Review Article

Blue light-induced retinal damage: a brief review and a proposal for examining the hypothetical causal link between person digital device use and retinal injury

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ABSTRACT

Background: There is growing concern that the increased use of personal digital devices, which emit a high proportion of their light in the blue wavelengths, may have harmful effects on the retina. Extensive historical as well as current research demonstrates that exposure to high energy visible light (blue light) can damage the retina under certain circumstances. There are, however, no studies that directly address whether blue light at the intensities emitted by digital devices can potentially cause such harm. The present review aimed to examine whether blue light exposure from computers, tablets, and cell phones can, when used habitually over a prolonged period of time, be harmful to the retinal.

Methods: A search of the literature on blue light-induced retinal damage was performed using a number of scientific search engines, including BioOne Complete™, Google Scholar™, Paperity™, PubMed™, and ScienceOpen™. Studies most significant for addressing the question of possible harmful effects of blue light emitted by personal digital devices were selected from this search and reviewed.

Results: The data from the selected studies were summarized and their limitations in addressing the question of whether the blue light from personal digital devices is capable of producing retinal damage were addressed. Based on these limitations, a practical experimental protocol for collecting the additional data needed was proposed. Data from pilot experiments are presented that indicate the practicality of this approach.

Conclusions: The currently available data on the effects of blue light on the retina are not sufficient to refute the hypothesis that the use of personal digital devices could, over a lifetime, produce retinal damage. Additional studies, such as those proposed in this article, are needed to resolve this issue.

KEY WORDS

blue-light-induced, light-induced, retinal damage, review, hypothesis, personal digital assistant, personal digital device

INTRODUCTION

The nature of retinal damage produced by light has been thoroughly discussed previously [1-3]. One such type of damage is photomechanical in nature [1-4]. This damage is caused by very intense light sources, such as pulsed lasers, and involves tissue disruption by shear forces or cavitation. Another type of damage by light

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How to cite this article: Kozlowski MR. Blue light-induced retinal damage: a brief review and a proposal for examining the hypothetical causal link between person digital device use and retinal injury. Med Hypothesis Discov Innov Optom. 2020 Winter; 1(3): 129-134. DOI: https://doi.org/10.51329/mehdioptometry118

Received: 04 December 2020; Accepted: 01 February 2021

Table 1. Comparison of blue light intensities used in laboratory research studies and those produced by personal digital devices

Study	Blue Light Intensity	Fold-Increase Over Personal Digital Devices*
Chamorra et al. [18]	0.005 W/cm²	109
Ham et al. [9]	0.03–0.15 W/cm²	652-3261
Paulter et al. [20]	0.02 W/cm²	435
Putting et al. [22]	0.014 W/cm²	217
Vincente-Tejedor [10]	5000 lux	37.8

***Values represent the intensity used in the research study, divided by the average intensities of a number of personal digital devices tested under various conditions (Gringas et al. [13], Table 2; 132.31 lux or 46.12 uW/cm²). Only research studies that used units comparable to those of Gringas et al. [13] were included. Abbreviations: W/cm², Watt per square centimeter; lux, luminous flux per unit area (equal to one lumen per square meter).**

is photothermal [1-4]. As implied by its name, photothermal damage results from light-induced temperature elevation in the retina, which denatures proteins. This type of damage can have therapeutic applications in the treatment of diabetic retinopathy [5].

Photochemical damage is the most extensively studied type of light-induced retinal damage [1-3, 6]. This damage is of interest because it can occur at relatively ambient light levels [2]. Photochemical damage is thought to occur under conditions in which exposure of retinal tissue to light generates free radicals, and may be mediated by mitochondria and chromophores in the retina [1-3, 7]. The most important wavelengths for the production of photochemical retinal damage are those in the visible blue light range [6, 8-10]. The proposed biochemical mechanisms of blue light-induced retinal damage include mitochondrial injury [11] and double-strand DNA breaks [12]. Many new devices, such as low-energy light bulbs and personal electronics, emit a higher percentage of light in the blue wavelengths than conventional light sources [13, 14]. Exposure to blue light from some of these light sources, such as light-emitting diodes (LEDs), has been shown to damage the retina and produce other potentially harmful physiological effects under certain conditions [15-18].

The purpose of the present review was to examine whether blue light exposure from computers, tablets, and cell phones can, when used habitually over a prolonged period of time, be harmful to the retinal.

METHODS

A list of articles was compiled by searching the terms "blue light" and "retinal damage" in BioOne Complete™, Google Scholar™, Paperity™, PubMed™, and ScienceOpen™. The searches were conducted from the respective inception dates until 20 September 2020. Each paper was then briefly reviewed by the author, and papers judged most relevant to address the hypothesis that blue light exposure from personal digital devices is harmful to the retina were selected from the list. After examining the data from these studies, an assessment was made of the need for additional data to rule out the hypothesis that blue light from digital device use could damage the retina. A parsimonious method for collecting these data was then proposed.

RESULTS

The data from the selected studies were summarized and their limitations in addressing the question of whether the blue light from personal digital devices is capable of producing retinal damage were addressed. Based on these limitations, a practical experimental protocol for collecting the additional data needed was proposed. Data from pilot experiments are presented that indicate the practicality of this approach.

Table 1 shows comparison of blue light intensities used in laboratory research studies and those produced by personal digital devices.

DISCUSSION

Laboratory Research Studies of Blue Light-Induced Retinal Damage

Evidence from over the last 50 years shows that exposure of the retina to blue light can produce damage under certain conditions. One of the earliest studies demonstrating this was published by Noell et al. in 1966 and showed that exposure to biologically equivalent intensities of blue or green light, but not red light, caused retinal damage [6]. This suggested that light-induced damage was wavelength-dependent and was not due to thermal injury, which would have made red light more harmful. These data were elaborated upon over the next decade by other investigators, including Ham et al., who demonstrated that the wavelength band primarily responsible for damaging the retina was that of blue light [8, 9]. Since then, the central role of blue light in retinal damage has been confirmed in many other studies [10, 18, 19]. Additional research conducted in the late 1980s and the 1990s identified photoreceptors and retinal pigment epithelium (RPE) as primary targets of blue light-induced damage [20-23].

Population-Based Studies of Blue Light-Induced Retinal Damage

Several population-based studies performed over the past 30 years were also consistent with the concept that exposure to blue light damages the retina [24-28]. In these studies, the measure of retinal damage was age-related macular degeneration (AMD). The Chesapeake Bay Waterman Study, performed in the late 1980s, demonstrated a significant correlation between visible light exposure during years working on the water and the occurrence of advanced AMD later in life [26]. In the 2000s, several other studies supported this finding. The Beaver Dam Eye Study showed a significant relationship between higher levels of summer sunlight exposure, specifically during the teens and fourth decade, and the occurrence of AMD [27]. The European Eye Study also found a correlation between sunlight exposure and late-stage neovascular AMD, but only in individuals with lower dietary antioxidant intake [29]. Two studies of Croatian populations have also found correlations between sunlight exposure and AMD [30, 31]. More recently, the European Genetic Database Study, similar to the Chesapeake Bay Waterman Study, found that the amount of exposure to sunlight during the years of employment correlated with the occurrence of advanced AMD [28]. Although the specific contribution of blue light was not examined in these studies, laboratory research discussed in the previous section strongly suggested that it is primarily blue light that is responsible for these effects [6, 8-10, 18, 19].

Concern About the Harmful Effects of Blue Light from Personal Digital Devices

Humans are spending increasing amounts of time in viewing the screens of personal digital devices, including cell phones, computers, and tablets [32]. A survey conducted in 2019 found that the average screen usage by teens in the United States was between 5 and 7.5 hours per day [32]. In addition, many jobs require screen usage during much of the 8-hour working day [33]. The usage of personal digital devices almost certainly increased markedly in 2020 due to the more extensive use of online media during the COVID-19 pandemic [34].

A reason for concern about the high use of personal digital devices is that a larger proportion of their light is emitted in the blue wavelengths than that of conventional incandescent and fluorescent lighting sources [13]. Elevated levels of blue light exposure from the use of these devices have been associated with several negative effects on human health and well-being, including visual discomfort (e.g., digital vision syndrome), disruption of circadian rhythms, elevated insulin resistance, increased affective disorders, and even a rise in the incidence of certain cancers [15, 35, 36]. Given the harmful effects of blue light exposure on the retina, as discussed above, it is also plausible that greater exposure to blue light caused by the increased use of these devices could also contribute to a higher incidence of retinal disorders, such as AMD [15, 35, 37].

Demonstrating a Relationship between the use of Personal Digital Devices and Retinal Damage

Whether blue light exposure from personal digital device use can cause retinal damage may ultimately have to be addressed by population-based studies, similar to those used to assess the harmful effects of sunlight on the retina. Laboratory research studies could, however, use an appropriate model of retinal damage and relevant values for the variable parameters of a blue light exposure regimen to shed light on the likelihood of damage occurring.

The drawback of such an approach is the simple nature of the laboratory system as compared to real life. Thus, during laboratory exposure, it would be difficult to make allowances for short rest periods, such as blinks, or briefly focusing the gaze away from the light. In addition, it does not consider the variety of viewing schedules that can occur during normal daily activities. However, the advantage of such an approach is that it can likely be performed over a shorter time-span. In addition, such studies would allow markedly better control of important variables, such as the exact nature of blue light exposure in terms of intensity, duration, and repetition. It seems likely that the drawback mentioned above would underestimate the damaging effects of blue light, given the recovery that can occur between exposures (see below) [20, 23, 24]. The confidence in a negative finding from laboratory studies would be increased. RPE cell layers may represent a good model for studying blue light-induced retinal damage. These cells are among the cell types that have been shown to be injured by blue light exposure in laboratory research studies [18-21]. In addition, dysfunction of RPE cells is a component of AMD pathology [38, 39]. This is significant because population-based studies on the effects of blue light on the retina used AMD as a marker for retinal damage. Several types of RPE cells are available for such studies, including the ARPE-19 cell line [40].

One of the important variable parameters when studying the effects of a blue light exposure regimen on retinal cells is its intensity. In the population-based studies discussed above, the source of blue light was the sun. The blue light radiance from a sunny sky is approximately 50 times that of personal digital devices [14]. The blue light intensities used to produce retinal damage in most laboratory research studies were even more excessive, at 38 to 3261 times those produced by personal digital devices (Table 1) [8-10, 18, 20, 22]. As the intensities of blue light used to search for retinal effects increase relative to those produced by personal digital devices, it becomes more problematic to assume that any observed effects would also occur in the intensity range of these devices [14]. Another important variable of blue light exposure is the duration of each individual exposure. Exposure to blue light is not continuous throughout the day. Thus, there may be periods of high exposure, such as during work or school hours, and periods of no exposure, such as when sleeping. Both the duration of individual exposure and the length of the intervals between them are important, because there is evidence that some of the potentially harmful effects of blue light on retinal functioning may be reversible after blue light exposure has been discontinued for a certain period of time [20, 23, 24]. To simplify the experimental design, however, it is necessary to group all periods of high digital device use into a single daily exposure, separated by periods of little or no exposure.

An additional critical variable is the length of time over which blue light exposure is repeated. The role of repeated exposures has only been marginally addressed in the laboratory research studies performed to date, which utilized either one or a few exposures to blue light, probably for reasons of practicality [6, 8-10, 18, 19].

However, the population-based studies discussed above suggest that the chronicity of the exposures is important for producing retinal effects, and that a period of exposures lasting months or even years may be necessary to observe the effects on the retina [24-29].

Given that the intensities of personal digital devices are well below the levels that produce acute retinal damage in laboratory studies or to result in an increase in AMD occurrence in population-based studies, it might be expected that a very extended period of exposure would be required to observe or rule out damaging effects [6, 8-10, 14, 18, 19].

The combination of the values of these three parameters of blue light exposure might be considered equivalent to a “cumulative dose” of blue light. It is important to appreciate, however, that these parameters might not combine linearly with respect to the effect of light exposure on the retina. For example, as discussed above, some of the effects of blue light on RPE cells are reversed over time after the exposure [20, 23, 24]. Thus, increasing the duration of each daily exposure might not be counterbalanced by a proportional decrease in the intensity of the exposures, since the effect of each daily exposure would have less time to dissipate before the next exposure. In this case, the effect of a longer duration of less intense blue light exposure on the retina could be greater than that predicted by the cumulative dose.

Given the complex interactions between the blue light exposure variables, the most parsimonious way to design an experiment to determine whether blue light exposure from personal digital devices could cause retinal damage may be to set two of the variable parameters to their most reasonable values, and then allow the third to vary. The parameters for which the most information is available are the duration of each daily exposure and the intensity of the exposure. A reasonable duration of exposure might be 8 h per day, based on both the length of the average day at work [33], which for many people involves screen time, and the average daily screen usage duration by teens in the United States [32]. The intervals between the exposures would then be 16 hours, to make them daily exposures.

Intensities as low as those of personal digital devices may be impractical to use in the laboratory research setting because such low intensities could require very long periods of repeated exposures before their effects, or lack thereof, could be assessed, as discussed above [6, 8-10, 14, 18, 19]. A compromise solution might be to use a range of relatively higher intensities to establish a relationship between intensity level and the third, independent variable, the duration of repeated exposures that are necessary to produce retinal damage. This relationship can then be extrapolated to the intensity levels produced by personal digital devices.

In preliminary studies conducted in our laboratory, layers of RPE cells were exposed to blue light for 8 hours per day at intensities of 0.6 to 0.1 mW/cm^2 [41-44]. This intensity range extends to that produced by personal digital devices. These studies showed that blue light exposure produced effects on RPE cell layers, consistent with the pathology seen in AMD [38, 39]. These defects included actual lesions, a decrease in cell number, and altered lysosomal and melanosomal activities. When the production of these effects was measured under different light intensities, there appeared to be a cumulative dose effect of blue light exposure.

These results suggest that the type of laboratory research proposed above is practical to perform. For further studies, lesions in RPE cell layers will be used as the endpoint for blue light-induced damage, because they are easily measured. The blue light intensity range will be expanded to extend from 0.6 to 0.05 mW/cm^2. The duration of daily exposure administration will be set to at least 1 year, if no blue light damage occurred sooner. The lowest light intensity in this study was approximately the average of that emitted by personal digital devices (Table 1) [14]. If a relationship between blue light exposure and RPE cell layer damage is found at each intensity tested, this relationship can be extrapolated to light levels for all personal digital devices. If, after this extrapolation, the duration of exposure necessary to damage RPE cell layers is within the range that a person could experience during a lifetime of use of these devices, it would indicate that their use may lead to retinal damage. If not, it will suggest that the use of such devices is not harmful to the retina.

CONCLUSIONS

The data collected to date on the effect of blue light exposure from personal digital devices are not currently sufficient to refute the hypothesis that the use of these devices could produce retinal damage over a lifetime. Additional studies to provide more relevant data concerning this issue, such as the one proposed in this article, are needed.

ETHICS DECLARATION

Ethical approval: This study was a review, and no ethical approval was required.
Conflict of Interest: None.

FUNDING

None.

ACKNOWLEDGMENT

None.

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