








Evidence on the effects of digital blue light on the eye: A scoping review



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Background: Digital blue light is the blue light emitted from light emitting diode (LED) displays, which may be regarded as a health hazard to our eyes and vision.

Aim: This review sought to map out evidence on the effects of blue light on the eye from digital devices.

Methods: The study design is a scoping review. Peer-reviewed studies published in the last 25 years were sourced from Google Scholar, PubMed, Cochrane and Medline databases. Data were extracted using the relevant search terms followed by thematic analysis. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework was utilised to report this process. The Mixed Method Appraisal Tool (MMAT) assessed the quality of included studies.

Results: Thirty-seven articles met the eligibility criteria. After the full-text screening, the exclusion of 32 articles resulted in five articles to map. The majority of studies included the indirect measuring of the effects of digital blue light using blue-blocking spectacles on blink rate, critical flicker frequency, near point of convergence and eyestrain. The central theme identified across mapped studies regarding the effects of digital blue light was its role in resultant visual discomfort. Of the five accepted studies, three studies had an MMAT score of 100%, whilst two studies scored 80%, suggesting that their results were reliable.

Conclusion: The review concluded that blocking short-wavelength blue light reduced visual discomfort or digital eyestrain. The gap identified was a lack of research on the exposure of digital blue light on the retina in human eyes *in vivo* and required more investigations to corroborate the animal studies.

Keywords: blue light; eye; e-devices; LED; short wavelength; blue hazard; digital blue light.

Introduction

The fourth industrial revolution today highlights that we live in a time where escaping from e-devices is unavoidable. Blue light emitted from electronic devices (e-devices) such as mobile phones, tablets and laptops with light emitting diode (LED) display screens is termed as digital blue light.¹ There is an exponential rise in screen time amongst users across all ages, with screen time doubling in children under the age of two years between 1997 and 2014,² with schools increasing their digital footprint, by implementing digital workbooks and textbooks on a tablet device. This exposure has now raised concerns that this may pose a safety hazard to vision and eyes.

Blue light has a short wavelength of approximately 380 nm – 500 nm, which is found in the atmosphere especially during the day and is also emitted from LED lighting, compact fluorescent lamps and all e-devices with LED displays.³ High-energy visible (HEV) light ranges from 400 nm to 500 nm, this high energy released from short wavelength or blue light is higher than long wavelength light, and thus, its effects are raising concerns.¹ It is imperative to show through primary evidence the effects of blue light with particular focus on using e-devices with LED displays to document the safety hazards of blue light to the human eye, as the natural filters of the human eye do not provide adequate protection against blue light exposure. The cornea absorbs wavelengths below 300 nm, the crystalline lens absorbs wavelengths ranging from 300 nm to 400 nm and the retina primarily absorbs 390 nm – 760 nm.^{4,5}

Blue light has also sparked the interest of scientists studying sleep patterns. The retina was known to have four photoreceptors, that is, L-cones, M-cones, S-cones and rods; however in the last decade, a fifth light receptor known as the intrinsically photosensitive retinal ganglion cell (ipRGC) was discovered. The ipRGC does not contribute to the function of vision but is sensitive to light on the

retina, with a peak sensitivity at approximately 470 nm – 480 nm. The ipRGC's function is to control pupil size, which works in conjunction with the S-cone to regulate the amount of light that enters the eye and reaches the retina and controls circadian rhythm which is the reason for several sleep studies involving blue light.⁶ Circadian rhythm is regulated by the sleep hormone melatonin, and blue light is said to suppress the secretion of melatonin affecting the sleep cycle.³

Blue blocking lenses were developed as a form of eye protection against HEV blue light, by passing visible light with wavelengths greater than 460 nm and reducing the harmful blue-violet wavelengths below.⁷

Studies have shown that reduction of blue light using a blue light filter by 50% could reduce retinal damage by 80%.⁸ However, there is also research that does not support the claim that blue blocking lenses work to reduce eyestrain and discomfort.⁹

Animal studies suggest that blue light exposed retinas showed a greater likelihood of potential retinal damage that may have negative ocular consequences. Studies conducted on rats suggested that exposure to blue light over long periods might result in irreversible retinal damage, specifically to the retinal pigment epithelium by releasing cytokines disturbing the integrity of the retinal pigment epithelium (RPE)-choroid complex, as well as affecting mostly the cones, which are highly concentrated at the macula.¹⁰ Blue light was found to cause atrophy of the outer nuclear cells, thus disturbing visual transduction.¹¹ Other established evidence of the effects of blue light from laboratory studies is limited to controlled environments and exposure.¹² All these studies establish that blue light exposure is harmful to the eye; however, there is a paucity in evidence of any of these replicated in humans as *in vivo* exposure to blue light.

Despite this, blue light emitted from e-devices, sometimes referred to as digital blue light, remains a public and health concern. The significance of evidence of the effects of digital blue light in studies performed *in vivo* on humans would provide tangible evidence if these concerns occur over-time or immediately when using e-devices. The awareness of this knowledge can alleviate public health concerns that may send a message that any form of screen time will cause eye disease, whilst the society is embracing digital empowerment and screen time is inextricable. The purpose of this research study is to map out empirical evidence on the effects of digital blue light on the eye or vision, by exploring any research that suggests that blue light from electronic devices is a cause for ocular health or visual concern amongst people who are physically utilising e-devices.

Methods

The researchers have conducted a scoping review instead of a systematic review because this scoping review maps any empirical evidence on the effects of blue light emitted from electronic devices on the eye. This approach will be useful in

providing direction for other researchers to identify more questions or aspects related to this topic. The team followed the step-wise methodology outlined by the Joanna Briggs Institute (JBI) Reviewers' Manual¹³ using a five-step process as illustrated in Figure 1.

Identifying the research question

The framework for determining the research question was the Population, Exposure, Comparator and Outcome (PECO) framework.¹⁴ The *population* included people using electronic devices, the *exposure* was related to blue light emitted from LED display devices, *comparator* was comparing minimal or greatest exposure, *outcome* was visual or ocular effects. The PECO question was appropriate as this review required the investigation into the *exposure* of blue light emitted from the screen of electronic devices. Thus, this scoping review sought to answer the following research question:

What are the effects of blue light on the human eye amongst electronic device users in the current digital age?

Inclusion and exclusion criteria

The study included primary studies published in the last 25 years, studies in all languages that reported evidence on the effects of digital blue light on the eye from e-devices, as well as studies that reported evidence of management of blue light from e-devices on the eye. The study excluded all animal and laboratory studies on blue light, studies on blue light from e-devices without LED and studies of blue light involving circadian rhythm or sleep.

Identifying relevant studies

The main aim of this review was to identify empirical evidence to assist in answering the proposed research question. To attain this, a search strategy was implemented for relevant studies from four electronic databases, namely, Google Scholar, PubMed, Medline and Cochrane.

Search strategy

In order to eliminate studies that did not address the research question, the adoption of a method similar to systematic reviews was utilised, which included the formulation of inclusion and exclusion criteria. The review included primary studies in the last 25 years, studies in all languages that reported evidence on the effects of digital blue light on the eye from e-devices as well as studies that

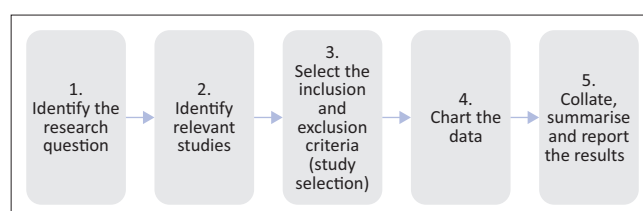


FIGURE 1: The five-step study process based on the Joanna Briggs Institute manual.

reported evidence of management of blue light from e-devices on the eye. The study excluded all animal and laboratory studies on blue light, studies on blue light from e-devices without LED and studies of blue light involving circadian rhythm or sleep.

Study selection

The following inclusion criteria were used to guide the search: primary studies published up to August 2019, studies in all languages, studies that reported evidence of the effects of blue light on the eye from e-devices and studies that reported evidence of the management of blue light from e-devices on the eye. Upon search completion and refinement, the studies of blue light from screens without LED and studies of blue light involving circadian rhythms were excluded.

Title screening involved two researchers (M.M. and M.R.) to screen the titles from all four databases, using the PECO framework. Following all accepted titles with abstracts downloaded onto the reference manager Mendeley, under 'Titles kept' folder, abstract screening commenced.

Abstract screening involved two independent teams consisting of two researchers each (Z.K., M.N. and K.G., S.C.), using an abstract screening tool. Disagreements between both teams for disputed abstracts that were not uniformly accepted or rejected were then resolved in consultation with both abstract screening teams failing which a third independent researcher decided if the article should be accepted. All accepted articles were stored on Mendeley under 'Abstracts kept' folder.

Full-article screening was then completed by the two researchers from the title screening team (M.M. and M.R.). The university interlibrary loan service sourced studies not freely attainable online. The reviewers used a full-text screening tool based on the inclusion and exclusion criteria. After completing a full-text screening, all accepted papers were stored on Mendeley under 'Full text accepted' folder.

Data charting and data characterisation

Following full-text screening, all accepted studies comprised data extraction by charting of data on a Microsoft Excel spreadsheet. This consisted of the following headings: Title, Author, Sample Size, Aim (purpose of the study), Study design, Methodology, Outcomes (key findings at the end of the study) and gaps in the research (did the study answer the research question? if gaps, mention them). Two reviewers in consultation extracted the study characteristics from included studies.

The data extraction tool extracted specific study characteristics and identified the relevance of the included studies. The following characteristics were identified: author, date, sample size, age, electronic device used, exposure duration, aim of the study, main outcome, gaps in the study to

formulate the results and these characteristics were then organised into tables according to the sub-themes, following which thematic analysis was completed.

Quality assessment of the included studies

All the primary studies included were scored according to the mixed method appraisal tool (MMAT), which has been created for the critical appraisal of systematic literature reviews.¹⁵ It appraises quantitative, qualitative and mixed method studies. After data charting, the utilisation of the MMAT tool-version 2018 critically appraised all studies accepted at full-text screening. An overall quality score for each study was used by assessing methodological domains for study designs. The MMAT consists of five criteria for qualitative, quantitative (descriptive, non-randomised and randomised) and mixed method studies. Each criterion met is 20%, with the scores ranging from 20% (one criterion met) to 100% (all five criteria met). Two study reviewers independently scored included studies, and any disagreement was then resolved by discussion.

Ethical considerations

This study received ethical clearance from the Biomedical Research Ethics Committee, University of KwaZulu-Natal (EXM143/19).

Results

Study selection

The original search conducted in August 2019 yielded 1155 potentially relevant citations. There were 20 additional records identified through other sources. After duplication and relevance screening 37 articles met the eligibility criteria based on the title and abstract screening. The exclusion of 32 articles after full-text screening left five articles that proved pertinent. These were included in the data charting and analysis. Of the 32 articles excluded, four were not in English, 10 included animal studies or no human participants. Seven articles made no mention of LED or e-devices and five did not speak directly of blue light or its effects on the eye. There were two studies conducted on human tissue *in vitro*, and the remaining two being a protocol and the other focused on the marketing of various blue blocking lens manufacturers and their comparison. Figure 2 shows the flow of articles from identification through to final inclusion in a PRISMA flowchart.^{16,17}

Characteristics of included studies

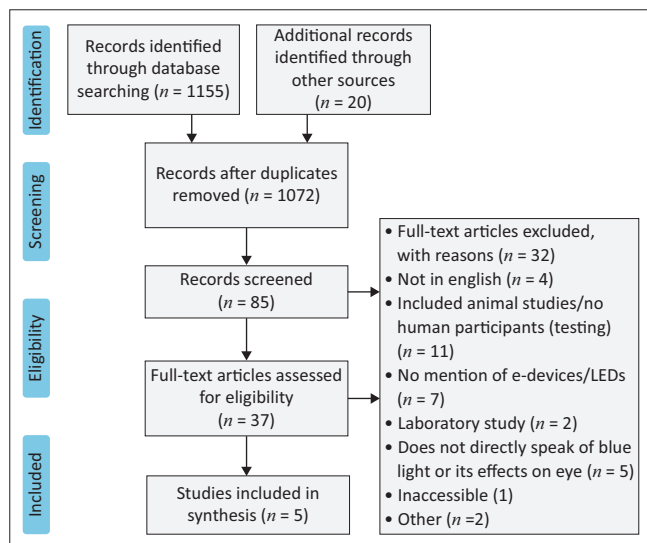
The characteristics of the included studies, namely author, date, sample size, age, geographic location, source, e-device and the aim of the study are discussed, as illustrated in Table 1. All papers included were peer-reviewed and made mention of e-devices. The most common form of e-device used across all studies was a computer screen (LED). The ages of participants across all the studies ranged from 18 to 55 years of age. Sample sizes of included studies ranged from

20 to 80 participants with an equitable gender representation. Geographical location of identified studies that were completed in the last five years was in Eastern Asia, United States (US) and Australia. Three out of the five accepted studies followed the indirect measure of the effects of digital blue light using blue blocking spectacle lenses. One of the two remaining articles discussed the direct exposure of participants watching four 15-min blue-light reduced modified 3D videos and the other was a review study. Clinical areas of investigation identified from located studies included the effects of digital blue light on near point of convergence (NPC), blink rate, saccadic eye movements, critical flicker frequency (CFF), colour vision and contrast sensitivity. Table 2 provides an overview of the findings of the review for clinical and non-clinical effects of digital blue light on vision, which will be discussed accordingly.

Clinical investigations of the effects of digital blue light on vision

The effect of digital blue light on critical flicker frequency

Two^{19,20} out of the five accepted studies investigated the effects of digital blue light on CFF as shown in Table 2. The definition



Source: Adapted from PRISMA. PRISMA 2020 flow diagram [homepage on the Internet]. Available from: <http://www.prisma-statement.org/>

LED, light emitting diode.

FIGURE 2: PRISMA flow diagram of study selection process.

TABLE 1: Characteristics of included studies.

Author, date	Sample size	Age (years)	Geographic location	E-device	Aim of study
Kim et al. ¹⁸	N = 20 (9 male, 11 female)	20–28	Korea	3D monitor (LED)	To reduce the visual discomfort by reducing components of blue light, which are highly sensitive to human eyes in a 3D video.
Lin et al. ¹⁹	N = 36 (20 male, 16 female)	21–39	United States	Laptop Computer VDT (Visual display terminal)	To determine if participants using short-wavelength blocking spectacles when performing computer-related tasks experience visual fatigue compared to those wearing spectacles with clear lenses.
Ide et al. ²⁰	N = 33 (17 male, 16 female)	28–39	Japan	Computer screen-VDT	To evaluate the effect of blocking short-wavelength light on critical flicker frequency (CFF).
Leung et al. ²¹	N = 80	18–30, 40–55	Hong Kong, United States	LED Computer screen	To evaluate the optical performances of blue-light filtering spectacle lenses and to investigate whether a reduction in blue light transmission affects visual performance and sleep quality.
Lawrenson et al. ⁹	N = 136 (combined studies)	N/A	Australia	Computer screen	To identify if the use of blue blocking spectacle lenses assists in enhancing visual performance by reducing eyestrain and discomfort.

LED, light emitting diode.

of CFF is the frequency at which a flickering light is indistinguishable from a steady, non-flickering light, which was a metric of visual discomfort. These followed an indirect approach that investigated the effects of blue light emitted from electronic device screens by using blue blocking spectacles to measure visual fatigue. Both studies^{19,20} randomly assigned participants to a control, a low-blocking blue light lens group (24.2% and 26.1% reduction in transmission of blue light wavelength) and a high-blocking blue light lens group (60.0% and 53.9% reduction in transmission of blue light wavelength) to determine the effect of digital blue light exposure on CFF using the Handy Flicker (Neitz Instruments, Tokyo, Japan). Participant exposure to LED screens was for 2 h to either watch videos, or engage in games or perform tasks that required constant attention using the ChipClick software (<http://www.vector.co.jp/soft/win95/game/se262423.html>). In both studies,^{19,20} the low and high groups protected against CFF decay implying digital blue light reduced CFF. The type of lens worn significantly affected the CFF. There was a consensus between both studies which conclusively indicated that the higher the blue blocking effect of the lens, the lower the reduction in the CFF, suggesting that blocking short-wavelength light may reduce eye fatigue and visual discomfort.

The effect of digital blue light on near point of convergence, saccades and blink rate

In one of the five accepted studies, NPC, saccadic eye movement and blink rate were directly assessed by exposing subjects to different variations of blue light reduced videos as means of measuring visual fatigue.¹⁸ The adjustment of the colour temperature of the videos allowed the removal of blue-light from the videos. Colour temperature refers to the temperature of the colour that radiates from the luminous source as the absolute temperature (K). A low colour temperature correlates with a lower amount of blue light emitted and a higher colour temperature correlates with a greater amount of blue light emitted. The measurement of NPC amongst all participants before and after watching the videos was an indirect measure of 3D recognition ability. As the amount of blue light emitted decreased, the NPC change similarly decreased, and the study showed that reducing blue light

TABLE 2: Characteristics of included studies on effects of digital blue light on vision.

Author, date	Investigation	Tool	Exposure, duration	Result	<i>p</i> *	Main outcome(s)
Kim et al. ¹⁸	Blink rate		Colour temperature adjusted to remove blue-light from the video, 15 min video	Blink rate reduction	< 0.05*	-
	Saccades	EyeLink 1000 plus		Saccadic eye movement increased	< 0.05*	Digital blue light causes eyestrain or visual discomfort.
	NPC			NPC receded	< 0.05*	-
Lin et al. ¹⁹	CFF	Handy Flicker	Participants using low (24.2%) versus high (60%) blue blocking lenses were exposed to the laptop or computer for 2 h.	CFF was more negatively affected with greater blue light exposure	0.027* 0.008*	Digital blue light causes eye fatigue associated with computer-related tasks.
Ide et al. ²⁰	CFF	Handy Flicker HF-II	Participants who used high (53.9% blue range cut) and low (26.1% blue range cut) blue blocking lenses were exposed to computer screen-VDT (LED) for 2 h.	CFF was more negatively affected with greater blue light exposure	< 0.01*	Suggests that high and low blocking short-wavelength light can reduce eye fatigue.
Leung et al. ²¹	Colour vision CSF	FM 100 Hue Mars chart	Participants using two blue light filtering spectacles, BF (blue-light transmittance: 82.2%) and a brown-tinted lens (BT blue-light transmittance: 77.5%) were exposed to a computer (LED) for 2 h every day for a month.	No degradation of colour vision or CSF	< 0.001* < 0.001*	The two blue light filtering spectacles did not significantly affect colour vision and contrast sensitivity.
Lawrenson et al. ⁹	Eye fatigue	Review study	Included studies used low and high blue blocking lenses, exposed to computers for over 2 h a day	CFF was negatively affected	0.03*	There was a lack of evidence found to support the uses of blue blocking spectacles to improve visual performance, alleviate visual fatigue and protect macular health.

CFF, critical flicker frequency; NPC, near point of convergence; CSF, contrast sensitivity function; VDT, visual display terminal; LED, light emitting diode.

*, *p*-value < 0.05 is statistically significant.

from the video reduces the change in NPC (magnitude unspecified). The change was the greatest for the 6500K video and lowest for the 3500K video. The lower the NPC value, the better the ability to watch a 3D video with greater ease. A reduced decay of NPC with blue light (wavelength) reduction implies that blue-light may degrade 3D content-recognition ability.

The study also investigated saccadic eye movement as a measure of eyestrain. The EyeLink 1000 plus was used to track and measure eye blinks and saccadic eye movement. The number of saccadic eye movements whilst watching each video is recorded by the EyeLink and thereafter compared and analysed. With reduction of larger amount of blue light from the video, the number of saccadic movements increased. The lower the number of saccadic eye movement, the higher is the level of eye fatigue. Conclusively, reducing the amount of digital blue light (wavelength) when watching videos increased the number of saccades and reduced the level of eyestrain from survey questions for eyestrain.

The third aspect the study investigated was blink rate as a marker for investigating dry eye, linking it to visual discomfort. The measured eye-blink-rate determined eye dryness, thus linking to eyestrain and the level of visual discomfort. A higher blink rate suggests eye dryness. The study noted that the greater the amount of blue light (wavelength) reduced from the videos, the lower the number of eye blinks, which highlighted that the digital blue light emitted from computer screens caused eye dryness, and when reduced, it allowed for less dryness in the eyes and thereby decreased associated visual fatigue.

The effect of digital blue light on contrast sensitivity function and colour vision

In one of the five studies²¹ mapped, blue-light filtering lenses were evaluated in a pseudo-randomised controlled study involving 80 computer users, which included the investigation of contrast sensitivity and colour vision after wearing blue-light filtering lenses for 2 h daily while using a computer (LED) for a month. The use of blue blocking lenses to eliminate blue light transmission showed indirect effects of blue light approach, for the evaluation of the optical and visual performances of blue-light filtering spectacle lenses.

Contrast sensitivity using with the Mars contrast sensitivity test revealed that both the clear lens with a blue-filtering anti-reflection coating and brown tinted lens (77.5% blue transmittance) did not significantly affect contrast sensitivity. Colour vision assessment with the Farnsworth Munsell 100 hue test and results revealed that the two blue-light filtering spectacles used did not significantly affect colour vision. The blue light filtering lenses with at least 70.0% blue light transmission (implying 30% blocking of transmission of blue light) did not show an obvious degradation in visual performance. The study recommended blue light filters as a viable option for protecting the eye from potentially hazardous digital blue light without substantially impacting contrast sensitivity function (CSF) and colour vision, which represented visual performance.

Non-clinical investigation of the effects of digital blue light on vision

Four of the accepted studies^{18,20,21} conducted independent validated questionnaires or surveys as a subjective measure to the common theme of visual fatigue experienced as a result

of digital blue light exposure. The questionnaires included common questions relating to the following symptoms: eyestrain, eye dryness, double vision, blurred or hazy vision, headaches, dizziness, sensational feeling felt in the eyes, difficulty in refocusing the eyes, photophobia (when outdoors), photophobia (when staring at the computer monitor), itchy eyes, general fatigue, mental stress and sleepiness when working, which encompassed an evaluation of visual fatigue. One of the accepted studies²¹ revealed that one-third of lens wearers found that a clear lens with a blue light filtering coating provided better anti-glare performance, and improved their vision for digital screens. This conclusion was obtained from all statistically significant observations from the questionnaires. Based on these studies,^{18,19,20} blue-light filtering spectacles reduced eye fatigue and visual discomfort from the digital blue light emitted from electronic device screens backlighting.

Exposure of digital blue light

All included studies exposed participants to at least 2 h of blue light exposure either directly or indirectly (using blue blocking lenses) that reduced transmission of blue light. The study by Leung et al.²¹ was the only one that had a prolonged exposure of 2 h a day, for one month. One study²¹ directly investigated the effect of reducing blue light on visual fatigue, whereas the three studies^{19,20,21} indirectly investigated blue light using blue light filtering spectacles. There was no difference in severity of symptoms reported from the groups directly exposed to blue light versus the groups indirectly exposed to blue light, as well as in groups exposed to blue light on a short-term versus a prolonged exposure.

Visual discomfort/fatigue and digital blue light exposure

The overarching theme of the accepted studies was that visual discomfort occurred from digital blue light exposure, as summarised in Table 2. The studies that investigated CFF revealed a reduction in the control groups versus the high and low blue blocking lens groups, indicating greater visual fatigue. Kim et al.¹⁸ investigated NPC, saccadic eye movement and blink rate as an indirect measure of visual fatigue and reported more exposure to blue light that resulted in greater visual fatigue. It was suggested that using clear lenses with a blue filter coat may serve as a viable option for protecting the eye from potentially hazardous digital blue light.²¹

Subjective assessment of visual strain in the form of surveys and questionnaires^{18,19,20,21} also showed an overall pattern amongst participants being less symptomatic and experiencing reduced visual fatigue when wearing blue blocking spectacle lenses, and a marked decrease in the level of eyestrain when the amount of blue light is reduced¹⁸. Therefore, exposure to digital blue light may be alleviated with the use of blue blocking spectacles and by reducing the amount of blue light emitted when viewing e-device screens. Furthermore, both low and high blue blocking spectacles aided visual fatigue reduction when compared with non-

blue blocking spectacles and did not substantially impact the integrity of CSF and colour vision.

Quality of evidence from included primary studies

The MMAT version 2018 served as quality appraisal of the five included studies by two reviewers independently. The studies first underwent two screening questions assessing the clarity of the research question and if the data collection method used was appropriate to answer the research question. Further appraisal was not possible if the study answered 'no' to any one of the screening questions. The number of criteria met served as the scoring basis of included studies. Scoring ranges from 20% (one criterion met) to 100% (all five criteria met). Low-quality studies had scores below 60%, average quality studies had 60% and high-quality studies had scores between 80% and 100%.

Table 3 shows that the included studies scored high (80% – 100%).²² From the included studies, three had an MMAT score of 100%. This implies that the quality of the included studies is significantly high and suggests that their results were reliable. For the two studies that reported an MMAT score of 80%, from the methodological criteria, each study scored a 'no' to one criterion, which means that adequate information was not provided regarding that criteria. By using the MMAT tool to assess the quality of the included studies, it allowed us to refine the studies to extract the most efficient results, thereby enhancing the reporting of our evidence that blue light exposure from electronic devices does affect the human eye. The advantage of the studies, having high MMAT scores (80% – 100%), is that it enhances the integrity of the current review.

Discussion

The aim of this scoping review is to identify evidence on the effects of digital blue light on the eye amongst people using electronic devices in today's electronic age. An extensive search strategy using relevant Boolean operators identified five relevant studies. The PECO framework guided the screening processes, whilst the quality of each study was assessed using the MMAT tool.

Main findings

The study focused on the effects of blue light emitted from e-devices utilising LED backlit display screens, also commonly referred to as digital blue light. The five studies mapped included evidence of blue light from laptops, tablets or computers, and its effects on vision. Identified clinical investigations of the included studies comprised NPC, colour vision, contrast sensitivity, blink rate, stereopsis and CFF. The salient theme across all papers was the effect of digital blue light on visual fatigue, which agrees that visual fatigue from LED electronic devices was because of blue light exposure. Light emitting diode computer screens were the most commonly utilised electronic devices amongst all studies. Most of the accepted articles focused on the use of blue blocking lenses as an indirect measure of the effects of

TABLE 3: Quality appraisal of studies included using the mixed method appraisal tool.

Author, date	Category of study design	Methodological criteria	Responses (yes, no, can't tell)	MMAT score
Kim et al. ¹⁸	Quantitative, Non-randomised	<ul style="list-style-type: none"> Are the participants representative of the target population? Are the measurements appropriate regarding both the outcome and intervention (or exposure)? Are there complete outcome data? Are the confounders accounted for in the design and analysis? During the study period, is the intervention administered as intended? 	yes yes yes yes yes	100%
Leung et al. ²¹	Quantitative, Non-randomised	<ul style="list-style-type: none"> Are the participants representative of the target population? Are the measurements appropriate regarding both the outcome and intervention (or exposure)? Are there complete outcome data? Are the confounders accounted for in the design and analysis? During the study period, is the intervention administered as intended? 	yes yes yes yes yes	100%
Ide et al. ²⁰	Quantitative, Non-randomised	<ul style="list-style-type: none"> Are the participants' representative of the target population? Are the measurements appropriate regarding both the outcome and intervention (or exposure)? Are there complete outcome data? Are the confounders accounted for in the design and analysis? During the study period, is the intervention administered as intended? 	yes yes yes can't tell yes	80%
Lin et al. ¹⁹	Quantitative, randomised	<ul style="list-style-type: none"> Is the randomisation appropriately performed? Are the groups comparable at baseline? Are there complete outcome data? Are outcome assessors blinded to the intervention provided? Did the participants adhere to the assigned intervention? 	yes yes yes yes yes	100%
Lawrenson et al. ⁹	Quantitative, descriptive	<ul style="list-style-type: none"> Is the sampling strategy relevant to address the research question? Is the sample representative of the target population? Are the measurements appropriate? Is the risk of non-bias low? Is the statistical analysis appropriate to answer the research question? 	yes yes yes yes can't tell	80%

Source: Mixed Methods Appraisal Tool (MMAT), version 2018. Registration of Copyright (#1148552), Canadian Intellectual Property Office, Industry Canada MMAT, mixed method appraisal tool.

digital blue light. Exposure to blue light resulted in a receded NPC as an indirect measure of stereopsis, reduced blink rate as a measure of dry eye, reduced CFF and suggested that blocking short-wavelength light may reduce saccadic eye movement as a measure of eye fatigue. The use of blue blocking lenses did not affect colour vision and CSF.

In vitro studies conducted on human retinal pigment epithelium cells exposed to blue light from electronic devices suggested increased amounts of short wavelength light from a LED lamp, which is equivalent to the lighting of an e-device that may lead to increased cell death, suggesting that blue light may be harmful to the eye.²³ Experiments conducted revealed that blue light between 400 nm and 490 nm can cause damage to the eye and eventually cause photoreceptor death.³ However, the blue light from an electronic device did not involve direct exposure using human participants. A fundamental difference with the animal studies is that the experimental conditions differ from the realistic working conditions that human eyes endure when using an electronic device. Nevertheless, it has raised a public health concern of blue light exposure damaging the retina, including concerns around the effectivity of blue blocking lenses regarding this. This review has not identified any studies of digital blue light exposure on human eyes that can corroborate the animal and laboratory studies' evidence of direct blue light exposure.

Relevance of findings

With animal studies, some used blue light of a certain wavelength for exposure and another study used light equivalent to a smartphone. Blue light studies need to move from animal studies to clinical trials similar to pharmaceutical trials. The current trend focusing on consumers who use electronic devices daily is that blue blocking lenses can prevent digital eyestrain. However, because a prospective study or randomised controlled trial (RCT) has not been conducted on the exposure of human eyes to digital blue light, the evidence that blue-blocking lenses provide protection against retinal or macula damage cannot be definitively answered.

Strengths and limitations

Limitations of the current study include the inability to retrieve some studies and the inability to translate the studies that were not in English. Utilisation of electronic databases may have limitations for inclusion of grey literature. Of the included studies, some of the limitations identified were small sample sizes used, and this provided results not representing the general population. The experimental conditions also differ from natural working conditions in the cited studies. All the participants may have had exposure to a different work environment. The participant's age range varied, and this affects the transmittance levels of light that varies greatly between the

young and old generation. The evidence on NPC, saccades and blink rate was limited to one study, as well as CSF and colour vision.

Proposed recommendations are that more investigations in the field of digital blue light from all types of electronic devices affecting the eye because of increased exposure to screen time are required, considering the electronic age we reside in. There is a great need for *in vivo* studies, as most studies conducted are *in vitro*. There is a lack of evidence on the retinal effects *in vivo* that blue light and digital blue light have on the human eye. When conducting future studies on the effects on visual fatigue, aspects such as dry eye, stereopsis, tear function and the blink rate of participants require an extended exposure beyond 2 h a day. The expansion of age ranges of the participants in the studies may show the effects of digital blue light on different age groups, to show at-risk age groups, particularly, the paediatric population as they may be an emerging market in the use of digital devices. Age affects different aspects of the human eye like pupil constriction, accommodation and the amount of light transmittance. A case in point is the role out of digital workbooks to schoolchildren in schools, which will affect screen time amongst children. Mountjoy et al. show evidence that the more time children are spending on education in front of screens, the risk of myopia increases.²⁴ Evidence is lacking on the effects of digital blue light on accommodative function and refractive error in the context of the myopia epidemic society is facing. The role blue light may have on this issue may influence myopia control management. Myopia has been associated with computer-related visual symptoms as they experience more symptoms, whilst they use the computer for longer hours.²⁵

Implications for future research

This scoping review can prove to be helpful to eye care practitioners and lens manufacturers in terms of the use of blue blocking spectacle lenses and patient education, especially with digital eyestrain. It also prompts further investigation and research regarding the safety of electronic devices and their effects on the retina but may serve as another step forward to guide the field of blue light research.

Conclusion

This scoping review allows us to identify if digital blue light is harmful to the eyes and identify any gaps in research regarding its effects in the context of an age range where there is an escalation in the use of e-devices with LED backlighting. The findings suggest that digital blue light does affect vision negatively but in the absence of retinal studies, the research question cannot be definitively answered. Digital blue light mainly causes visual discomfort that influenced changes in CFF, blink rates and NPC. Visual discomfort from digital blue light is alleviated using blue blocking lenses. These findings show that there is a need for more research on long-term effects of digital blue light on human eye and

vision. Research on the exposure of digital blue light on the retina of human eyes *in vivo*, investigating short-term and long-term effects from direct exposure to LED devices, is lacking.

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Competing interests

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Authors' contributions

All co-authors (M.M., Z.K., K.G., M.N., S.C., M.R.) constructed, read and approved the final manuscript.

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Data availability

Data supporting the findings of this study are available from the corresponding author, A.J.M., on request.

Disclaimer

The content is solely the responsibility of the authors and does not necessarily represent the official views of DRILL and the National Institutes of Health.

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