Vision impairment and traffic safety outcomes in low-income and middle-income countries: a systematic review and meta-analysis


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Vision impairment and traffic safety outcomes in low-income and middle-income countries: a systematic review and meta-analysis

Prabhath Piyasena, Victoria Odette Olvera-Herrera, Ving Fai Chan, David M Wright, Graeme MacKenzie, Gianni Virgili, Nathan Congdon

Summary
Background Road traffic injuries are a major public health concern and their prevention requires concerted efforts. We aimed to systematically analyse the current evidence to establish whether any aspects of vision, and particularly interventions to improve vision function, are associated with traffic safety outcomes in low-income and middle-income countries (LMICs).

Methods We did a systematic review and meta-analysis to assess the association between poor vision and traffic safety outcomes. We searched MEDLINE, Embase, PsycINFO, CINAHL, Web of Science, Cochrane Database of Systematic Reviews, and the Cochrane Central Register of Controlled Trials in the Cochrane Library from database inception to April 2, 2020. We included any interventional or observational studies assessing whether vision is associated with traffic safety outcomes, studies describing prevalence of poor vision among drivers, and adherence to licensure regulations. We excluded studies done in high-income countries. We did a meta-analysis to explore the associations between vision function and traffic safety outcomes and a narrative synthesis to describe the prevalence of vision disorders and adherence to licensure requirements. We used random-effects models with residual maximum likelihood method. The systematic review protocol was registered on PROSPERO, CRD-42020180505.

Findings We identified 49 (1.8%) eligible articles of 2653 assessed and included 29 (59.2%) in the various data syntheses. 15394 participants (mean sample size n=530 [SD 824]; mean age of 39-3 years [SD 9-65]; 1167 [7.6%] of 15279 female) were included. The prevalence of vision impairment among road users ranged from 1.2% to 26.4% (26 studies), colour vision defects from 0.5% to 17.1% (15 studies), and visual field defects from 2.0% to 37.3% (ten studies). A substantial proportion (range 10.6-85.4%) received licences without undergoing mandatory vision testing. The meta-analysis revealed a 46% greater risk of having a road traffic crash among those with central acuity visual impairment (risk ratio [RR] 1.46 [95% CI 1.20-1.78]; p=0.0002, 13 studies) and a greater risk among those with defects in colour vision (RR 1.36 [1.01-1.82]; p=0.041, seven studies) or the visual field (RR 1.36 [1.25-1.48]; p<0.0001, seven studies). The I² value for overall statistical heterogeneity was 63.4%.

Interpretation This systematic review shows a positive association between vision impairment and traffic crashes in LMICs. Our findings provide support for mandatory vision function assessment before issuing a driving licence.

Funding None.

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Introduction
As the leading global cause of death among people aged 5–29 years, road traffic injuries are a major public health concern, and without sustained action could become the seventh leading global cause of death for all ages by 2030.1,2 Road traffic injuries caused 1.35 million deaths worldwide in 2016,3 and the burden is especially great in low-income and middle-income countries (LMICs), with annual fatality rates per 100 000 population of 24.1 in low-income countries, compared with 9.2 in high-income countries (HICs).4 Globally, although only 60% of cars are driven in LMICs, 93% of traffic deaths occur in these countries.3 In LMICs, 30–86% of hospital admissions for trauma are due to road crashes. Furthermore, the continuous expansion of cities, rapid urban migration, and growing rates of private car ownership are adding to a rapidly growing burden.5 The socioeconomic effect of road traffic injuries is profound: 40–75% of those injured or killed in road traffic crashes in LMICs are their family’s principal earners.6 Road traffic crashes cost LMICs 1–2% of their gross national product annually, exceeding the total amount received from development aid.7

The main domains of visual function necessary for safe driving are visual acuity, visual field, colour vision, stereo vision, and contrast sensitivity.8 In HICs, research has shown that vision problems such as glare and field loss are likely to be associated with increased risk of crashes.
Research in context

Evidence before this study

The visual ability of road users is fundamental to traffic safety, but, despite the high burden of traffic crashes and associated mortality in low-income and middle-income countries (LMICs), evidence for an association between vision function and traffic safety outcomes is scarce. This fact makes it difficult to advocate that policy makers should develop effective vision-based road crash prevention strategies. We searched MEDLINE (Ovid) and the Cochrane Database of Systematic Reviews from database inception up to April 2, 2020, for systematic reviews and meta-analyses of vision interventions to reduce traffic crashes. We identified 12 reviews and three meta-analyses based mainly on studies from high-income countries. This search confirmed a major gap in evidence syntheses for vision and traffic safety in LMICs, which we sought to address.

Added value of this study

To our knowledge, this study is the first systematic review and meta-analysis of the association between vision function and traffic safety outcome in LMICs. We assessed 29 studies that described prevalence of vision disorders among drivers, 14 studies on adherence to vision-related driving licensure requirements, and 20 studies of the association of vision function with traffic safety outcomes. With use of data from these 20 studies, we did a meta-analysis on 39 vision-related parameters and risk of involvement in a traffic crash.

Implications of all the available evidence

People with poor central visual acuity are 46% more likely to have a road traffic crash than people with normal vision and there is a significant association between colour vision or visual field defects and safety outcomes. In addition, we identified a high prevalence of vision disorders among drivers and poor adherence to vision-related driving licensure requirements in some LMICs. There appears to be a significantly elevated risk of road traffic crashes for people with poor central visual acuity, colour vision, and visual field defects, but the cross-sectional nature of these studies, and the absence of randomised trials of interventions to improve vision, limits inference of cause and effect. Data from LMICs, particularly for younger drivers who might be at higher risk and women, are scarce.

Methods

Search strategy and selection criteria

We did a systematic review and meta-analysis, in which we used Cochrane guidance on systematic reviews and the PRISMA guidelines to conduct and report the review (appendix p 1).14–16

We searched MEDLINE, Embase, PsycINFO, CINAHL, Web of Science, Cochrane Database of Systematic Reviews, and the Cochrane Central Register of Controlled Trials in the Cochrane Library, from database inception to April 2, 2020. A broad search strategy was developed under consultation with an information specialist to capture road users and traffic safety outcomes and a list of search terms as recommended by the Cochrane Effective Practice and Organisation of Care Group was used to identify studies from LMICs.7 The full search strategy is shown in the appendix (p 3). Database searches were performed by PP and VOO-H under guidance of the information specialist.

We included any interventional or observational studies assessing whether vision is associated with traffic safety outcomes, studies describing prevalence of poor vision among drivers, and adherence to licensure regulations in LMICs. Eligible participants were road users in LMICs, including drivers, cyclists, pedestrians, and those using public transit, with special attention to individuals whose income was derived from driving a vehicle. We excluded studies from high-income countries. The primary outcome of this review was any traffic-crash-related injury to any road user that had potential to cause morbidity and mortality. We also included surrogate outcomes such as hard braking, or accelerometer-measured events, mostly based on self-reported data. The exposure of interest was poor vision functions of drivers. The study protocol is available online.
Data collection and analysis
Two reviewers (PP, VOO-H) independently checked titles and abstracts retrieved by our searches against the review’s eligibility criteria, resolving disagreements by discussion. The full text of all potentially eligible articles was retrieved, and data extraction was done by two reviewers (PP and VOO-H) if eligibility was confirmed. Data were extracted into a Microsoft Excel spreadsheet by adapting the data extraction forms and guidelines of Cochrane, including country, setting, year, study design, sample size, participant characteristics, type of vehicle and driver, measure of visual acuity or other vision-related domains, and reported outcomes. One reviewer extracted the data and a second verified it.

Risk of bias and quality of studies were assessed using the appropriate tool for each study: the National Institutes of Health (USA) quality assessment tool for observational cross-sectional studies and the relevant tool from the Critical Appraisal Skills Programme for other study designs.18,19

Data synthesis
We first described study characteristics, such as study design, country, setting, type of driver, and category of vehicle, and then provided meta-analyses of the findings for reported outcomes, using odds ratios or risk ratios (RRs) for binary outcomes. We also did a narrative synthesis of the prevalence of vision disorders among drivers and rates of compliance with vision-related licensure requirements.

Statistical analysis
Statistical heterogeneity was assessed across the studies. When meta-analyses were appropriate, a random-effects model was applied using Stata-SE, version 17.0. The suite of commands was used to fit random-effects models with the residual or restricted maximum likelihood method to estimate $\tau^2$, which produces an unbiased, non-negative estimate of between-study variance.20 We used reported RRs comparing risk of crashes among drivers with poor vision function against those with good vision function. If RRs were not reported, we calculated them using other data in the publications (appendix p 32). Separate meta-analyses were applied for visual acuity, colour vision, and visual field outcomes. If sufficient data were available, we did subgroup analyses for individuals whose income derived from driving a vehicle in an LMIC.

Small-study bias was assessed using Harbord’s test21 and by plotting data in a contour-enhanced funnel-plot with a non-parametric trim-and-fill method22 of imputation of potentially missing data from small studies. Multivariate meta-regression to assess confounding was attempted; however, modelling was not successful due to an insufficient number of studies and scarcity of necessary primary data within studies (appendix p 34). The systematic review protocol was registered on PROSPERO, CRD-42020180505.

Role of the funding source
There was no funding source for this study.

Results
The electronic database search yielded 2653 titles and abstracts, and 49 (1.8%) eligible studies were selected for full review, among which 20 (40.8%) did not meet criteria for inclusion (figure 1).

The 29 included studies were cross-sectional and observational in design; no randomised trials or other studies of interventions were identified. Only one (3.4%) study was done in a low-income country, Ethiopia.23 22 (75.9%) studies were from lower-middle-income countries: 11 in Nigeria,11,12,24–32 nine in India,33–41 and
<table>
<thead>
<tr>
<th>Country</th>
<th>Total sample size</th>
<th>Sex</th>
<th>Age, years</th>
<th>Identity of cohort</th>
<th>Visual acuity (in better, worse, or both eyes; any visual acuity cutoff, ≤6/9 to ≥6/24)</th>
<th>Monocular blindness</th>
<th>Uncorrected refractive errors</th>
<th>Cataract</th>
<th>Glaucoma</th>
<th>Corneal opacity</th>
<th>Posterior segment pathologies</th>
<th>Colour vision defects</th>
<th>Visual field defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethiopia</td>
<td>1879</td>
<td>6·3% female, 93·7% male</td>
<td>33·5 (NR)</td>
<td>Drivers in vehicle parks</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Nigeria</td>
<td>291</td>
<td>100% male</td>
<td>41·5 (23–65)</td>
<td>Commercial vehicle drivers in a city</td>
<td>26·1% (&lt;6/9 in worse eye; 14·4% in better eye)</td>
<td>—</td>
<td>2·1% (&lt;3/60 in worse eye)</td>
<td>2·4%</td>
<td>2·4%</td>
<td>—</td>
<td>—</td>
<td>2·2%</td>
<td>4·4% (at least one eye), 2·1% (for both eyes)</td>
</tr>
<tr>
<td>Nigeria</td>
<td>399</td>
<td>100% male</td>
<td>44·7 (41–50)</td>
<td>Commercial vehicle drivers in a city</td>
<td>2·8% (&lt;6/18 in better eye), 11·5% had less than FRSC *</td>
<td>3·3%</td>
<td>1·5% (better eye), 2·5% (second eye)</td>
<td>2·0–2·5%</td>
<td>0·5%</td>
<td>0·5% (ARMD, optic atrophy)</td>
<td>—</td>
<td>4·3%</td>
<td>5·5%</td>
</tr>
<tr>
<td>Ghana</td>
<td>520</td>
<td>100% male</td>
<td>39·2 (20–75)</td>
<td>Commercial vehicle drivers in a town</td>
<td>2·5% (&lt;0·2 logarithm of minimal angle of resolution or &lt;6/9)</td>
<td>10%</td>
<td>60% (including presbyopia) 39·6%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>7·1% (protanopes 45·9%, deuteranopes 35·1%, and tritanopes 18·9%)</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>146</td>
<td>100% male</td>
<td>NR</td>
<td>Drivers in a refresher training</td>
<td>10·9% (visual acuity cutoff not defined)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>17·1%</td>
<td>27·6%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>328</td>
<td>100% male</td>
<td>46·0 (20–70)</td>
<td>Commercial vehicle drivers in a capital</td>
<td>9·2% (better eye), 12·0% (second eye)</td>
<td>2·7%</td>
<td>2·7% (better eye), 6·4% (second eye)</td>
<td>0·3–0·9%</td>
<td>0·9%</td>
<td>0·6–1·2%</td>
<td>9·5% (both eyes), 19·5% (better eye), 20·4% (second eye)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nigeria</td>
<td>340</td>
<td>100% male</td>
<td>52·5 (24–72)</td>
<td>Commercial vehicle drivers in a state</td>
<td>27·1% (night eye), 26·4% (left eye), 15·3% (both eyes; &lt;6/9)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>Turkey</td>
<td>200</td>
<td>100% male</td>
<td>41·4 (23–60)</td>
<td>Drivers registered in a Drivers’ Association</td>
<td>—</td>
<td>21·5%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2·2%</td>
<td>—</td>
</tr>
<tr>
<td>Iran</td>
<td>200</td>
<td>100% male</td>
<td>42·5 (NR)</td>
<td>Truck drivers (commercial and military)</td>
<td>1·5% (military), 2·0% (commercial; binocular visual acuity ≤20/30)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1·0% (military), 3·0% (commercial)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nigeria</td>
<td>99</td>
<td>100% male</td>
<td>45·9 (NR)</td>
<td>Commercial vehicle drivers in motor parks</td>
<td>6·1% (&lt;6/18 in either eye; WHO definition)</td>
<td>3·1%</td>
<td>24·3%</td>
<td>13·6%</td>
<td>6·6%</td>
<td>—</td>
<td>6·1% (ARMD, optic atrophy)</td>
<td>2·7% (ARMD, optic atrophy)</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>148</td>
<td>100% male</td>
<td>37 (NR)</td>
<td>Truck drivers in drivers’ camps at highways</td>
<td>45·9% (&lt;6/9 all, both eyes), 25·0% (&lt;6/18)</td>
<td>31·1%</td>
<td>9·4%</td>
<td>4·7%</td>
<td>4·0%</td>
<td>2·7% (ARMD, optic atrophy)</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>195</td>
<td>100% male</td>
<td>45·4 (22–65)</td>
<td>Inter-state truck drivers</td>
<td>5·6% (&lt;6/18, better eye), 8·7% (second eye)</td>
<td>—</td>
<td>4·8% (presbyopia) 29·6% (any lens opacity)</td>
<td>—</td>
<td>—</td>
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</tr>
</tbody>
</table>

Note: Table continues on next page.
<table>
<thead>
<tr>
<th>Country</th>
<th>Total sample size</th>
<th>Sex</th>
<th>Age, years</th>
<th>Identity of cohort</th>
<th>Visual acuity (in better, worse eye, or both eyes; any visual acuity cutoff, ≤6/9 to ≥6/24)</th>
<th>Monocular blindness</th>
<th>Uncorrected refractive errors</th>
<th>Cataract</th>
<th>Glaucoma</th>
<th>Corneal opacity</th>
<th>Posterior segment pathologies</th>
<th>Colour vision defects</th>
<th>Visual field defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>100</td>
<td>4%</td>
<td>65.2 (40-82)</td>
<td>Drivers with glaucoma identified in an eye clinic</td>
<td>NR</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>67% (primary open angle glaucoma)</td>
<td>--</td>
<td>--</td>
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</tr>
<tr>
<td>Nigeria</td>
<td>122</td>
<td>100%</td>
<td>33.8 (NR)</td>
<td>Commercial divers in a motor park</td>
<td>1.2% (&lt;6/12)</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<td></td>
</tr>
<tr>
<td>Nigeria</td>
<td>215</td>
<td>100%</td>
<td>41.5 (21-75)</td>
<td>Registered commercial drivers in a local government area</td>
<td>3.2% (&lt;6/18, better eye)</td>
<td>--</td>
<td>17.2% (8.8% presbyopia)</td>
<td>14.4%</td>
<td>5.6%</td>
<td>1.4%</td>
<td>2.9%</td>
<td>0.5% adjusted with sample size</td>
<td>10.2% (one eye)</td>
</tr>
<tr>
<td>Nigeria</td>
<td>90</td>
<td>100%</td>
<td>45.2 (22-70)</td>
<td>Commercial drivers identified in community</td>
<td>2.2% (&lt;6/18, better eye), 8.9% (second eye)</td>
<td>--</td>
<td>3.6% (presbyopia)</td>
<td>33.3% (lens opacity)</td>
<td>4.4%</td>
<td>--</td>
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<td>--</td>
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</tr>
<tr>
<td>Nigeria</td>
<td>524</td>
<td>100%</td>
<td>46.8 (39-66)</td>
<td>Commercial motor vehicle drivers</td>
<td>11.6% (&lt;6/18, 6/18 to 6/60, 8.2% right eye, 9.4% left eye)</td>
<td>Counting fingers and no perception of light 2.3% to 2.9%</td>
<td>--</td>
<td>4.2%</td>
<td>3.6%</td>
<td>2.3%</td>
<td>10.0%</td>
<td>0.6%</td>
<td>--</td>
</tr>
<tr>
<td>Ghana</td>
<td>206</td>
<td>100%</td>
<td>39.2 (18-68)</td>
<td>Commercial drivers in a municipality park</td>
<td>6.8% (&lt;6/18, better eye)</td>
<td>--</td>
<td>32.0%</td>
<td>8.2%</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Difficulty in seeing colour lights 0.5%</td>
<td>Constricted field 6.8%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>299</td>
<td>100%</td>
<td>27.5 (85% 20-39)</td>
<td>Commercial motorcyclists</td>
<td>8.1% (out of road traffic accidents n=136, visual acuity cutoff not defined)</td>
<td>--</td>
<td>10.4% (hyperopia)</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<td></td>
</tr>
<tr>
<td>Nigeria</td>
<td>400</td>
<td>100%</td>
<td>37.8 (25-62)</td>
<td>Commercial drivers in a motor park</td>
<td>1.8% (cutoff not given, WHO, 1984 definition of visual impairment)</td>
<td>3.5%</td>
<td>8.4% (myopia and hypermetropia)</td>
<td>14.1%</td>
<td>11.5%</td>
<td>0.4%</td>
<td>5.7%</td>
<td>4.5%</td>
<td>4.0%</td>
</tr>
<tr>
<td>India</td>
<td>140</td>
<td>NR</td>
<td>NR (21 to &gt;=60)</td>
<td>Truck drivers in their rest stops</td>
<td>15.0% (&lt;6/18)</td>
<td>--</td>
<td>28.5% (31.4% presbyopia)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>4059</td>
<td>100%</td>
<td>34 (17-74)</td>
<td>Truck drivers in an eye camp</td>
<td>26.4% (cutoff not given)</td>
<td>--</td>
<td>26.4% (any refractive error in at least one eye, 8.8% distant correction, 24.3% near correction)</td>
<td>--</td>
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</tr>
</tbody>
</table>

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two in Ghana, and there were six from upper-middle-income countries (20-77%): four in China and one each in Turkey and Iran.

Among the 29 included studies, 20 (69.0%) assessed the association between vision function and traffic safety outcomes (appendix p 11), 26 (89.7%) reported prevalence of vision disorders among drivers (appendix p 19), and 14 (48.3%) described adherence with driving licensure requirements (appendix p 26). Several studies reported multiple outcomes. Among 20 studies reporting on vision and traffic safety outcomes, 14 (70.0%) qualified for our meta-analysis of the association between visual impairment and road traffic crashes. No studies were found assessing interventions to improve vision function.

The 29 included studies enrolled 15394 participants (mean sample size n=530, SD 824, range 23–4059) with a mean age of 39·3 years (SD 9·65, range 14·6–65·2). Only five studies included women (1167 [7·6%] women of 15279 included individuals with known sex or gender). Most included studies (22 [75.9%] of 29) described vision and traffic safety outcomes among commercial drivers of trucks, buses, or taxis (appendix p 11). Two studies assessed safety outcomes on driving simulators, one enrolled patients from a glaucoma clinic, one assessed self-reported crashes among schoolchildren riding bicycles in China, and one included motorcycle delivery drivers.

Studies used both Snellen and logarithm of the minimum angle of resolution charts and most (16 [61.5%] of 26) used WHO definitions of visual impairment. Prevalence of visual impairment among drivers, at cutoffs of ≤6/9 to ≥6/24 in the better eye or worse eye or second eye reported in 26 studies across seven countries ranged from 1·2% to 26·4%. In Nigeria, visual impairment among commercial drivers in 11 (37-9%) studies ranged from 1·2% to 26·1%, and in Ghana from 2·5% to 6·8%. Monocular blindness ranging from 1·0% to 5·0% was reported among drivers in five studies in Nigeria and one in Ghana (table, appendix p 19).

18 studies provided prevalence of the main causes of visual impairment among drivers. Prevalence of uncorrected refractive errors (including presbyopia) ranged from 1·5% to 31·3% in the better-seeing or second eye in Nigeria; 11,12,24–26,31,32 1·6% to 25·1% in Turkey; 35 to 60·0% in Ghana; 12·3% in China, and 4·8% to 31·1% in India. Murthy and colleagues reported glaucoma prevalence in India of 69·0% early, 29·0% moderate, and 4·8% to 31·1% in India. Murthy and colleagues reported glaucoma prevalence in India of 69·0% early, 29·0% moderate, and 4·8% to 31·1% in India. Murthy and colleagues reported glaucoma prevalence in India of 69·0% early, 29·0% moderate, and 4·8% to 31·1%. In Nigeria, visual impairment among commercial drivers in 11 (37-9%) studies ranged from 1·2% to 26·1%, and in Ghana from 2·5% to 6·8%. Monocular blindness ranging from 1·0% to 5·0% was reported among drivers in five studies in Nigeria and one in Ghana (table, appendix p 19).

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reported no colour vision defects among Nigerian commercial drivers. In Ethiopia, Abebe and Wondmikun reported a prevalence of 4·5%. In India, colour vision defects ranged from 1·3% to 17·1% in four studies, while in Iran, colour vision defects were present in 1·0% of military drivers and 3·0% of commercial drivers, and in Ghana 7·1% of commercial drivers had protanopic vision colour defects. Overall from these 15 studies, the range of colour vision defects was 0·5% to 14·4%.

Although terminology was not defined consistently, the prevalence of visual field defects among drivers varied from 2·0% to 37·3% in ten studies, from 4·0% to 20·4% (second eye) in Nigeria, 6·8% in Ghana (constricted field), while in India, Verma and colleagues reported peripheral defects in 2·0% and altitudinal defects among 21·9%. There were very few data for prevalence of other vision anomalies among drivers in LMICs: abnormal stereopsis was reported among 18·2% in Nigeria and 15·4% in Ghana, while one study found a 4·0% prevalence of abnormal contrast sensitivity in India (appendix p 19).

A substantial proportion of drivers in included studies received licences without undergoing vision testing, although vision testing was mandatory in all countries included in this review. The proportion who did not receive vision testing ranged from 10·6% in Ghana to 85·4% in Nigeria. In India, legal licence renewal was bypassed by 45·0% of drivers and only 47·5% of drivers needing glasses or spectacles had them. Vision testing during renewal of driving licences was reported to be inadequate in Ethiopia, India, Ghana, and Nigeria (appendix p 26).

Among 14 articles assessed for methodological quality and risk of bias (appendix p 9), the most common issues were: (1) absence of sample size justification (35·8%); (2) inability to measure vision function of drivers before assessing safety outcomes (100·0%); (3) inadequate time to assess exposure and outcome (50·0%); (4) limitations of cross-sectional design (100·0%); and (5) failure to mask study personnel (100·0%; figure 2).

Among 20 studies eligible for the meta-analysis, six (30·0%) were excluded: one enrolling patients in a glaucoma clinic, reporting insufficient data to calculate RRs, and two with outcomes incompatible with the objective of the meta-analysis. Another study contributed no RR data as visual impairment was assessed based on self-report. For the remaining 14 studies, 39 sub-components describing visual acuity (assessed in 13 studies), colour vision (seven studies) and visual field (seven studies), and traffic safety outcomes were used to calculate summary estimates (appendix p 32). Inadequate data were available for meta-analyses of stereopsis or contrast sensitivity.

The overall meta-analytic estimate (RR) of the effect of different types of visual impairment on adverse road safety outcomes was 1·41 (95% CI 1·26–1·59; Z=6·61; p<0·0001). We observed an overall statistical heterogeneity of $I^2=63·4\%$ ($p=0·0002$; $H^2=2·73$; $Q=77·1$). According to our review protocol, we reported data separately by type of visual perceptual parameter.

Among the seven studies (35·0%; n=4348 participants) that reported defects in colour vision, most assessed colour vision using Ishihara pseudochromatic colour plates, while Boadi-Kusi and colleagues used the Hardy-Rand-Rittler pseudochromatic plate. The heterogeneity among included studies was moderate ($I^2=64·0\%; p=0·0031$). Most studies concluded that colour vision defects presented variable amounts of increased risk of traffic crashes. The included studies showed a RR range of 0·85–2·47, with summary estimate of 1·36 (95% CI 1·01–1·82, test for overall effect $Z=7·28$; $p=0·0001$), showing increased risk (figure 3).

Among seven studies (35·0%; n=2119 participants) that reported visual field defects, methods of measuring visual fields included direct confrontation, automated perimetry, Epson 910, and supra-threshold Optifield KP-910 automated perimetry. The summary RR was 1·36 (95% CI 1·25–1·48, test for overall effect $Z=7·28$; $p<0·0001$) indicating a 36% increase in crash risk among

![Figure 2: Methodological quality assessment of studies included in the meta-analysis](https://doi.org/10.1016/S2214-109X(21)00303-X)
<table>
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<tr>
<th>Colour vision defects</th>
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Heterogeneity: τ²=0.09, I²=64.0%, H²=2.78
Homogeneity: Q=4.71; p=0.0159

Visual field defects

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Heterogeneity: τ²=0.00, I²=0.0%, H²=1.00
Homogeneity: Q(9)=4.34; p=0.89

Visual impairment

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Heterogeneity: τ²=0.10, I²=69.2%, H²=3.25
Homogeneity: Q=8.70; p=0.0031

Overall

<table>
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<th>Weight (%)</th>
<th>Risk ratio (95% CI)</th>
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<tr>
<td></td>
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Heterogeneity: τ²=0.06, I²=63.4%, H²=2.73
Homogeneity: Q(38)=77.06; p=0.0001

Test of group differences: Q(2)=0.43; p=0.81

Figure 3: Association between colour vision defects, visual field defects, and visual impairment of road users and road traffic crashes
Some papers are cited more than once as they have reported vision related outcomes using different cutoff levels.
those with field defects. No variation in effect sizes was attributable to heterogeneity ($I^2=0\%$; $p=0.89$; figure 3).

13 (65·0%) studies reported effects of impaired central visual acuity on traffic safety outcomes ($n=3747$ participants). Mean prevalence of visual impairment was 7·3% (SD 7·07, 95% CI 2·52–12·10). The summary estimate revealed a 46% increased risk of road traffic crash among those with visual impairment (RR 1·46 [95% CI 1·20–1·78], test for overall effect $Z=4.55$; $p=0.0002$), with a moderate level of heterogeneity ($I^2=69.2\%; p<0.0030$; figure 3).

A substantial association between poor central visual acuity and traffic crashes was present at a visual acuity cutoff of ≤6/18 in either eye (RR 1·61 [95% CI 1·10–2·36], test for overall effect $Z=2.68$; $p=0.015$, six studies), with a moderate level of heterogeneity ($I^2=72.5\%; p=0.0025$; appendix p 28). A post-hoc analysis including only commercial vehicle drivers showed a significant association between central visual acuity and traffic safety outcomes (RR 1·46 [95% CI 1·11–1·93], test for overall effect $Z=2.98$; $p=0.0077$, 11 studies) with moderate heterogeneity ($I^2=68.7\%; p=0.0004$; appendix pp 29–30). There was no effect of age on traffic safety outcomes ($<40$ years RR 1·41; $≥40$ years RR 1·48; $p=0.072$ for the difference; appendix p 31).

The visual inspection of the contour-enhanced funnel plot (figure 4) suggested that a few smaller and non-significant study results might be missing in the right portion of the plot. Using the trim-and-fill methods, there was little difference between the observed (RR 1·41) and imputed (RR 1·53) estimates, and the imputed data were in the direction of a greater effect. This result was confirmed by Harbord’s test for small study bias, which was not significant ($p=0.13$).

Discussion
Visual functioning of road users is fundamental to traffic safety. This systematic review and meta-analysis highlights that vision impairment significantly increases the risk of road traffic crashes in LMICs, especially among commercial vehicle drivers, who are an important group of high-intensity users. It also shows that vision disorders are common among road users in LMICs, as is poor adherence to driving licensure standards in terms of vision requirements in some settings. These findings suggest the need for tighter controls on the licensing of drivers based on vision, and highlight the need for trials on interventions to improve vision function and road safety in LMICs.

Among 1·35 million people killed annually by road traffic crashes, 93% of deaths occur in LMICs.39 The importance of traffic regulations is illustrated by the reduction of traffic deaths and injuries by 13% in the WHO European Region between 2010 and 2016 through enactment and enforcement of road safety legislations by political and technical commitment.57 The Global Burden of Diseases, Injuries, and Risk Factors Study 2017 showed that, although mortality from road traffic injuries decreased globally over time, it did not in south Asia and southern Latin America.30 The economic burden of road traffic crashes is increasing in LMICs52 and exceeds that in HICs due to increases in urbanisation,54 road infrastructure, and access to private vehicles.59 Sustainable Development Goal 3·6 aims to “halve the number of global deaths and injuries from road traffic accidents” by 2020, echoing the Stockholm Declaration target of reducing road deaths by 50% by 2030.55 These goals will not be achievable in LMICs without concerted effort.

Under-reporting of road crashes in low-income countries has led to important gaps in the evidence base, and consequently lower prioritisation of strategies to reduce the burden of traffic-related morbidity and mortality. Our review found only one article from a low-income country.23 We identified 12 systematic literature reviews and three meta-analyses on vision and traffic safety (appendix p 38), mainly of studies from HICs, and one from LMICs that reviewed studies of traffic safety published up to 1994, but did not report on vision.38 Three meta-analyses from HICs describe effectiveness of cataract surgery in reducing driving-related difficulties (reduced by 88% following surgery),58 association of useful field of vision as a valid vision parameter of driving performance,59 and scarcity of randomised trials on the effect of vision screening on safety outcomes among older drivers.60 Such data are needed, or similarly absent, for LMICs.

We found evidence for a significantly elevated risk of traffic crashes with impaired central visual acuity in LMICs, as has been observed in studies in HICs.6465 However, strategies from HICs that might help with this factor cannot be directly implemented in LMICs without evidence for what works in these settings.7980 Furthermore, studies in HICs have largely focused on older drivers and the results might not be relevant to the younger driving populations in LMICs.8182 For instance, participants in the study by McGwin and colleagues83 in
the USA were aged from 55 to 85 years, whereas those included in the LMIC studies in this review had a mean age of 39–8 years. Very little data for women were available.

Johnson and Keltner’s 1983 study in the USA, one of the largest studies of visual fields and drivers in HICs, reported that among 10000 drivers, those with binocular visual field loss had crash and conviction rates twice as high as those without such loss. This finding is consistent with the current review, in which the summary estimate of the number of crashes due to visual field defects was 36% higher (RR 1·36). With respect to colour vision, people with protanopic colour vision defects are not allowed to obtain a commercial vehicle licence in some HICs due to their inability to identify red traffic lights. This factor might partly explain the high number of people with colour vision defects who had traffic crashes (nine [52·9%] of 17) in LMIC studies compared with those in HICs (14% among those with difficulty in seeing traffic lights). The observed moderate level of statistical heterogeneity of the current meta-analysis could have arisen due to variations in effect sizes within observational studies, due to different levels of diagnostic test accuracy of vision tests, different cutoff points of vision parameters, and different definitions of primary outcome that had been assigned by study investigators. Time gap between traffic crash and data collection might have also influenced effect estimates through recall bias. We have presented our main results based on subgroup level analyses, taking heterogeneity into account, and not purely based on effect estimates derived in pooling all studies together.

Our study has some limitations. The absence of data from randomised controlled trials and reliance on observational studies to show causal connection between visual impairment and traffic safety outcomes is suboptimal. Most studies were from the African region, and record a high prevalence of visual impairment and blindness, minimising the generalisability of review outcomes. Participant-reported outcomes and different methods used to collect vision-related data affect the internal validity of the primary data. Most studies described visual acuity without spectacle correction and there could be more than one underlying pathology causing visual impairment. Evidence was scarce on other road users and surrogate outcomes. Some authors selected participants in public motor parks (ie, public car parking facilities), and there is a propensity for self-selection of those who have had a crash. We have minimised the limitations of confounding at the stages of statistical analysis and interpretation. However, effects of unidentified confounding on our results are a main weakness for the ability to draw conclusions and there...
was insufficient primary data to assess these factors through a meta-regression analysis (appendix p 38).

This review provides evidence for a clear association between vision impairment and traffic crashes in LMICs, and provides support for mandatory vision function assessment before issuing driving licences, especially for drivers of commercial vehicles. However, there are still several gaps in the evidence base for LMICs that need to be filled to fully inform policy and practice (see panels 1, 2) and establishing robust systems to collect good quality data in these countries should be a priority. Although vision testing was mandatory in all countries included in this review, enforcement challenges are sometimes further increased in LMICs if policies are lax, or when existing tighter regulations are unenforced, such as inadequate vision testing during licence renewal in Ghana, Ethiopia, Nigeria, and India. Randomised trials of interventions to improve vision and their effect on driving safety are needed in LMICs to identify strategies to promote policies of more thorough vision screening of drivers and interventions that will improve the vision of drivers.

**Contributors**

NC, MC, GM, VFC, DMW, VOO-H, and PP contributed to conceptualisation, review design, protocol writing, conducting the review, data analysis, interpretation of the results, and manuscript preparation. PP and VOO-H did the database searches, title and abstract screening, data extraction from full articles, and synthesis as co-reviewers. GV contributed to re-analysis of the data and interpretation. NC, GV, MC, GM, VFC, DMW, VOO-H, and PP provided revisions, edited earlier versions of the manuscript, and approved the final version for submission. VOO-H and PP had full access to all the data in the study, verified the extracted data, and had final responsibility for the decision to submit for publication.

**Declaration of interests**

NC works as director of research for Orbis International, an organisation working on global eye health, including vision and traffic safety. NC is supported by the Ulverscroft Foundation, UK. GM reports personal fees for consulting on regulatory compliance in Japan, the UK, and the USA for Adlens, a manufacturer of eyewear, outside the submitted work. GM reports personal fees supported by the Ulverscroft Foundation, UK. GM, VFC, DMW, VOO-H, and PP provided revisions, edited earlier versions of the manuscript, and approved the final version for submission. VOO-H and PP had full access to all the data in the study, verified the extracted data, and had final responsibility for the decision to submit for publication.

**Data sharing**

All datasets generated and analysed are available in the Article and appendix.

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