. These habits include avoiding short wavelength (i.e., blue-enriched) light, typically from a smart device, before sleep and having a regular nighttime routine. Avoiding these blue-enriched emissions for a certain period before sleep can enhance sleep quality and mood.

Conclusion

As shown through the research presented in this review, many studies have been conducted that demonstrate the various effects that blue light has on the human body. At this point, it is known that excessive blue light exposure can have negative effects on the circadian rhythm, retinal components of the eye, brain maturation, and a few other ramifications. It is important to understand that more research is necessary to understand the specific relationships between blue light and other aspects of human health. More research is also needed to understand blue light's impact on children and how blue light may impact brain maturation and development in particular. Disruptions in children's brain maturation and cognitive development can have effects even decades after childhood and can lead to a prominent issue later in life.

Furthermore, it is important to note that the preventative measures discussed in this review such as the blue-light blocking glasses and the intraocular lenses (IOLs) are best leveraged after other measures have been taken to adjust sleep schedule and other lifestyle factors. Changing such lifestyle factors can have a higher impact in blocking blue light compared to external devices, which is why it is advisable to adjust these lifestyle factors first. External devices may be utilized afterward if sleep schedule is still an issue.

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