Author/s:
Lawrenson, JG;Hull, CC;Downie, LE

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PROF. JOHN GERARD LAWRENSON (Orcid ID : 0000-0002-2031-6390)

PROF. CHRISTOPHER C HULL (Orcid ID : 0000-0002-2205-4443)



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**Title page**

**Full title: The effect of blue-light blocking spectacle lenses on visual performance, macular health and the sleep-wake cycle: a systematic review of the literature**

**Running head:** Blue-light blocking spectacle lenses

**Authors' names and institutional affiliations:** John G Lawrenson (1), Christopher C Hull (1) and Laura E Downie (2)

(1) Centre for Applied Vision Research, Division of Optometry and Visual Science, City University of London, UK.
(2) Department of Optometry and Vision Sciences, The University of Melbourne, Victoria, Australia.

**Corresponding author**

**John G Lawrenson**

E-mail address: j.g.lawrenson@city.ac.uk

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**Keywords**: spectacles, blue light blocking, visual performance, macular changes, sleep-wake cycle, systematic review



**ABSTRACT**

*Purpose:* Blue-blocking (BB) spectacle lenses, which attenuate short-wavelength light, are being marketed to alleviate eyestrain and discomfort when using digital devices, improve sleep quality and potentially confer protection from retinal phototoxicity. The aim of this review was to investigate the relative benefits and potential harms of these lenses.

*Methods*: We included randomised controlled trials (RCTs), recruiting adults from the general population, which investigated the effect of BB spectacle lenses on visual performance, symptoms of eyestrain or eye fatigue, changes to macular integrity and subjective sleep quality. We searched MEDLINE, EMBASE, the Cochrane Library and clinical trial registers, until 30 April 2017. Risk of bias was assessed using the Cochrane tool.

*Results*: Three studies (with 136 participants) met our inclusion criteria; these had limitations in study design and/or implementation. One study compared the effect of BB lenses with clear lenses on contrast sensitivity (CS) and colour vision (CV) using a pseudo-RCT crossover design; there was no observed difference between lens types (log CS; Mean Difference (MD)=-0.01 [-0.03, 0.01], CV total error score on 100-hue; MD=1.30 [-7.84, 10.44]). Another study measured critical fusion frequency (CFF), as a proxy for eye fatigue, on wearers of low and high BB lenses, pre- and post- a two-hour computer task. There was no observed difference between low BB and standard lens groups, but there was a less negative change in CFF between the high and low BB groups (MD=1.81 [0.57, 3.05]). Both studies compared eyestrain symptoms with Likert scales. There was no evidence of inter-group differences for either low BB (MD=0.00 [-0.22, 0.22]) or high BB lenses (MD=-0.05 [-0.31, 0.21]), nor evidence of a difference in the proportion of participants showing an improvement in symptoms of eyestrain or eye fatigue. One study reported a small improvement in sleep quality in people with self-reported insomnia after wearing high compared to low-BB lenses (MD=0.80 [0.17, 1.43]) using a 10-point Likert scale. A study involving normal participants found no observed difference in sleep quality. We found no studies investigating effects on macular structure or function.

*Conclusions*: We find a lack of high quality evidence to support using BB spectacle lenses for the general population to improve visual performance or sleep quality, alleviate eye fatigue or conserve macular health.

**INTRODUCTION**

***Rationale***

Studies, in animal models[1, 2] and cell culture,[3, 4] have shown that wavelengths in the blue, visible portion of the electromagnetic spectrum (400-500nm) can induce phototoxic retinal damage. Historically, two mechanisms of photochemical damage have been recognised and eponymously named as 'Noel damage' and 'Ham damage' after the original investigators.[1, 5] Noel, or Class I, damage was first observed following prolonged exposure of albino rats to fluorescent light (490-580nm). Cellular disruption occurred initially in photoreceptors, followed by the retinal pigment epithelium (RPE). By contrast, Ham[5] (Class II damage) described disruption that occurred after shorter, high intensity light exposures (between 10 seconds and two hours' duration). Shorter wavelengths were associated with more intense cellular damage, initially at the level of the RPE, with a peak of the action spectrum occurring at around 440nm in the phakic eye. International standards have been developed based on these empirical studies[6], which define exposure limits, below which adverse effects are unlikely to occur. However, driven by requirements for brighter and lower energy lighting, the last 10 years has seen significant changes in light sources for both commercial and domestic applications, with an increased use of compact fluorescent lamps (CFL) and high intensity light-emitting diodes (LEDs). Moreover, white-light LEDs (the most common type of LED) have become ubiquitous in backlight displays in smartphones and tablet computers. Although the light emitted by these LEDs appears white, their emission spectra show peak emissions at wavelengths corresponding to the peak of the blue light hazard function. It has been shown that exposure of cultured RPE cells to light equivalent to that emitted from mobile display devices causes increased free radical production and reduced cell viability.[7] This has raised concerns that the cumulative exposure to blue light from such sources may induce retinal toxicity and potentially increase the risk of age-related macular degeneration.[8]

The rationale for the introduction of blue-blocking ophthalmic lenses was to mitigate the risk of retinal toxicity by blocking, or attenuating, short wavelength visible light, usually in the range 400nm to 500nm. These ophthalmic devices, which include spectacle lenses, contact lenses and intra-ocular lenses (IOLs), contain or are coated with dyes that selectively absorb blue and violet light. The choice between a conventional ultraviolet (UV) light blocking IOL and a blue-blocking IOL following cataract surgery has generated significant debate in the literature in terms of achieving a balance between photoreception and photoprotection.[9-12] Possible disadvantages of blocking short-wavelength visible light transmission include disturbances of colour perception, decreased scotopic sensitivity (leading to poorer performance in dim lighting conditions) and disruption of the timing of the circadian system.[13] Intrinsically photosensitive retinal ganglion cells, which provide photic input to the central

circadian clock in the suprachiasmatic nucleus, express melanopsin and have an absorption peak at approximately 480nm in the blue part of the spectrum.[14]

Compared to their intra-ocular counterpart, blue-blocking spectacle lenses have received relatively little scientific attention. Standard spectacle lenses generally offer protection against UV (up to wavelengths of 380nm) and the adding of a yellow chromophore can also reduce or eliminate blue light transmission. Alternatively, anti-reflection interference coatings can be applied to both the anterior and posterior lens surfaces, to selectively attenuate parts of the blue-violet light spectrum (415 to 455 nm); this range of wavelengths includes a significant proportion of the blue light hazard function[15], while the lens remains transparent to other wavelengths of visible light. In addition to their putative benefit for retinal protection, blue-blocking spectacle lenses have also been claimed to improve sleep quality following the use of electronic devices at night,[16] and reduce eye fatigue and symptoms of eye strain during intensive computer tasks.[17]

A systematic review of the best available research evidence is essential to assess the appropriateness of marketing blue-blocking spectacle lenses at the general spectacle wearing population. This evaluation will consider both the relative benefits and potential harms of these lenses.

***Objectives***

The primary aim of this systematic review is to evaluate the effectiveness of blue-blocking spectacle lenses for improving visual performance and reducing visual fatigue. Our secondary aims are to assess whether these lenses are effective in maintaining macular health and to determine any positive or negative effects on the sleep-wake cycle. The review will attempt to find scientific evidence to answer the following questions:

1. Compared to standard (non blue-blocking) spectacle lenses, do blue-blocking lenses enhance visual performance?
2. Compared to standard spectacle lenses, do blue-blocking lenses improve visual comfort and/or reduce symptoms of visual fatigue?
3. What is the evidence that blue-blocking spectacle lenses provide protection to the macular and preserve macular function?
4. What is the evidence that blue-blocking spectacle lenses disrupt circadian entrainment and affect alertness and/or sleep quality?

**METHODS**

The protocol for this review was prospectively published on PROSPERO (2017:CRD42017064117) Available from http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42017064117),

***Search strategy***

We conducted searches using the following bibliographic databases: Ovid MEDLINE, Ovid EMBASE, PubMed and the Cochrane Library for relevant articles published before May 2017. We did not use any date or language restrictions for the bibliographic searches. An example search strategy for one of the databases (Ovid MEDLINE) is included in Supplementary File 1. We also scanned the reference list of included studies and contacted experts in the field to ask if they are aware of additional published or on-going trials investigating blue-blocking lenses. We searched the PROSPERO database for relevant systematic reviews and searched clinical trials registries (Clinical trials.gov and the ISRCTN registry) for recently completed or on-going trials.

***Inclusion and exclusion criteria***

We included randomised controlled trials (RCTs) and pseudo-randomised controlled trials, which recruited adults, aged 18 years and above, from the general population and compared blue-blocking spectacle lenses to standard spectacles lenses, or any other comparator, where it was possible to isolate the effect of the blue-blocking lens for any of our primary or secondary outcomes. We defined blue-blocking lenses as those that block or attenuate short wavelength optical radiation between 400nm and 500nm. The review team decided post-hoc that this should include comparisons between high and low blue-blocking lenses.

The following outcomes were considered:

Primary outcomes:

- Any measure of visual performance (e.g., logMAR visual acuity, contrast sensitivity, critical fusion frequency (CFF), colour discrimination under photopic or mesopic conditions, scotopic sensitivity, dark adaptation, stray light and glare sensitivity) conducted during the follow up period of the trial.
- Any measure of visual fatigue or discomfort (e.g., using questionnaires or visual analogue scales) conducted during the follow-up period of the trial.

Secondary outcomes:

- Proportion of eyes with a structural change in the macula using clinical observation, fundus photography or optical coherence tomography (OCT) between six and 24 months following the start of the intervention. This could include development of early AMD, progression of AMD or progression to late stage AMD, as defined by the trial investigators.
- Objective or subjective assessment of alertness and/or sleepiness.
- Effect on average macular pigment optical density (MPOD), measured as the proportion of eyes that had a significant increase in MPOD at six months.
- Overall participant satisfaction with blue-blocking lenses (e.g.,. using questionnaires or rating scales).

Adverse effects:

- Any ocular and systemic adverse effects associated with the intervention, as reported by the study authors.

For the evaluation of visual performance and effect of the intervention on alertness and/or sleep quality, we included any measure conducted during the follow-up period of the trial. To assess the effects of blue-blocking spectacle lenses on macular health or function, studies had to be at least six months duration.

***Data extraction and analysis***

Following removal of duplicates, two reviewers (JL and CH) independently screened the titles and abstracts identified from the bibliographic searches and resolved any discrepancies by discussion and consensus. We obtained full-text copies of potentially eligible studies and these were assessed by both reviewers to decide whether they met the inclusion criteria. Reasons for exclusion were documented at this stage. We used a data extraction form that was developed and piloted for the purpose of this review. We collected data on: study design, details of participants, details of intervention, methodology, quantitative data on outcomes and funding sources. Data extraction was conducted independently by two reviewers (JL and CH) and any discrepancies resolved by discussion. The extracted numerical data was entered into Revman 5[18] meta-analytical software by one reviewer (JL) and this was checked by a second reviewer (CH).

Two review authors (JL and CH) independently assessed the risk of bias in included studies using the Cochrane Risk of Bias tool as detailed in Chapter 8 of the Cochrane Handbook.[19] We evaluated risk of bias using the following bias domains:

- selection bias (random sequence generation and allocation concealment);
- performance bias (masking of participants and personnel);
- detection bias (masking of outcome assessment);
- attrition bias (incomplete outcome data);
- reporting bias (selective reporting of outcomes);
- other bias (funding source, other conflicts of interest).

Any differences of opinion in risk of bias assessments were resolved by discussion.

Our measure of treatment effect was the risk ratio (RR) for dichotomous outcomes and the mean difference (MD) for continuous outcomes, with 95% confidence intervals [CIs].

By definition, the intervention was applied to the person and therefore the unit of analysis was the same as the unit of randomisation. However, where data was presented from both eyes, we analysed the data from the right eye only to avoid a unit of analysis error. Insufficient studies were available to conduct the planned meta-analysis. However a descriptive summary of the results of the included studies has been provided. Publication bias could not be assessed, as there were an insufficient number of studies to conduct this analysis.

We assessed the certainty of the evidence using the Grades of Recommendation, Assessment and Evaluation (GRADE) Working Group approach,[20] using customised software (GRADEpro GDT). One reviewer (JL) conducted the initial assessment and this was checked by the other reviewers (CH and LD). We considered risk of bias, inconsistency, indirectness, imprecision, and publication bias when judging the certainty of the evidence.

## RESULTS

### *Results of the searches*

The electronic searches yielded 118 references (see *Figure 1* for the PRISMA flow diagram). After 19 duplicates were removed, we screened the remaining 99 references and obtained the full-text reports of 15 references for further assessment. Twelve of these[17, 21-31] were eliminated (see Table of Excluded Studies in Supplementary File 2 and three RCTs that met the *a priori* criteria for inclusion

were included in the final analysis (see Characteristics of Included Studies in Supplementary File 3. We did not identify any on-going studies from our searches of the clinical trials registries.

**Characteristics of included studies**

We included three studies in this review.[32-34] Two of the studies were conducted in the USA and one in Hong Kong.

Burkhart and Phelps[32] randomised 20 adult volunteers reporting sleep difficulty to wear either amber tinted glasses (blocking wavelengths <550nm) or yellow tinted placebo glasses (blocking wavelengths <465nm) for three hours prior to sleep. The primary outcome measure was sleep quality as determined by sleep diaries, which incorporated a 10-point Likert sleep quality scale. Sleep diaries were completed for one week prior to the intervention (baseline) and for two weeks afterwards.

Leung and co-workers[33] conducted a pseudo-randomised controlled trial involving 80 computer users from two age cohorts: young adults, 18-30 years, n=40 and middle aged adults 40-55 years, n=40. Participants were randomised into one of three groups to assess the performance of two blue-blocking spectacle lenses (blue-blocking anti-reflection coating and a brown tinted lens) and a regular clear control lens, using a crossover design. The primary outcomes were contrast sensitivity, using the Mars contrast sensitivity letter chart under standard and glare conditions, and colour discrimination using the Farnsworth-Munsell 100-hue test. Following the visual assessment tests, participants wore each assigned lens for one month for a minimum of two hours per day. At the end of each wearing period, lens performance was subjectively assessed using a 13-item questionnaire. Each question was rated on a 1-5 scale (where 1=very unsatisfactory and 5=very satisfactory).

Lin and co-workers[34] recruited 36 adult subjects who were randomised to one of three groups and wore either spectacles with low or high blue-blocking lenses or non-blue blocking lenses for a 2 hour computer task using a laptop computer. At the end of the task, critical fusion frequency (CFF) was assessed and symptoms of eyestrain were evaluated using a 15-item questionnaire. The CFF is the lowest level of continuous flicker that is perceived as a steady source of light and a reduction in CFF was interpreted as a measure of eye fatigue.

**Risk of bias and certainty of the evidence**

We evaluated the risk of bias in the included studies using the Cochrane risk of bias tool.[19] *Figures 2* and *3* present a graph and summary of the risk of bias for the included studies. Overall the studies were at an unclear or high risk of bias. We rated two studies[32, 34] as having an unclear risk of selection bias, since they did not describe the method for random sequence generation or how this

was concealed. Leung and colleagues[33] allocated participants to different sequences of lens wear by date of admission and therefore the sequence was non-random and at a high risk of selection bias. Given that two of the included studies randomised small numbers of participants,[32, 34] there were baseline differences in the outcome of interest, which may have affected the results. Although attempts were made to mask outcome assessors to the intervention received, it was not possible to mask participants due to differences in appearance between the lenses being tested. We judged one study[34] to be at a high risk of selective reporting bias, due to a failure to report on 2/15 of the questions from the symptom questionnaire and no protocol or trial registration was available. Two studies[32, 33] were judged to be at an unclear risk of selective reporting since either no protocol or trial registry entry was available, or in one case the trial was retrospectively registered.[33]

We rated the certainty of evidence for each outcome using GRADE (see *Table 1*).

**Effects of the intervention**

*Primary outcome measures*

Two studies[33, 34] randomising 116 participants, provided data on differences in visual performance with blue-blocking lenses compared to a clear control lens. Leung *et al*[33] investigated the effect of blue-blocking lenses on contrast sensitivity and colour vision using a crossover design. There was no evidence of a difference in log contrast sensitivity or total error score on the FM 100-hue test between the intervention and control lenses (*Table 1*). Lin *et al*[34] measured CFF (a proxy measure of eye fatigue) before and after a two-hour computer task. There was no observed difference between the low-blocking and no-blocking (clear) lens groups, but there was evidence of a less negative change in CFF between the high and low-blocking lens groups indicating less fatigue with computer use for the high-block group (*Figure 4*).

These studies also compared symptoms of eyestrain for the intervention and control lenses using Likert rating scales.[33, 34] Leung *et al.*[33] measured symptoms of eyestrain on a 5-point scale after one month of wearing low blue-blocking (blue-filtering anti-reflection coating), high blue-blocking (brown-tinted) or control (non blue-blocking) lenses. There was no significant difference between the intervention and control lenses for either the low blue-blocking lens (Mean difference (MD)= 0.00 [-0.22, 0.22]) or the high blue-blocking lens (MD=-0.05 [-0.31, 0.21]). Lin *et al*[34] compared symptoms related to eye fatigue or eye strain before and after a two hour computer task for participants wearing clear (control) lenses or low or high blue-blocking lenses using a 15-item questionnaire. Since there was no statistical difference between the low blue-blocking and clear lens

groups, the study authors pooled the data for the low blue-blocking and clear lens participants and compared the symptom scores, after the task, for each question. Statistical differences between groups, for each questionnaire item, were then investigated using the Mann-Whitney U test. For the current review, we analysed the ordinal data from the 13 questionnaire items reported and calculated the proportion of subjects in each group showing a post-task symptomatic improvement for each question. The risk ratio (RR) with 95% confidence intervals was calculated for each question using Revman[18] (*Table 2*). A significant symptomatic improvement was found for only one question 'My eyes feel itchy' (RR 2.68 [1.32, 5.44]).

*Secondary outcomes*

There was no available data on the proportion of eyes with any structural change in the macula or the effect of blue-blocking spectacle lenses on average MPOD.

Two studies provided data on the subjective assessment of sleep quality. Leung *et al.*[33] found no evidence of a difference in sleep quality for low or high blue-blocking lenses compared to control lenses for normal participants (low blue-blocking, MD=0.04 [-0.26, 0.18]; high blue-blocking, MD=0.00 [-0.23, 0.23]). By contrast, Burkhart and Phelps[32] found a small improvement in sleep quality in participants wearing high blue-blocking lenses compared to low blue-blocking lenses in individuals experiencing sleep-onset or mid-sleep insomnia (MD=0.80 [0.17, 1.43]).

One study[33] reported on the overall performance of blue-blocking lenses. There was no evidence of a difference in performance for either low or high blue-blocking lenses compared with control lenses.

None of the included studies reported on ocular or systemic adverse effects associated with the interventions.

**DISCUSSION**

Blue-blocking spectacle lenses, with varying degrees of short-wavelength light attenuation (ranging from 10% to 100%), are being marketed at the general population with claims that they can alleviate eyestrain and discomfort (particularly when using computers and other digital devices), improve sleep quality and possibly confer protection from retinal phototoxicity. The current systematic review did not identify any high quality clinical trial evidence to support these claims. Rather, the included studies provided evidence, albeit of low certainty, that there was no significant difference in relation to the proportion of subjects showing an improvement in symptoms of eyestrain or eye fatigue between the intervention (blue-blocking) and control spectacle lenses. This conclusion differs from the authors of one of the included studies. Using Likert scales, Lin and colleagues compared

symptoms in subjects wearing high-blocking lenses to a combined low block/no block group following a two hour computer task. They found symptomatic improvement for the high block group in three of the 15 questionnaire items (pain around/inside the eye , eyes were heavy and the eyes were itchy) following the computer task, compared to subjects not wearing high-blocking lenses. However, the authors did not indicate whether this analysis was pre-specified or was part of an exploratory post-hoc comparison. Furthermore, there was no suggestion that the authors had considered the risk of a type I error associated with multiple statistical comparisons.[35] For the current study we used the analyses plan that was specified prospectively in the review protocol (PROSPERO 2017:CRD42017064117). In addition, we also considered that it would be statistically more appropriate and clinically more meaningful to present the data from Lin et al[34] as a comparison of the proportion of subjects showing a post-task symptomatic improvement for each item in the questionnaire, given that we do not accept that the questionnaire responses can reasonably be considered to fall on a continuous scale.

Subjective ratings of overall lens performance were reported in one crossover trial in which 80 participants wore spectacles with low blue-blocking, high blue-blocking or control (clear) lenses for four weeks. There was no observed difference in performance ratings between lens types. A parallel group RCT reported that high blue-blocking lenses (but not low blue-blocking lenses) produced a less pronounced reduction in CFF after a two-hour computer task indicating less visual fatigue. However, the clinical significance of this finding is unclear, since CFF has been shown to decline after reading irrespective of whether the task is performed on paper or using an e-reader. This suggests that the CFF parameter may be independent of blue light exposure.[36]

In modern society, computers and other digital electronic devices are ubiquitous in both the workplace and domestic environments and given the high number of hours per day that most individuals spend viewing small text on electronic devices at short working distances, it is not surprising that up to 90% of users periodically experience asthenopic symptoms including, eyestrain, headaches, ocular discomfort, dry eye, diplopia and blurred vision.[37] However, what is now termed computer (or digital) vision syndrome is a multifactorial condition with several potential contributory causes, such as uncorrected refractive error, oculomotor disorders, tear film abnormalities and/or musculoskeletal problems.[38] Therefore, the role played by blue light in these symptoms is difficult to extricate.

Despite the putative benefits of blue light blocking lenses, concerns have been raised that these lenses could adversely affect some aspects of visual performance (e.g., contrast sensitivity or colour vision). Using standard clinical tests, Leung *et al*.[33] did not observe any detrimental effects on log-

contrast sensitivity or total error score using the FM 100-hue colour vision test. This is consistent with a previous systematic review[39] and meta-analysis comparing blue-blocking IOLs with UV-blocking IOLs, following cataract surgery. The results showed that there was no evidence of any difference in post-operative contrast sensitivity or overall colour vision, although colour vision with blue-blocking IOLs was impaired at the blue end of the spectrum under mesopic conditions.[39]

Given the role of blue light in the timing of the circadian system we examined evidence on the influence of blue-blocking lenses on sleep quality. This outcome was reported in two studies. Leung and co-workers[33] found no observed difference in the effect of either low or high blue-blocking lenses on the subjective assessment of sleep quality in normal participants. By contrast, Burkhart and Phelps[32] recruited participants reporting sleep difficulties who wore either high or low blue-blocking lenses for three hours prior to sleep for two weeks. High blue-blocking lenses were associated with a statistically significant improvement in self-reported sleep quality, based on a 10-point Likert scale, for the high blue-blocking group compared to the low blue-blocking lens group (MD=0.80 [0.17, 1.43]: p=0.03).

No studies reporting on the effects of blue-blocking spectacle lenses on macular health were identified. With the widespread incorporation of backlit LED displays in modern digital devices, concerns have been raised regarding the long-term safety of these screens, which have emission peaks in the 460nm to 490nm spectral range. One of the suggested benefits of blue-blocking spectacle lenses is to protect the retina against these potentially damaging wavelengths. However, despite the perceived risks, the spectrally weighted irradiance from these devices does not reach international exposure limits, even for prolonged viewing. Moreover, the emissions have been shown to be lower than natural exposure from sunlight, even on a cloudy day in winter, in the United Kingdom.[40]

In summary, the findings of this systematic review indicate that there is a lack of high quality clinical evidence for a beneficial effect of blue-blocking spectacle lenses in the general population to improve visual performance or sleep quality, alleviate eye fatigue or conserve macular health. Only three studies met our inclusion criteria and these were generally poorly reported, with several limitations in study design and/or implementation. All three included studies were at risk of selection bias; differences in the appearance of the lenses meant that it was impossible to fully mask participants to the trial intervention; and we were unable to exclude the possibility of selective outcome reporting. We rated the overall certainty of the evidence using GRADE[20] as low or very low, and therefore we have little to no confidence in the effect estimates. None of the included studies reported on adverse effects associated with the use of blue-blocking lenses.

There is a need for high quality studies to address the effects of blue blocking spectacle lenses on visual performance, and the potential alleviation of symptoms of eyestrain and/or visual fatigue. There should be an agreed standard set of outcomes, known as 'core outcome sets' (COS) as recommended by the COMET initiative.[41] These sets could then be collected and reported to allow the results of studies to be compared and combined as appropriate. The studies investigating these outcomes should adopt a RCT design and be conducted on a general population, using blue-blocking lenses with varying degrees of blue light attenuation. Sampling could be stratified to include participants varying in age, gender, ethnicity and occupational or domestic exposure to blue light. Outcome measures investigated in trials should include those that are important to potential blue-blocking lens users (e.g., the maintenance of macular health and function, or alleviation of digital eyestrain). Furthermore, attempts should be made to mask participants and outcome assessors to the intervention, to reduce the risk of performance bias. Finally, given the importance of blue light for scotopic sensitivity and in regulating the sleep-wake cycle, the potential harms of blue-blocking spectacle lenses should also be considered alongside the putative benefits of these devices.

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The authors report no proprietary interest in any of the materials mentioned in this article. The lead reviewer (JL) has given lectures on this topic at conferences for which travel and accommodation has been paid by the organisers. The other two authors (CH, LD) declare that they have no known conflicts of interest related to the review topic.

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**Figure Legends**

**Figure 1.** Study flow diagram

**Figure 2.** Risk of bias graph presented as a % across all included studies

**Figure 3.** Risk of bias for included studies

**Figure 4.** Comparison of change in Critical Fusion Frequency (CFF), in Hz, before and after a computer task for high and low blue-blocking lenses versus control. The high blue-blocking lens is associated with a significant change in CFF. Data from the same control group are used in both comparisons.

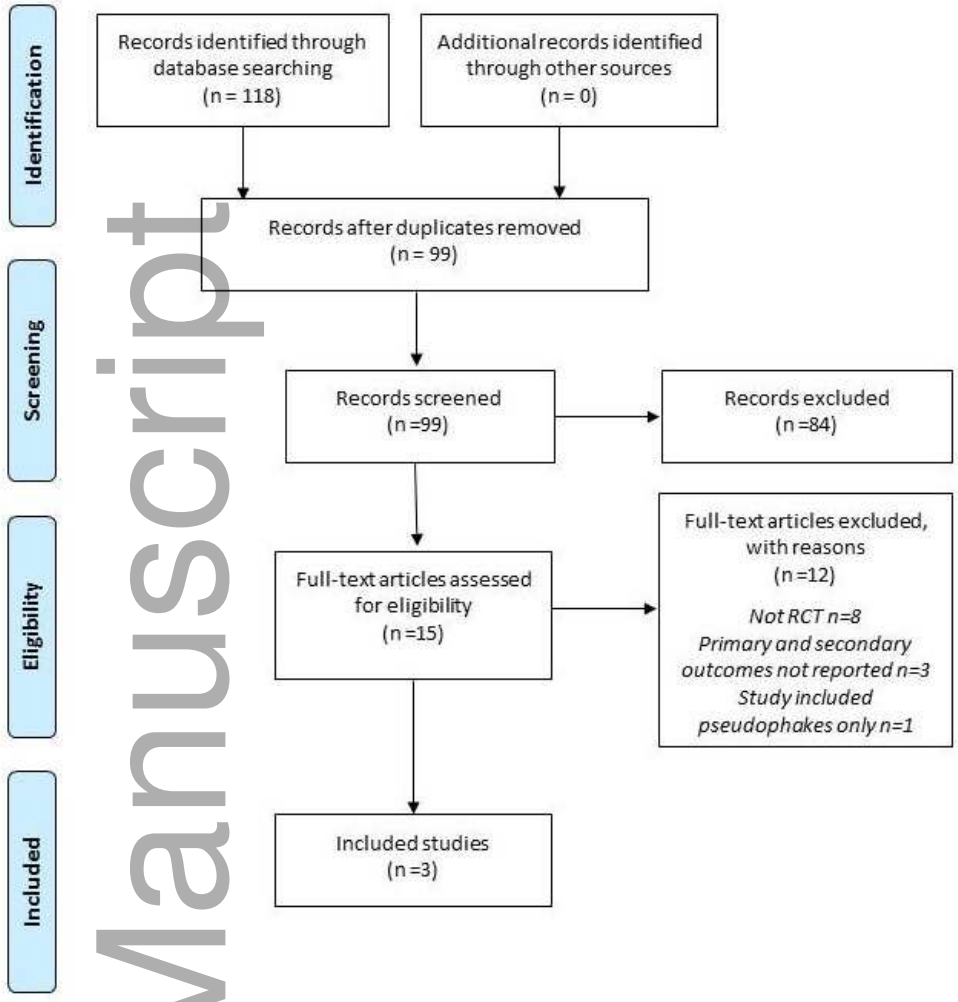



**Figure 1**

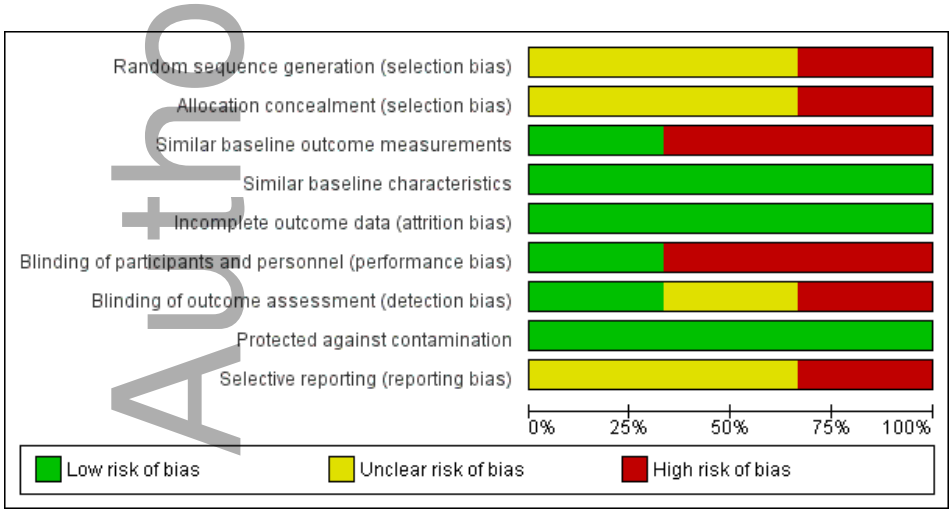



**Figure 2.**

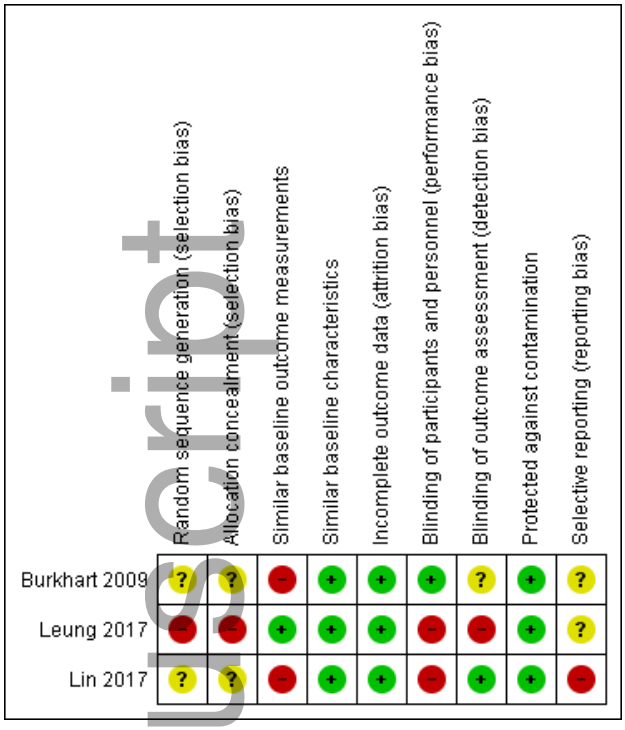



**Figure 3.**

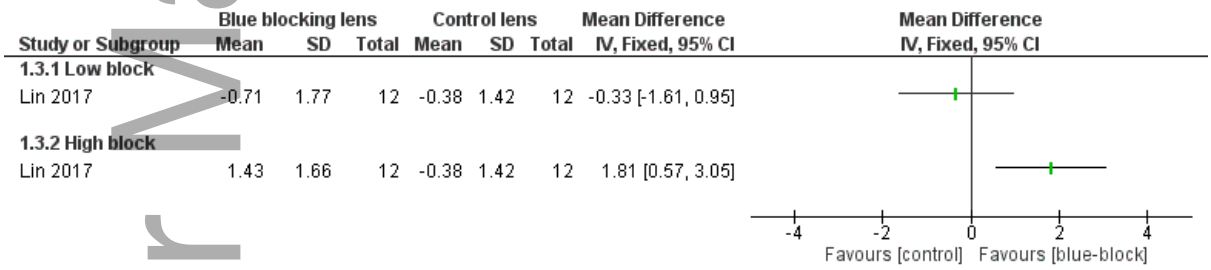



**Figure 4.**

**Table 1.** Results table for primary and secondary outcomes

| Outcome | Study | Comparison | Number of participants | Intervention effect | Certainty of Evidence (GRADE[20]) |
|---|---|---|---|---|---|
| **Any measure of visual performance conducted during the follow up period of the trial.** | Leung 2017 | Low blue-block vs. clear lens | 80 | Log contrast sensitivity (combined young and middle aged subjects) MD=-0.01 [CI -0.03, 0.01] | LOW[1] |
| | Leung 2017 | High blue-block vs. clear lens | 80 | Log contrast sensitivity (combined young and middle aged subjects) MD=-0.01 [CI -0.03, 0.01] | |
| | Leung 2017 | Low blue-block vs. clear lens | 80 | Colour vision (TES) (combined young and middle aged subjects) MD=4.03 [CI -4.96, 13.02] | |
| | Leung 2017 | High blue-block vs. clear lens | 80 | Colour vision (TES) (combined young and middle aged subjects) MD=1.30 [CI -7.84, 10.44] | |
| | Lin 2017 | Low blue-block vs. clear lens | 36 | CFF pre- and post-task MD=-0.33 [CI-1.61, 0.95] | |
| | Lin 2017 | High blue-block vs. clear lens | 36 | CFF pre- and post-task MD=1.81 [CI 0.57, 3.05] | |

| | | | | | |
|---|---|---|---|---|---|
| **Any measure of visual fatigue or discomfort conducted during the follow-up period of the trial.** | Leung 2017 | Low blue-block vs. clear lens | 80 | Relief of eyestrain (combined young and middle aged subjects) MD=0.00 [CI -0.22, 0.22] | LOW[1] |
| | Leung 2017 | High blue-block vs. clear lens | 80 | Relief of eyestrain (combined young and middle aged subjects) MD=-0.05 [CI-0.31, 0.21] | |
| | Lin 2017 | High blue-block vs. not high blue-block | 36 | Proportion showing an improvement in symptoms of eyestrain/eye fatigue pre- and post-task. *'My eyes feel tired'* RR=3.33 [0.95, 11.66]; *'I feel pain around or inside my eyes'* RR=2.60 [0.85, 7.98]; *'My eyes feel heavy'* RR=2.50 [0.95, 6.57]. | |
| **Objective or subjective assessment of alertness/ and/or sleepiness.** | Leung 2017 | Low blue-block vs. clear lens | 80 | Sleep quality (combined young and middle aged subjects) MD=0.04 [CI -0.26, 0.18] | VERY LOW[1,2] |
| | Leung 2017 | High blue-block vs. clear lens | 80 | Sleep quality (combined young and middle aged subjects) MD=0.00 [CI-0.23, 0.23] | |
| | Burkhart 2009 | High blue-block vs. low blue-block | 20 | Improvement in sleep quality | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | MD=0.80 [CI 0.08, 1.52] | |
| **Overall participant satisfaction with blue-blocking lenses** | Leung 2017 | Low blue-block vs. clear lens | 80 | Overall lens performance MD=-0.14 [CI-0.36, 0.08] | LOW[1] |
| | Leung 2017 | High blue-block vs. clear lens | 80 | Overall lens performance MD=0.05 [CI -0.17, 0.27] | |
| **Proportion of eyes with a structural change in the macula following the start of the intervention.** | Not reported | N/A | N/A | N/A | N/A |
| **Effect on average macular pigment optical density (MPOD).** | Not reported | N/A | N/A | N/A | N/A |

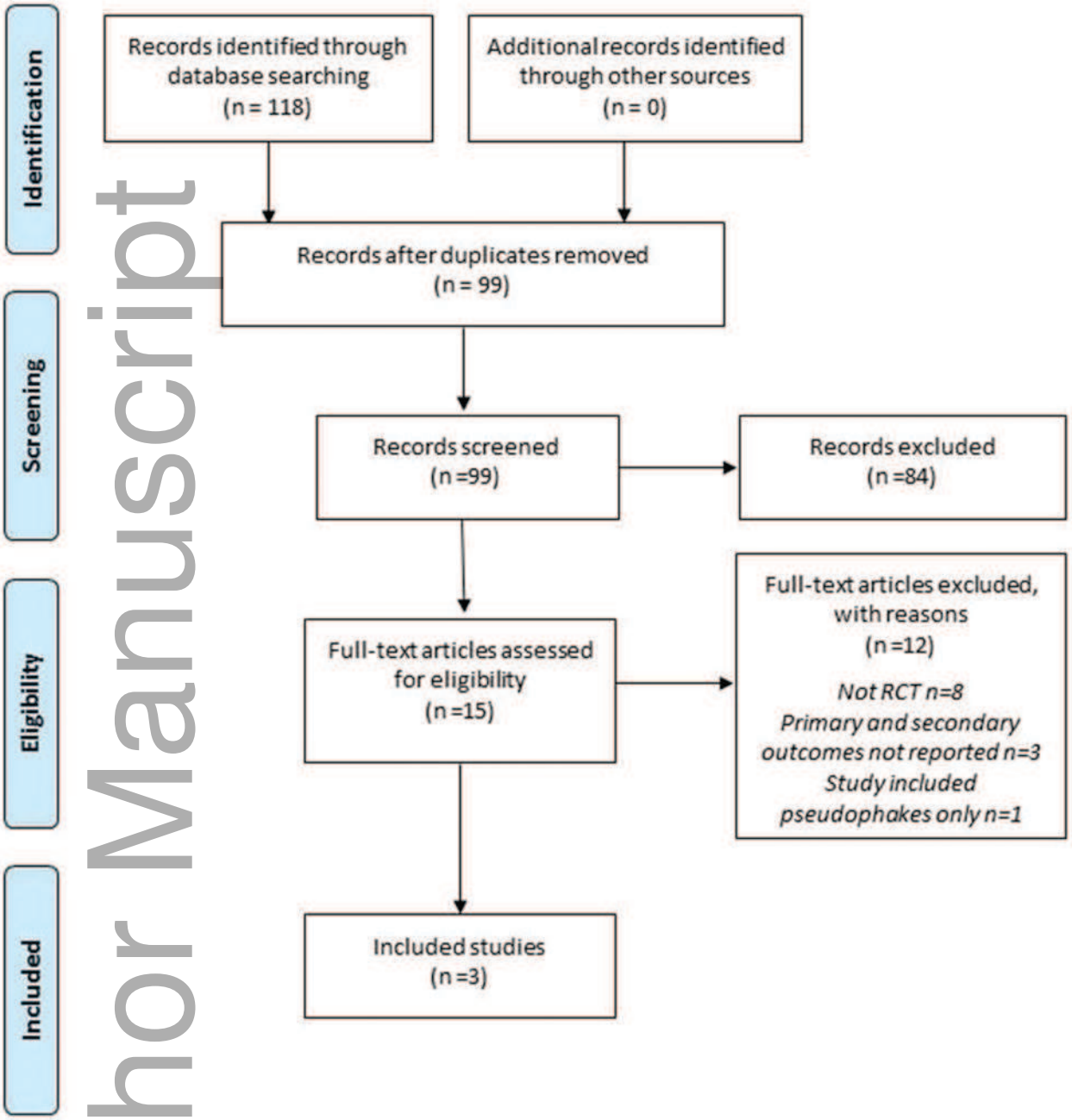
[1]Downgraded two levels for risk of bias. [2]Downgraded one level for indirectness.

A GRADE certainty of evidence rating of "low" indicates that our confidence in the effect estimate is limited; the true effect may be substantially different from the estimate of the effect. A GRADE certainty of "very low" indicates that we have very little confidence in the effect estimate; the true effect is likely to be substantially different from the estimate of effect.

Legend: CFF=critical fusion frequency; MD=mean difference; RR=risk ratio; TES=total error score

**Table 2.** Analysis of symptom questionnaire from Lin *et al*[34] comparing subjects wearing high blue blocking lenses to those wearing low blue-blocking or clear lenses . *RR=Risk Ratio.*

| **Question** | **RR (95%CI)** |
|---|---|
| I feel pain around or inside my eyes | 2.60 [0.85, 7.98] |
| My eyes feel heavy | 2.50 [0.95, 6.57] |
| My eyes feel itchy | 2.68 [1.32, 5.44] |
| My eyes feel tired | 3.33 [0.95, 11.66] |
| I find it hard to focus my eyesight | 1.75 [0.83, 3.67] |
| I see written or computer text as blurry | 1.67 [0.54, 5.11] |
| My computer monitor looks too bright | 1.28 [0.44, 3.67] |
| I feel tired when doing work | 2.08 [0.74, 5.84] |
| My neck shoulders, back and lower back hurt | 0.52 [0.13, 2.09] |
| My fingers hurt | 0.52 [0.07, 4.17] |
| I feel mentally stressed | 1.30 [0.54, 3.14] |
| The suns glare affects my eyes when outdoors | 1.37 [0.55, 3.40] |
| I find fluorescent office lighting to be bothersome to my eyes | 7.00 [0.88, 55.66] |

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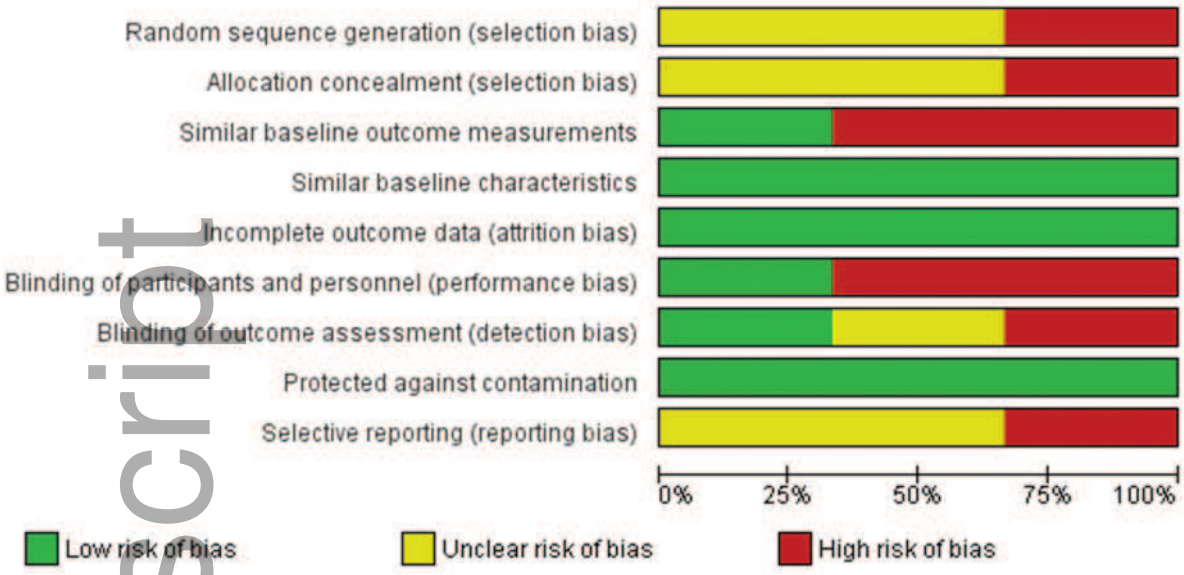


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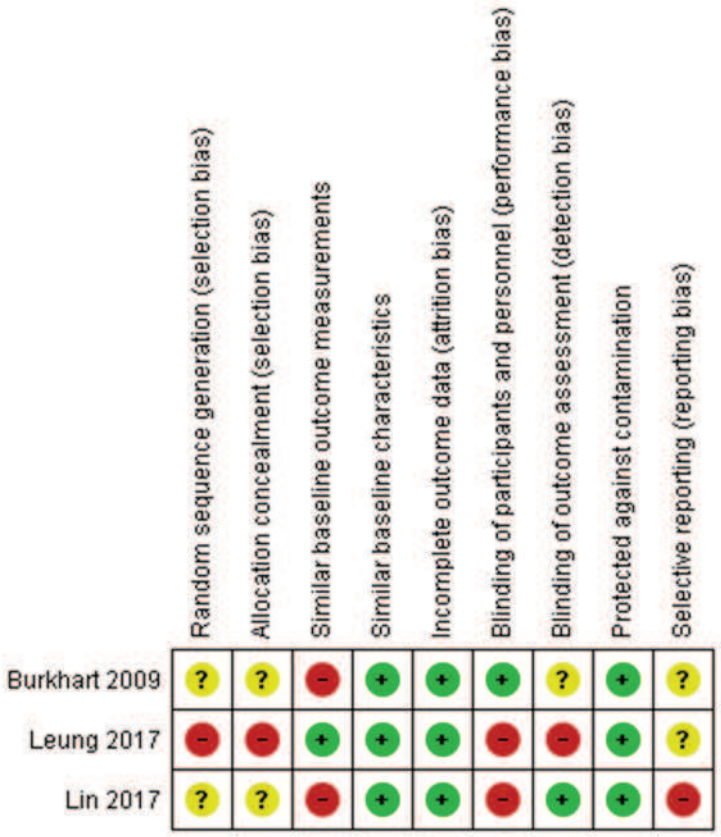


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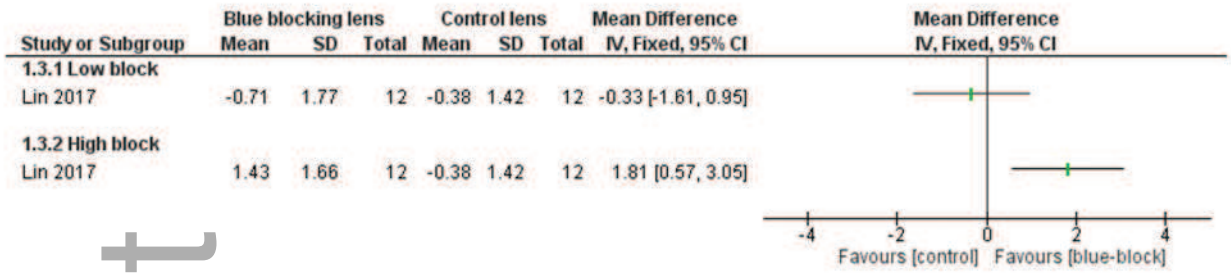


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