How do different lighting conditions affect the vision and quality of life of people with glaucoma? A systematic review

Jamie Enoch[1], Lee Jones[1], Deanna J. Taylor[1], Carol Bronze[2], James F. Kirwan[3], Pete R. Jones[1], David P. Crabb[1*]

Author affiliations

1. Division of Optometry and Visual Science, School of Health Sciences, City, University of London, London, UK.
2. Patient representative, London, UK.
3. Department of Ophthalmology, Queen Alexandra Hospital, Portsmouth, United Kingdom.

*Corresponding author details:

Professor David Crabb

Division of Optometry and Visual Science, School of Health Sciences, City, University of London, London, UK

Email: David.Crabb.1@city.ac.uk

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Contents

What was known before

- Glaucoma is a progressive optic neuropathy which may have few symptoms in its early stages.
- Some evidence points to difficulties people with glaucoma may experience in extremes of lighting (e.g. very bright or very dark conditions) or when transitioning between different luminance levels (e.g. light or dark adaptation).
- Dark adaptation and glare are common concerns in patient-reported outcome measures of vision-related quality of life in glaucoma.

What this review adds

- This systematic review, including 56 studies, is the first to focus on the impacts of lighting and luminance conditions on people with glaucoma.
- Issues with lighting, especially lighting extremes or transitions, are highly prevalent in glaucoma and become worse with increasing visual field loss. However lighting concerns do not feature among glaucoma patients' most bothersome concerns.
- Psychophysical studies suggest glaucoma negatively affects low-luminance contrast sensitivity, glare symptoms, and dark adaptation time and extent. However, performance-based studies seldom show significant differences between individuals with glaucoma and age-matched controls on tasks simulating daily activities under non-optimal lighting conditions.

Abstract (*250 words*)

This article is a systematic review of evidence regarding the impact of different lighting conditions on the vision and quality of life (QoL) of people with primary open-angle glaucoma (POAG).

A systematic literature search was carried out using CINAHL, MEDLINE, PsycARTICLES, PsycINFO, Embase and Ovid Nursing Database for studies: published up to April 2019, including people diagnosed with POAG, and assessing visual function or QoL in response to changing lighting/luminance levels or glare. Two researchers independently screened studies for eligibility. Data were extracted

from eligible studies regarding study design, participant characteristics, outcomes and results. Quality of included studies was critically appraised.

Of 8437 studies, 56 eligible studies were included. Studies investigated the effects of lighting on the following themes among people with POAG: QoL (18/56), psychophysical measures (16/56), functional vision (10/56), activities of daily living (10/56) and qualitative findings (2/56).

POAG negatively affects low-luminance contrast sensitivity, glare symptoms, and dark adaptation time and extent. In vision-related QoL questionnaires, people with POAG report problems with lighting, glare and dark adaptation more frequently than any other domain. These problems worsen with progressing visual field loss. Early-stage POAG patients experience significantly more difficulties in low-luminance or changing lighting conditions than age-matched controls (AMCs), challenging perceptions of early-stage POAG as asymptomatic. However, performance-based studies seldom show significant differences between POAG participants and AMCs on tasks simulating daily activities under non-optimal lighting conditions. Further research with larger samples is required to optimise ambient and task-oriented lighting that can support patients' adaptation to POAG.

Introduction

Glaucoma refers to a heterogeneous group of diseases which damage the optic nerve and visual field (VF). Globally, glaucoma is the most frequent cause of irreversible blindness, with an estimated age-standardised prevalence of approximately 3.5% among people aged 40 or older.[1]

Primary open angle glaucoma (POAG) comprises 74% of all glaucoma cases.[2] By 2020, it is expected that POAG will affect around 53 million people worldwide.[3] POAG is a chronic, progressive disease which may not have obvious symptoms until significant VF loss has occurred. It can therefore remain undetected in up to half of cases, yet people with POAG may maintain good visual outcomes with prompt diagnosis and treatment.[4] Since the condition is often asymptomatic in the early stages, it is important to understand associated functional changes. This may in turn help develop new methods to raise awareness of POAG's impacts, thus facilitating help-seeking and potential diagnosis.[5]

This review will include studies that consider how lighting levels affect people with glaucoma at the mild, moderate and advanced disease stages. This is of significant clinical interest, as there is some evidence that early-stage POAG, often considered asymptomatic, may cause issues in non-standard lighting conditions. For example, a recent study suggests that differences in the vision of early-stage glaucomatous patients compared to healthy controls may be magnified in non-optimal luminance conditions.[6] This systematic review therefore aims to draw together evidence on how different light levels affect visual function and vision-related QoL among people with glaucoma, from psychophysical studies, patient reported outcome measures (PROMs) and performance-based tasks. Vision-related

QoL can be considered as “the degree to which vision impacts an individual’s ability to complete activities of daily living and one’s social, emotional and economic well-being”.[7] Table 1 provides a glossary of key lighting terminology used here.

Table 1. Glossary of lighting-specific terms

Term	**Definition**
Glare *Disability glare* *Discomfort glare*	A visual sensation caused by excessive brightness. *Reduced vision caused by light scatter from a bright source.* *Sensation of discomfort or annoyance caused by bright light.*[8]
Luminance	Intensity of light per unit area traveling in a certain direction.[9]
Mesopic	Mesopic conditions exist in the range between photopic and scotopic, and mesopic vision involves both rods and cones.
Photopic	Photopic conditions are well-lit (e.g. outside on a sunny day), and photopic vision involves cones, facilitating colour perception.
Scotopic	Scotopic conditions are low light conditions (e.g. outside at night under starlight). Scotopic vision involves only rods, providing limited colour perception.

Methods

A search of the electronic databases CINAHL Complete, MEDLINE Complete, PsycARTICLES and PsycINFO (via EBSCOhost) and Embase and Ovid Nursing Database (via OVID) was undertaken. Keywords used related to (open angle) glaucoma, and a group of terms relating to lighting, brightness, darkness, glare, luminance and photopic/mesopic/scotopic conditions. For detailed search terms, see Appendix 1. Prospective and retrospective citation tracking was performed using Scopus and Google Scholar.

Studies considered eligible for inclusion were those that involved people diagnosed with glaucoma, and were written in English, French or Spanish. Studies were required to include at least some participants with chronic primary open angle glaucoma (POAG). If studies solely involved participants with other types of glaucoma (e.g. angle-closure glaucoma or congenital glaucoma), they were excluded. Additionally, included studies had to consider the impact of different general or task lighting conditions on vision and vision-related QoL. For example, because “photopic” was a keyword, many articles were returned about the photopic negative response, a test using the electroretinogram which can detect retinal ganglion cell dysfunction. Such articles were not included, because this is a very specific clinical use of light that is distinct from how photopic environmental conditions affect people with POAG. Studies were also excluded if their main interest related to colour, such as how specific wavelengths or coloured light (e.g. blue light) may affect people with open angle glaucoma.

Review articles were excluded, as were studies where only an abstract was published (e.g. conference proceedings). However due to the heterogeneity of the

phenomena under investigation, and the pragmatic orientation of this review, studies with only abstracts available are considered in Appendix 4, to avoid omitting potentially useful insights.

Two authors (JE and LJ) screened studies using Covidence systematic review software (Veritas Health Innovation Ltd, Melbourne, Australia; available at www.covidence.org) to assess eligibility. In the case of disagreements unresolved through discussion, a third author (DJT) was consulted. Relevant information (e.g. publication details, characteristics of participants, study design, outcomes measured, study results, and conclusions) from eligible papers was entered into a data extraction table.

Studies were assessed for quality using Kmet, Lee and Cook's *Standard Quality Assessment Criteria for Evaluating Primary Research Papers from a Variety of Fields*.[10] This quality appraisal was chosen because of the variety of quantitative and qualitative studies which are relevant to the review's questions, spanning several research fields. Full details of assessment criteria are shown in Table 2. This review is registered with the International prospective register of systematic reviews (PROSPERO; http://www.crd.york.ac.uk/prospero/ ; Reference CRD42018118953).

Table 2. Kmet, Lee and Cook (2004) quality assessment checklists. For each question, the checklist authors provide guidance on study aspects which should be considered when making a decision. For example, on Quantitative checklist Question 4 (Subject characteristics sufficiently described?), to score a Yes (2), the study in question must provide at least the age and sex of control participants.

Quantitative studies	Qualitative studies
1. Question / objective sufficiently described?	
2. Study design evident and appropriate?	
3. Method of subject/comparison group selection or source of information/input variables described and appropriate?	3. Context for the study clear?
4. Subject (and comparison group, if applicable) characteristics sufficiently described?	4. Connection to a theoretical framework / wider body of knowledge?
5. If interventional and random allocation was possible, was it described?	5. Sampling strategy described, relevant and justified?
6. If interventional and blinding of investigators was possible, was it reported?	6. Data collection methods clearly described and systematic?
7. If interventional and blinding of subjects was possible, was it reported?	7. Data analysis clearly described and systematic?
8. Outcome and (if applicable) exposure measure(s) well defined and robust to measurement / misclassification bias? Means of assessment reported?	8. Use of verification procedure(s) to establish credibility?
9. Sample size appropriate?	9. Conclusions supported by the results?
10. Analytic methods described/justified and appropriate?	10. Reflexivity of the account?

11. Some estimate of variance is reported for the main results?	
12. Controlled for confounding?	
13. Results reported in sufficient detail?	
14. Conclusions supported by the results?	

Results

Searches were run on 1 April 2019 and yielded 21,009 results (to which 10 further studies were added through reference list searching). Of these, 12,582 were automatically removed as duplicates. This left 8,437 studies to screen using title and abstract, of which 8,125 were excluded and 312 articles were assessed for full-text eligibility. Many studies were excluded at the title and abstract screening stage because they involved animals or concerned aspects of glaucoma unrelated to lighting. Ultimately, 56 full-text studies were selected for inclusion. The study selection process is shown in a PRISMA diagram in Figure 1. Fifty-four of the 56 studies (96%) were quantitative, and two (4%) were qualitative.

Quality appraisal was conducted on 55 studies. One study[11] could not be quality assessed as it dated from 1929 and was not presented in a format that allowed for comparison with other studies. The lowest and highest score was 0.67 and 1.00 respectively (i.e. all responses to relevant questions in the Kmet, Lee and Cook criteria was Yes). Frequent issues were limited information about subject/comparison group selection and limited description of group characteristics (Figure 2). Appendix 2 shows quality appraisal results for the 53 quantitative and 2 qualitative studies.

Figure 1. PRISMA diagram showing study selection process

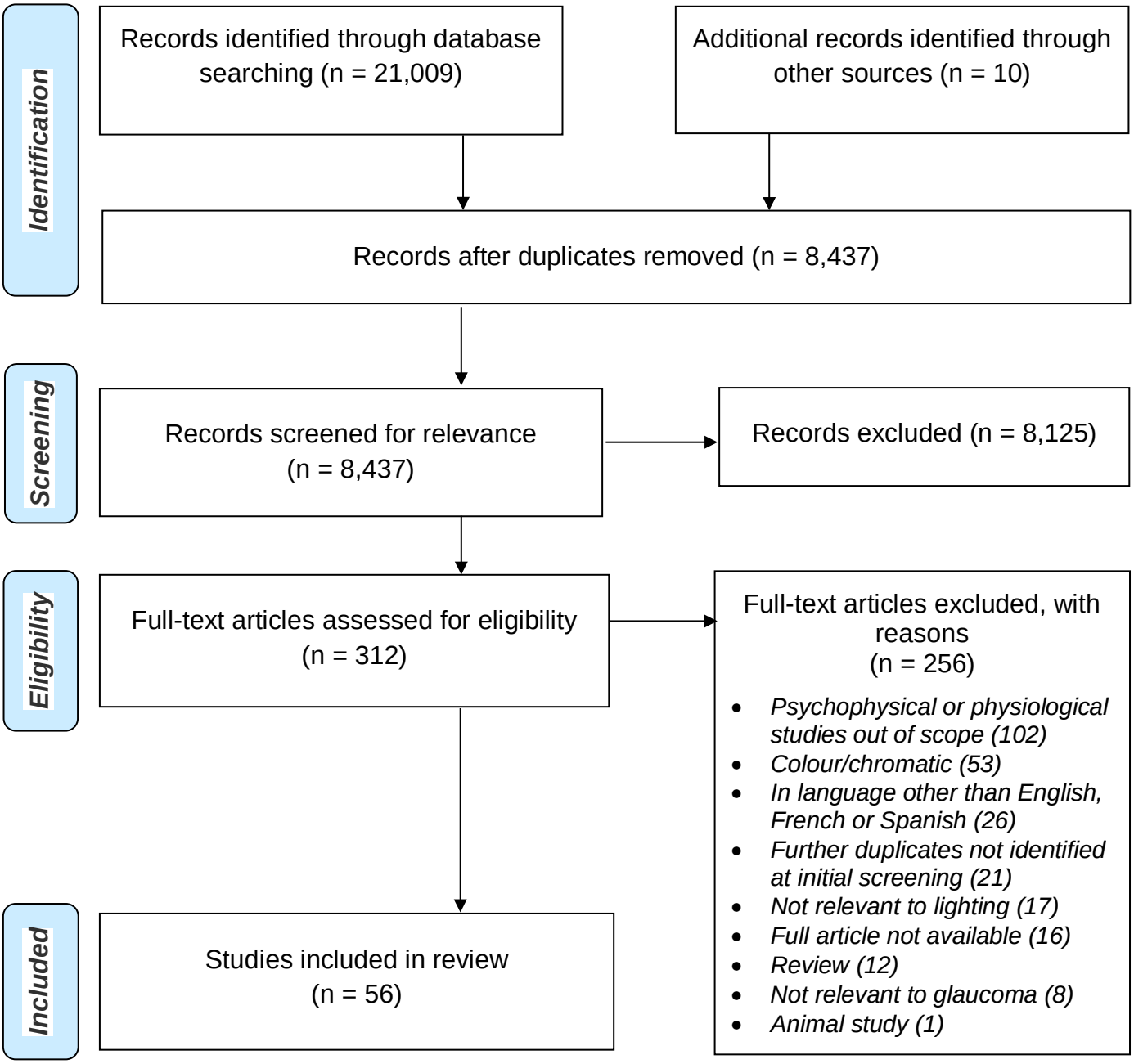
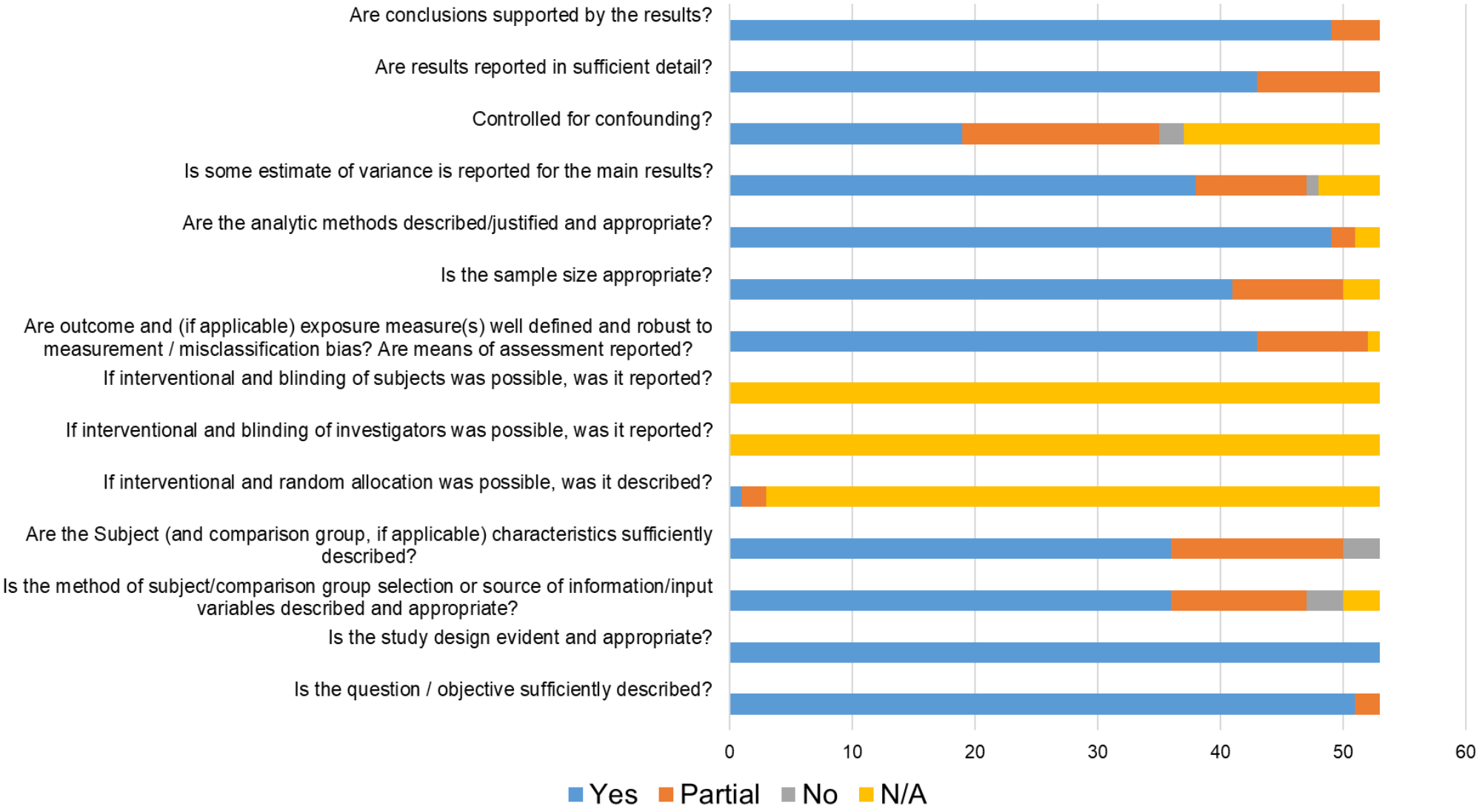
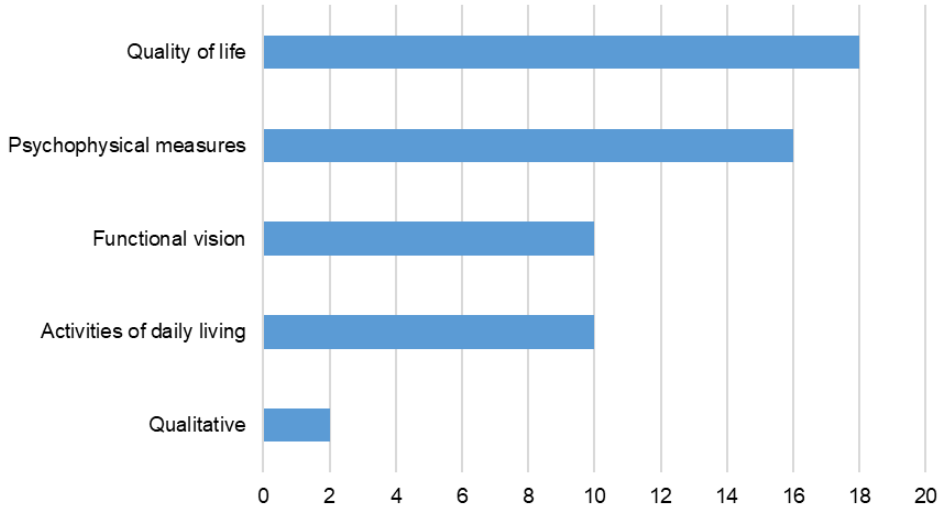


Figure 2. Quantitative study (N= 53) quality appraisal results



For full details of included studies, see the data extraction table (Appendix 3). The subsequent overview of study findings is organised according to main outcome domain. Figure 3 shows the different domains of the studies included in this review, the most frequent of which was QoL (32% of studies), followed by psychophysical measures (29%). The vast majority of the included studies were case-control (48%) and cross-sectional (41%) studies.

Figure 3. Thematic domains considered in the included studies



Quality of life (QoL)

Eighteen studies (32%) explored how lighting conditions affected QoL among people with glaucoma. Eleven of the 18 (61%) studies were cross-sectional while seven (39%) were case-control studies. In total, 2,354 participants with glaucoma were involved in the 11 cross-sectional studies. In the case-control studies, there were 708 participants with glaucoma and 539 control participants. All the studies in this section explored QoL using patient-reported outcome measures (PROMs), including both novel questionnaires and ones extensively developed, tested and validated for use.[12]

Twelve of the 18 QoL studies explicitly excluded individuals with “visually significant”, “clinically significant” or “dense” cataracts. Five cross-sectional studies provided no information about whether participants were excluded on the basis of cataracts, while in one case-control study six of the 68 glaucoma cases also had cataracts.[13] The majority of case-control studies controlled for age when analysing their main results, by matching groups by age and/or by adjusting for the influence of age. However, in two studies with significant differences between glaucomatous and control participants,[14 15] the review authors could not establish whether the lighting-relevant findings were adjusted for age.

Novel questionnaires

Nelson et al.’s study of 63 glaucoma patients found significant differences in adjusting to bright lighting ($P = 0.02$) and disability glare ($P = 0.02$) when comparing participants with mild/moderate glaucoma against those with advanced glaucoma (severe binocular VF loss).[16] There was also a marginal, though non-significant difference in adaptation, when transitioning from a bright to dark room or vice versa ($P = 0.055$). In the authors’ questionnaire on visual disability when performing daily activities, the most commonly reported problems were glare (reported as a difficulty by 70% of participants), and adaptation to different lighting levels (reported by 54%).

The Glaucoma Symptom Scale was developed by Lee et al (1998) using data from 147 participants with glaucoma and 44 individuals without eye disease.[17] Of the glaucomatous participants, 120 (82%) reported problems seeing in the dark, versus 14 (32%) in the control group. Fifty-eight (39%) glaucomatous participants reported haloes around lights, versus 6 (14%) participants in the control group. Sixty-nine

(46%) glaucomatous participants had problems seeing in daylight, versus 7 (16%) in the control group. There was a significant difference in age between glaucomatous and control participants ($P < 0.01$), though multivariate linear regression adjusted for age still showed significant differences ($P < 0.001$) between groups on these questionnaire items. The multivariate model also controlled for presence of cataract, although there were few cataract cases and their inclusion did not substantively affect overall scores, even without correction.

A later study by Mogil et al. (2017)[18] adapted validated questionnaires such as the National Eye Institute Visual Function Questionnaire (NEI-VFQ) and Glaucoma Quality of Life (GQL-15) to create a new questionnaire with five domains: general eyesight, visual symptoms, activities, socioeconomic factors, and ocular symptoms. This was administered to 152 glaucomatous participants, including 97 with POAG. In the visual symptom domain, difficulty seeing in the dark was the second-most common concern (reported by 21% of participants) and glare the third most common (reported by 15%). However, a non-lighting specific concern, blurry vision, was the most common visual symptom (32%). Difficulty “adjusting to changes in light settings” was reported by 4% of participants.

Glaucoma Quality of Life (GQL-15)

The GQL-15 questionnaire was first compiled and tested by Nelson et al. (2003).[19] The authors found that glare disability, as tested with the brightness acuity test, correlated moderately with summary score on the GQL-15 ($r = −0.41$; $P < 0.001$). Furthermore, dark adaptation, as tested using the Goldmann Weekers Dark Adaptometer, correlated moderately with improved scores on the GQL-15 ($r = 0.34$,

P = 0.007). Out of the psychophysical tests used by the authors, only the correlation between GQL-15 summary score and Pelli-Robson contrast sensitivity was stronger ($r = -0.45$; $P < 0.001$). The authors suggest that of the four different GQL-15 subscales (central and near vision; peripheral vision; glare and dark adaptation; and outdoor mobility), the glare and dark adaptation questions could best distinguish between glaucoma severity group (mild, moderate or severe). Glare and dark adaptation showed lower (worse) scores than the other three subscales at each glaucoma severity level. There were no significant differences in age between groups, and results were adjusted for the influence of small inter-group differences in age.

The GQL-15 was used to compare a group of 121 participants with glaucoma (subdivided into mild, moderate and severe) with 31 healthy controls.[14] There was no significant difference in scores on the glare and dark adaptation scale between participants with mild glaucoma and controls, whereas the glaucoma participants were significantly more compromised than controls on all the other three GQL-15 subscales (central and near vision, peripheral vision, and outdoor mobility). Nonetheless, scores were consistently higher/worse for controls and glaucoma participants at each stage of severity on the glare and dark adaptation subscale than for any other subscale. Controls were on average seven years younger than glaucoma participants ($P < 0.001$).

The finding that glare and dark adaptation emerges for both glaucoma participants (at each disease stage) and age-matched controls as the most problematic of the four GQL-15 subscales has been found in other studies, such as Onakoya et al.[20] Additionally, when a Chinese version of the GQL-15 was administered to 508 glaucoma patients, the worst scores (out of the four subscales)

were reported for glare and dark adaptation, closely followed by central and near vision.[21] In a Serbian translation of the GQL-15, the glare and dark adaptation subscale showed the worst score, with no significant difference between mild (N=101) and moderate (N=38) glaucoma stages, but with advanced glaucoma (N=38) participants showing significantly worse scores.[22] Another translation of the GQL-15 into Chinese found that the most problematic activities related to lighting transitions and dark adaptation. Across glaucoma severity, participants had worst scores for the questionnaire items “adjusting to bright lights” and “going from a light to a dark room or vice versa”.[23] The third worst score was for “seeing at night”.

Studies by Aspinall and colleagues nuanced this finding that glare and dark adaptation is the most consistently problematic subscale on the GQL-15, by exploring how glaucoma patients prioritise their QoL concerns. Aspinall et al. (2008) found that lighting and glare were the most frequently reported problems, but third in a priority list after central vision and outdoor mobility.[24] An earlier study by Aspinall et al. (2005) with a different sample of patients similarly illustrated that despite their frequency, the subjective importance of glare and dark adaptation problems may be relatively low.[25] The authors suggest that the low relative impact of glare and dark adaptation on QoL may be explained by the feasibility of accommodating to the changes through behavioural or environmental modifications. The authors also found that of the different attributes of vision-related QoL, contrast sensitivity only had an effect on the prioritisation of the glare and dark adaptation subdomain ($P = 0.038$).

A QoL assessment among participants in the Collaborative Initial Glaucoma Treatment Study (CIGTS) came to a similar conclusion: that lighting and glare issues may be frequent concerns, but not necessarily the most bothersome.[26] The authors found that at baseline of enrolment into CIGTS, over 40% of participants

experienced problems with bright light and light-to-dark adaptation the most frequently reported problems. Furthermore, almost 30% of participants reported problems seeing in dark places. However, rating their symptoms on a 1 (not at all) to 5 (a lot) scale of how bothersome symptoms were, participants' worst symptoms related to visual distortion (mean bothersome score: 4.1) and distant vision (mean bothersome score 3.8), compared to a mean score of 3.5 for bright light, 3.2 for dark adaptation, and 3.3 for seeing in the dark.

Glaucoma Activity Limitation (GAL-9)

One study by Skalicky and colleagues (2016) included 200 participants with glaucoma, 73 of whom also had some degree of age-related macular degeneration (AMD).[15] The authors found that adjusting to dim lights was one of the GAL-9 items which was significantly more difficult for glaucoma patients without AMD than those with AMD ($P = 0.04$). All other GAL-9 items with reference to light ("Walking after dark"; "Seeing at night"; and "Going from light to dark room or vice versa") were all more difficult for study participants with glaucoma alone, compared to those with both glaucoma and AMD, although these differences were not statistically significant ($P = 0.20$, 0.42 and 0.11 respectively).

A hospital-based study with 50 glaucoma participants showed that among GAL-9 items, "adjusting to dim lights" and "going from light to dark room and vice versa" had a relatively high difficulty score. However of all GAL-9 domains, "Adjusting to dim lights" had the weakest correlation with VF damage in the central 10 degrees ($r = -0.147$, $P = 0.309$).[27]

Comparisons between different PROMs

A study comparing the GQL-15 with the NEI-VFQ-25 among 132 glaucoma participants and 132 age-matched control participants found a strong correlation between the glare and dark adaptation subscale of the GQL-15 and the distance activities domain of the NEI-VFQ-25.[28] The driving domain of the NEI-VFQ-25 most strongly correlated with the glare and dark adaptation subscale out of the four GQL-15 subscales (*rho* = -0.644, $P < 0.01$). Glare and dark adaptation GQL-15 scores became higher/worse as glaucoma severity increased, particularly when comparing mild and severe. A moderate association was found between mean deviation, and glare and dark adaptation scores (*rho* = 0.374).

Kumar and colleagues[29] compared two glaucoma-specific PROMs, the GQL-15 and the 10-item questionnaire developed by Viswanathan et al.[30], with the NEI-VFQ-25 (a generic ophthalmology PROM). In total, 140 participants with glaucoma (49 with mild glaucoma, 55 with moderate glaucoma, and 36 with severe glaucoma) completed all three instruments. The authors found that scores from the three instruments correlated especially well in the domain of glare and dark adaptation, as well as peripheral vision. When comparing the NEI-VFQ-15 subscales and GQL-15 subdomains, the NEI-VFQ-15 driving subscale had a strong correlation with the GQL-15's glare and dark adaptation subdomain (*r* = -0.615).

Wren et al. (2009) compared the NEI-VFQ with the Visual Activities Questionnaire (VAQ) among participants enrolled in the Collaborative Initial Glaucoma Treatment Study.[31] Of the eight subscales on the VAQ, the light-dark adaptation subscale was the most problematic for participants, followed by glare disability. Light-dark adaptation on the VAQ correlated most strongly with Distance

Activities (r = 0.56) and Near Activities (r = 0.53) on the NEI-VFQ, while glare disability correlated most with Distance Activities (r = 0.51) of all the NEI-VFQ subscales. The driving subscale of the NEI-VFQ only had moderate correlations with light-dark adaptation (r = 0.44) and glare disability (r = 0.43) on the VAQ.

Sherwood and colleagues (1998) used several questionnaires with 56 participants with glaucoma and 54 healthy controls (who did not differ significantly in age, P = 0.10).[13] They used the Activities of Daily Vision Scale (ADVS), and of the six subscales (day vision; night vision; far vision; near vision; glare; overall vision), the glare item showed the greatest difference in mean score between patients and controls. Investigating correlations between ADVS and Medical Outcomes Study Test (MOS-20) scores, glare had significant associations with the physical, role, mental health and general health subscales of MOS-20, although was not significantly correlated with the social and pain MOS-20 domains.

Psychophysical measures

Sixteen included studies (29% of the total) considered how specific lighting conditions affect psychophysical outcomes such as contrast sensitivity, glare, and dark/light adaptation. These studies in total involved 517 participants with diagnosed glaucoma, and 205 participants with suspected glaucoma. The majority (14/16 = 88%) of the psychophysics studies were case-control studies, while two were cross-sectional studies.

Studies considering how glaucoma affects psychophysical measures such as glare and dark adaptation generally considered how age and presence of cataracts could influence results. Among the 14 case-control studies, five studies reported

mean ages of glaucoma and control groups which were clearly matched; five studies adjusted for age at analysis stage; while four only provided minimal information on participant age (e.g. an indicative age range). Regarding cataract, three of the 16 studies expressly excluded participants with cataracts, while two studies deliberately included participants with cataracts. Five studies more broadly excluded people with "eye abnormalities", while two studies excluded individuals who had undergone previous cataract surgery. Four studies gave no indication of having excluded individuals with cataracts.

Contrast sensitivity (CS)

Using luminance-modulated gratings, CS thresholds at all spatial and temporal frequencies have been found to be significantly poorer among people with early to moderate stage OAG relative to healthy age-matched controls.[32]

Foveal CS is lower in glaucomatous eyes than eyes of age-matched controls in both mesopic and photopic conditions, even in glaucomatous participants with good visual acuity.[33] For example, foveal CS, across luminance conditions, has been found to be 0.4 log units lower for glaucomatous participants than for controls (age-adjusted $P < 0.001$).[34]

However, differences in CS between healthy participants and people with glaucoma appear more pronounced in mesopic than photopic lighting conditions.[35] Even when differences in CS between glaucoma participants and age-similar controls are fairly modest overall, the difference is greater in lower luminance conditions.[36] Furthermore, differences between glaucoma participants and age-

matched controls in CS in the peripheral VF are most pronounced at low luminance levels.[34]

Glare

Glaucomatous damage has been found to be moderately positively correlated with increased glare factor (*rho* = 0.485; *P* = 0.01), with glare factor being the difference between log CS with glare and log CS without glare.[37] It should be noted, however, that this finding comes from a study in which all participants had cataract.

Disability glare among people with open-angle glaucoma has also been linked with macular pigment levels. For example, one study by Siah and colleagues[38] found that 54 of 88 glaucomatous participants (61%) complained of glare symptoms. Among these participants reporting glare symptoms, lower macular pigment optical density was found at all retinal eccentricities (for 0.25° and 1°, *P* =0.05 each; for 0.5°: *P* =0.04). There was no difference in age between participants with and without glare symptoms (*P* = 0.51); the authors controlled for the presence of mild cataract and excluded individuals with moderate-to-significant cataract.

Dark adaptation

Much of the knowledge regarding dark adaptation among people with glaucoma is based on studies from the early- and mid-20th century.

Derby and colleagues (1929) showed that dark adaptation was abnormal in healthy eyes of participants who had a confirmed glaucoma diagnosis in their other eye.[11] The authors attempted to recruit controls of similar age to the glaucomatous

participants (between 50 and 70) although no exact data are provided. Derby et al. also suggest that changes in the minimum amount of light which the eye can perceive could be one of the earliest signs of glaucoma.

It was thus hypothesised that the dark adaptation thresholds of glaucoma patients were reached later and were higher than in healthy eyes. Subsequently, Zuege and Drance (1967) showed that eyes with advanced glaucoma could be distinguished from age-matched healthy eyes by using the dark adaptation threshold ratio 15:30 degrees from fixation.[39]

Relating to problems with dark adaptation experienced by people with POAG is the loss of scotopic sensitivity. In one study by Drum and colleagues (1986), participants with suspected glaucoma (no measurable VF loss, but intraocular pressure > 20 mm Hg) and participants with confirmed glaucoma had elevated scotopic and photopic adaptation thresholds. However, among participants with confirmed glaucoma, the scotopic threshold elevation was significantly greater than the photopic threshold elevation (i.e. loss of scotopic sensitivity was greater than loss of photopic sensitivity). In addition, it was also found that the localised scotomas of glaucomatous participants were of similar depth in scotopic and photopic conditions, but in scotopic conditions, scotomas were spread out more “diffusely” across the VF.[40] When stratified by age, Drum et al. found that in their <40 age bracket, glaucomatous and control participants were indistinguishable, while in the 40-60 age bracket, inter-group differences were only seen for the scotopic condition.

Progressing optic nerve damage underpins decreased dark adaptation among people with glaucoma. This has been demonstrated in a study involving participants with glaucomatous and non-glaucomatous optic nerve atrophy.[41] While the authors

found that the extent and velocity of dark adaptation decreases with increasing age, after controlling for age several measurements were significantly worse among people with glaucoma, and even worse with the non-glaucomatous optic nerve atrophy group (who had more severe optic nerve damage than the glaucoma group).

Bierings and colleagues (2018) recently showed that age-adjusted dark adaptation times are similar between glaucoma participants and controls, with only marginally (statistically non-significant) longer times among glaucoma patients relative to controls (P = 0.10 for 5 log unit luminance change, and P = 0.14 for 6.5 log unit luminance change).[42] In keeping with earlier studies, they found that the dark adaptation curve for glaucoma participants has a lower CS plateau. To explain these results in line with previous findings that people with glaucoma may struggle to adjust to low luminance conditions, the authors suggest that glaucoma participants may not strictly take longer to dark adapt to their plateau; however, because the CS plateau is lower for glaucoma participants, they will take longer when dark adapting to reach their minimum CS required for adequate everyday vision.[42]

Light adaptation

In contrast to the numerous studies focused on dark adaptation, only one included study considered light adaptation, examining 23 glaucoma participants and 51 controls.[42] The study authors were unable to measure light adaptation times because of how quickly this occurred. However, in line with findings on dark adaptation, they found that after light adaptation, glaucoma participants have a lower CS plateau than healthy control participants (after adjusting for age).

Visual evoked potentials (VEP)

Arvind and colleagues (2011) explored the specific luminance aspects of the blue-on-yellow (BonY) multifocal visual evoked potential as a tool for identifying early glaucoma.[43] This study found that using a low-luminance contrast achromatic (LLA) stimulus worked as effectively as BonY in identifying early glaucoma, while a high-luminance contrast achromatic stimulus performed significantly worse than LLA and BonY in identifying VF problems. They conclude that the low-luminance contrast aspects of the BonY stimulus specifically may explain BonY's usefulness in detecting early glaucoma.

Retinal function

One study used the modified global flash multifocal electroretinogram (ERG) paradigm with luminance modulation, which allows adaptive changes in the retina to be measured.[44] The authors found that in response to a global flash stimulus at different luminance levels, participants with glaucoma had a reduced response compared to age-matched controls which correlated with glaucomatous VF damage ($r = 0.58$, $P < 0.0001$).

In response to flash ERG after dark adaptation, glaucoma patients showed longer implicit times than age-matched controls at several flash intensities, but especially for high intensity flash.[45]

A retinal sensitivity test (using flashing white light) performed under scotopic conditions has been shown to discriminate between healthy and glaucomatous participants. The study involved participants with suspected, as well as confirmed,

glaucoma, and the test effectively indicated signs of early optic nerve injury among glaucoma suspects.[46]

Functional vision

Ten studies (18%) focussed on how functional vision changes under different lighting conditions. Five of the 10 studies were case-control studies, three were cross-sectional and two were descriptive case-series. In the case-control studies, there were 355 participants with confirmed glaucoma and 285 controls. There were 359 glaucomatous participants in the two cross-sectional studies, and 98 glaucoma participants in the two descriptive case-series.

Functional difficulties linked to lighting conditions

Among participants with early or moderate glaucoma (33 of 99 study participants), the most commonly reported visual symptoms were needing more light (58%), blurry vision (52%) and seeing glare (52%).[47] When considering all participants in this study, needing more light was reported as a symptom by 57% of participants, blurry vision by 55% and seeing glare by 46%.

The assessment of key markers of visual function among people with glaucoma has been shown to be dependent on lighting conditions. One study compared measures such as distance and near visual acuity (VA) and CS in the clinic and at home, with glaucomatous participants and healthy controls.[48] 29% and 22% of glaucoma participants read at least two more lines of a distance VA chart and near VA chart respectively in the clinic than at home. 10% of glaucoma

participants read at least two triplets of a Pelli-Robson chart better in the clinic than at home. Multivariable regression analysis demonstrated that lighting levels were the strongest single factor associated with improved visual performance in the clinic. Across the whole sample of glaucoma and healthy participants, at least 85% of home lighting levels assessed were lower than recommended levels. Among glaucomatous participants, there was no statistically significant difference in lighting levels by glaucoma severity. This finding is reaffirmed by Yonge et al. (2017), who found that that individuals with more severe glaucoma symptoms were no more likely to adapt their home lighting than those with less advanced symptoms.[49]

Functional difficulties linked to glare

A descriptive study in an Australian low vision clinic reported the high prevalence of self-reported glare problems, with 34% of those whose low vision is primarily linked to glaucoma reporting being greatly affected by glare, and an additional 38% of patients being moderately affected.[50] Prevalence of glare problems was even higher among those with low vision whose secondary cause was glaucoma; with these patients, 49% were greatly affected and 29% moderately affected by glare.

Functional difficulties linked to transitions in lighting or luminance

One recent questionnaire study by Bierings and colleagues (2018) compared the responses of 178 glaucomatous and 182 control participants to fifteen questions about visual function when performing activities in conditions such as outdoor at night (low luminance), outdoor on a sunny day (high luminance), and sudden

increases or decreases in luminance level.[51] Participants were considered to have visual complaints if they responded to such questions with either ‘A lot of difficulty’, ‘Extreme difficulty’ or ‘Stopped doing this because of my eyesight’. The authors found that 4% of participants with glaucoma had visual complaints in optimal luminance versus 0% of control participants ($P = 0.02$). Meanwhile 48% of participants with glaucoma versus 6% of controls ($P < 0.001$) experienced visual problems in low luminance conditions. The percentages of glaucoma participants versus controls with visual complaints was respectively 22% versus 1% for high luminance ($P < 0.001$), 32% versus 1% for a sudden decrease in luminance ($P < 0.001$) and 25% versus 3% for a sudden increase in luminance ($P < 0.001$). The largest differences between glaucoma participants and controls were found for the low luminance questionnaire items. 48.4% of glaucoma participants reported complaints for “Seeing outside at night when there is no moonlight” (compared to 6.3% of controls); 53.6% for “Walking or cycling at night on an unlit country road” (compared to 13.7% of controls); and 49.7% for “Driving at night on an unlit country road” (compared to 12.7% of controls). The study illustrates the particular difficulties experienced by many people with glaucoma when performing daily activities in dark conditions. Further, the majority (62%) of glaucoma patients in the study were considered to have early glaucoma in their least affected eye. As such, the findings suggest that glaucoma symptoms may be exacerbated in non-standard luminance conditions even if a patient is largely asymptomatic in optimal luminance.

In contrast, an older questionnaire study by Carta and colleagues (1998) found no significant difference between 33 POAG participants and 20 controls (with minor refractive problems or presbyopia, and whose mean age was 9.1 years less than the POAG group) on a group of questions concerning adaptation to lighting

transitions and glare (P = 0.11).[52] This discrepancy may result from differences in Likert-type scales used (five points in the Bierings et al. (2018) study versus three points in the Carta et al. study), differences in sample size, and/or the subject matter of the questions and how they were presented.

A population-based study in Japan used frequency doubling technology (FDT) perimetry and a questionnaire with 10,214 participants[53], of whom 447 exhibited visual field abnormalities (VFAs, as determined by the FDT perimetry), 227 of which were attributed to glaucoma. The definitive glaucomatous subgroup were significantly more likely to report difficulty seeing in dark places, when compared with visually healthy subjects (age-adjusted odds ratio = 1.55, 95% CI = 1.11–2.17, P = 0.01).

Motion perception

No significant differences overall have been found between the performance of POAG and age-matched control participants in their sensitivity to motion under photopic and scotopic conditions.[54] In photopic conditions, sensitivity to moving targets in both central and peripheral vision declined with age (P < 0.01). In scotopic conditions, sensitivity to moving targets was lower for age-matched controls and participants with POAG than for young controls, but only for peripheral and not for central vision.

Object recognition

An experimental study has been conducted to investigate how people with glaucoma, relative to healthy controls, can recognise or classify common objects in different lighting levels.[55] Visual categorization tasks were employed in two different contrast conditions (medium 50% and high 100%). The medium contrast setting aimed to simulate sub-optimal lighting conditions, such as fog, dazzling sunlight, or dusk or dawn light. There was no difference between the performance of glaucoma patients and controls when contrast was 100%. Conversely, the authors found that patients with glaucoma had 7% lower accuracy (P =0.046) for the medium contrast stimuli (87% responses correct) compared with controls (94% responses correct). Interestingly, object categorisation in this condition was impaired despite presentation of the stimuli within the intact central area of participants' VF. This suggests that in many real-world situations where contrast is unlikely to be 100%, categorising objects may be more difficult for people with glaucoma than visually healthy controls, even when considering those without significant VF loss.

Another study considered detection and categorisation of face and scene images among glaucoma patients with central VF defects compared to glaucoma patients without central VF defects in two different luminance levels.[56] Two different contrast levels (10% and 2.5%) were used to simulate twilight conditions, lower levels than in the study discussed above. For scene images, there was no main significant main effect of the luminance contrast. However, the decrease in performance moving from the detection to categorisation task in the scene experiment was marginally greater in the 2.5% contrast condition (mean ± SD = 1.92 ± 0.96) compared to the 10% contrast (mean ± SD = 0.96 ± 0.85) for patients without central VF defects.

Use of visual aids

Among low vision patients with sensitivity to light whose preferences for different light filters were assessed, over 85% of the glaucoma patients chose the two filters providing the greatest light transmission.[57]

Activities of daily living (ADL)

Ten (18%) of the 56 studies focussed on ADL. Of these, one was focussed on home-based modifications to lighting, four on driving, three on reading, and two on mobility. Seven of the 10 ADL studies were cross-sectional, and one each was a case-control, longitudinal and randomised control trial. These ADL studies involved a total of 1,674 participants.

Modifying lighting in the home

Participants with low vision (Visual acuity < 0.3 or 6/18) were randomised to receive standard adaptations (control group), or specific light improvements in the kitchen, hall and bathroom of their home over a six-month period (intervention group).[58] Participants' low vision resulted from several different kinds of eye disease, with only 5 of the 46 participants diagnosed with glaucoma. There were only marginal, non-significant improvements in ease of daily activities among the intervention group, although the intervention group's improvement in QoL was significant.

Driving

Lighting conditions can play a particularly significant role in making driving more difficult for people with glaucoma, irrespective of the degree of VF loss.

Using a large dataset on activity limitation involving 293 participants with different types and severity of glaucoma, researchers focused in on responses to the driving questions, about “Driving at night”; “Driving towards oncoming headlights”; and “Driving towards the sun”. In contrast, more generic aspects of driving such as “‘Noticing when the car in front of you is speeding up or slowing down” and “Driving during the day” were considered the least difficult.[59]

In a sub-study of the CIGTS, researchers compared the concerns of drivers (N = 471) and non-drivers (N = 84) living with glaucoma.[60] Problems related to glare were the most reported, with over 50% of participating drivers experiencing “some difficulty” when performing tasks affected by glare. More than 20% of the glaucomatous drivers reported “often” or “always” having difficulty seeing the road at night in the rain because of headlights. The authors suggest that glare could be a particularly useful indicator of risk for visual problems while driving, particularly since glare is one of the earliest symptoms noticeable to the patient. At 54-month follow-up, drivers with moderate-to-severe bilateral VF loss reported significantly more problems driving at night than drivers with mild bilateral VF loss.

One study explored whether glaucomatous patients ceased driving specifically because of issues with lighting, dark adaptation and glare.[61] Among 99 participants, those with moderate or severe glaucoma were more likely to have discontinued driving than those with mild glaucoma (33% vs. 8%; $P = 0.002$), and to have more difficulties with dark adaptation (31% vs. 10%; $P = 0.011$) and glare (27% vs. 6%; $P = 0.012$). Participants with self-perceived difficulty with dark adaptation or

glare were not statistically more likely to give up driving than those without. However, difficulty with dark adaptation was associated with an approximately four-fold likelihood of experiencing difficulty driving at night (adjusted prevalence ratio (PR) = 3.94; *P* <0.0001) or experiencing difficulty in poor driving conditions (adjusted PR = 4.09; *P* <0.001). Self-perceived glare was not associated with difficulty driving at night, but showed a marginally significant association with difficulty in poor driving conditions (PR = 4.17; *P* = 0.050).

In a study of real-world driving performance among 21 drivers with bilateral moderate and advanced glaucoma (compared with 38 healthy controls), participants' driving was evaluated and scored either a pass or marginal/fail.[62] No difference was found for the glaucomatous participants who passed and failed attributable to glare (*P* = 0.88), and other psychophysical measures. The only predictor of differences between passing and failing glaucomatous drivers was performance on vision-dependent psychometric tests (especially the Trail Making Test).

Reading

Three studies were included which provided some evidence of how lighting conditions impact upon people with glaucoma's reading ability.

Two studies used the Assessment of Disability Related to Vision (ADREV), a nine-task performance-based measure which includes one task of reading in reduced illumination. Evaluation of the ADREV involving 194 participants with glaucoma showed that reading in reduced illumination was similarly difficult to a test of locating objects.[63] Further analysis of ADREV results from 192 glaucomatous participants showed that there were no statistically significant correlations between

any measure of VF loss and reading in reduced illumination task performance.[64] Nonetheless, an earlier version of the measure, the Assessment of Function Related to Vision (AFREV) had found that reading in dim light had a strong correlation with CS, visual acuity of the worse eye and binocular visual acuity (r = 0.68, -0.69 and -0.67 respectively, all $P < 0.01$).[65]

Although not formally included in the review (as it does not directly focus on lighting), research has shown that when letter contrast is reduced from 100% to 20%, individuals with glaucoma read significantly more slowly than healthy controls. The relevant implication of this study is that increasing luminance in which people with glaucoma read could reduce difficulties with reading.[66]

Mobility

Only two included published studies focussed on mobility. However, several of the abstracts shown in Table 3 explore mobility in different lighting conditions, suggesting this to be an emerging research priority.

One cross-sectional study used a mobility questionnaire and performance-test developed originally for patients with retinitis pigmentosa (RP) to assess 83 glaucoma patients.[67] Comparison of the glaucoma and RP groups' responses showed that glaucoma patients reported changes in lighting at night causing more mobility difficulties than the RP patients. In contrast, RP patients reported more overall difficulty walking at night.

A cross-sectional study nested within a larger US-based study (the Falls in Glaucoma Study – FIGS) considered lighting and mobility.[49] Assessing fall-related hazards in the homes of 174 people with glaucoma, ambient lighting of <300 lux and

exposed light bulbs were the most frequently encountered fall-related hazards, in 98.9% and 96% of assessed homes respectively. There was no relationship between VF loss and better lighting, suggesting that home lighting is often not modified even as glaucoma worsens, despite the low cost of this adaptation and its potential to reduce falls.

Qualitative findings

Two studies (4%) used qualitative data collection methods, including interviews and focus groups, involving a total of 44 participants living with glaucoma who discussed lighting-related issues in their accounts.

In focus groups conducted in 2002, participants with glaucoma discussed problems related to lighting such as seeing halos, and shared advice with fellow group participants on how to adapt to lighting difficulties and glare; these included improving lighting in the home, and wearing hats outside to reduce the discrepancy between indoor and outdoor lighting.[68]

In analysis of interviews from a more recent study, participants spoke of issues driving at night due to the bright lights of oncoming vehicles.[69] Authors identified 'the importance of lighting' as one of their main themes impacting on patients' functioning and coping behaviours. For example, some participants spoke of needing support particularly in dark environments – particularly when navigating steps or obstacles - and when transitioning between light and dark, such as entering the cinema. Sunlight was referred to as 'blinding' by one participant. Participants suggested that artificial lights such as daylight bulbs could help. One participant

found a bright light installed above her sewing machine as helpful, but felt that making the adaptation involved admitting to having a problem.

Trends in publishing

There has been an increase over time in published studies considering the impact of lighting conditions on people with glaucoma. These studies only represent a very small proportion of the total research in glaucoma. A PubMed search for articles with ‘glaucoma’ in the title yields 11726 results since the beginning of 2010 alone; while in that same period just 29 articles (0.25%) were published that were relevant to lighting and included in this review.

Discussion

This review shows that lighting transitions, glare and dark adaptation clearly present problems for both the vision and QoL of people with glaucoma. They emerge as some of the most consistent and frequent symptoms among people with POAG. Studies using the GQL-15 with large numbers of participants and in different geographical contexts consistently find glare and dark adaptation to be the most commonly problematic subscale for people with glaucoma. Yet the QoL literature suggests that while difficulties relating to lighting and glare are frequently expressed, they not perceived by patients to be the most bothersome symptoms. Indeed, Spaeth and colleagues suggest in a review of the glaucoma and QoL literature that a 'threshold' of dark adaption and glare disability may be reached as glaucoma progresses, beyond which the issue ceases to increase in importance.[70] Where QoL studies have explored associations between scores on the glare/dark adaptation domain and psychophysical measures, the only reliable correlation appears to be with CS.[19 25]

Evidence regarding the impact of different lighting conditions on psychophysical measures and functional vision suggests that transitioning from light to dark or vice versa is difficult for people with glaucoma. This is also borne out by qualitative studies.[69] Although a recent study from Bierings et al suggests that people with glaucoma may not strictly take longer to dark adapt than controls,[42] most evidence suggests people with glaucoma show diminished classical dark adaptation than healthy aged-matched controls (AMCs).[39 40 41] Bierings and colleagues' questionnaire about visual performance when transitioning between different levels of ambient illumination also showed very large significant differences between glaucoma patients and AMCs.[6] Nonetheless, when glaucoma patients and AMCs

undertake performance-based measures in non-optimal (e.g. scotopic) luminance on tasks such as motion perception,[54] or object detection or categorisation, [55] [56] the differences are not significant or only show small effects. A similar pattern is found in studies considering driving, with over 50% of glaucomatous drivers reporting difficulties linked to glare[60] and with problems with dark adaptation associated with a four-times higher likelihood of difficulties with night driving.[61] However when real-world driving behaviour of glaucoma patients and age-matched controls was compared, glare and other psychophysical measures did not seem to affect performance.[62] Many of the included performance-based studies have relatively small samples of glaucoma patients and controls, potentially limiting the statistical power to detect differences.

Notably, during the literature search, it emerged that many pertinent findings directly considering how lighting affects ADL exist only in conference abstracts (Appendix 4). The focus on mobility performance in many of these abstracts contrasts with the fact that only two published studies included focused on glaucoma, lighting and mobility. It is perhaps revealing that many of these abstracts, either from conferences or articles currently in proof/press, are recent and focus more directly on lighting issues than many of the included studies which only consider lighting conditions incidentally (e.g. as part of a more general questionnaire). It could therefore be inferred that improving understanding of how and why glaucoma patients may have difficulties in certain lighting conditions is becoming more of a priority concern in glaucoma research. This is becoming more feasible with research facilities like HomeLab, a simulated home environment with automated systems allowing real-world everyday task performance in different lighting levels to be monitored.[71]

The included studies seldom focus specifically on adaptations and modifications that may help people with glaucoma cope with lighting related issues. However, select parts of some studies do provide some helpful insights. Nelson, Aspinall and colleagues suggest that simple environmental modifications can help diminish glare problems and avoid rapid changes in lighting levels for people with glaucoma.[19] These include increasing brightness in dark areas (e.g. staircases), repainting dark walls in paler colours, installing or changing blinds or curtains, and considerate (re)design of window, glass and mirror areas to reduce glare. Other adaptations may include using dark lenses, and allowing longer for dark adaptation or ceasing to drive at night.[25] A study from a low vision clinic suggests illuminated magnifiers may be useful aids, and hats with a visor and sunglasses may help against glare.[50] Arguably, it is the fact that adaptations are simple and low-intensity that may explain why such frequently encountered symptoms are low priority for many patients.[25]

Nonetheless, the review suggests that lighting issues are frequently neglected in the clinical management of glaucoma. Some studies indicate people with glaucoma are living in homes with inadequate, potentially hazardous lighting, and that individuals with worse VF damage do not appear to use improved lighting.[48 49] One study showed disparities in home and clinic lighting levels, showing that at least 85% of participants with glaucoma had inadequate home lighting, and as such had significantly worse visual acuity and CS in their home than when measured in clinic; this highlights the importance of clinicians discussing lighting with their patients as a means of minimising visual and functional difficulties in their everyday life. Advice is clearly needed that is personalised to the patient with glaucoma and their affected

activities, for example ensuring that sufficient illumination is balanced against the need to minimise glare.[58]

To the authors' knowledge, this is the first systematic review to focus squarely on lighting, glare and dark adaptation among people with chronic forms of glaucoma. A review in 2011 considered therapeutic uses of lighting for older adults, but with only a limited focus on the specific concerns of people with eye disease.[72] A 2011 systematic review of patient-reported outcomes in glaucoma considered studies which had used the GQL-15, but was more focused on methodological aspects of the PROMs' development and validation, rather than their thematic content.[73] Many of the present review's findings are supported by relevant sections of broader reviews on visual disability in glaucoma (see Table 3). Additionally, reviews on vision, ageing and age-related eye disease make clear that decreases in CS, in light to dark adaptation and in sensitivity to glare often occur in the healthy ageing eye without any underlying pathology. For example, glare has been found to cause significant difficulty for healthy older adults driving at night.[74] However glaucoma, and other age-related eye diseases, such as AMD and cataracts, can clearly aggravate such problems.

Table 3. Select findings relevant to lighting from key reviews

Author(s)	**Year**	**Title**	**Select findings related to lighting**
Derby, GS Waite, JH Kirk, EB	1926	Further studies on the light sense in early glaucoma[75]	"It is our distinct impression that an examination of the light minimum… is of real value to us in making the diagnosis of early glaucoma".
Marlow, SB	1947	The field of vision in chronic glaucoma (a comparison of full with reduced illumination)[76]	"The evidence presented here permits the conclusion that reduction of illumination is more than sometimes useful and that it is of definite value in the discovery of incipient changes as well as in the amplification of known or suspected defects".

Ramulu, P	2009	Glaucoma and disability: which tasks are affected, and at what stage of disease?[77]	"Difficulties related to lighting such as glare and difficulty adapting to different levels of light consistently ranked as the most frequent complaint… The lighting conditions under which tasks are performed may be even more important than the task itself".
Medeiros, FA Weinreb, RN Boer, E Rosen, PN	2012	Driving Simulation as a Performance-based Test of Visual Impairment in Glaucoma[78]	"Increasingly challenging visual tasks on the [driving] simulator, under low contrast, low luminance conditions and performed under the pressure of time, could potentially reveal functional impairments that would not be detected by standard visual field assessment. This hypothesis remains to be investigated."
Nassiri, N Mehravaran, S Nouri-Mahdavi, K Coleman, AL	2013	National Eye Institute Visual Function Questionnaire: Usefulness in Glaucoma[79]	"Contrast sensitivity, glare sensitivity, and dark adaptation are potential items that could be added to the [NEI-VFQ] questionnaire to make it more responsive to changes in vision-related QoL in patients with glaucoma".
Wang, Y Alnwisi, S Ke, M	2017	The impact of mild, moderate, and severe visual field loss in glaucoma on patients' quality of life measured via the Glaucoma Quality of Life-15 Questionnaire: a meta-analysis[80]	"Glare and dark adaptation did not differ significantly between patients with mild and moderate visual field loss… glare and dark adaptation differed significantly between patients with moderate and severe glaucoma".
Owsley, C Ghate, D Kedar, S	2018	Vision and Aging[81]	"Contrast sensitivity loss tends to be more severe in older adults who have one or more of the common eye chronic conditions of aging mentioned earlier. In glaucoma these losses are largely attributable to the loss of ganglion cells… There is also evidence suggesting that glaucoma impairs rod-mediated dark adaptation".

The number of studies exploring lighting in glaucoma is growing and Appendix 4 shows several abstracts, some of which will soon be published. Nonetheless, this review has shown there are as yet a limited number of published studies considering how naturalistic, real world activities are affected by lighting conditions. The included studies using the ADREV and AFREV performance measures point to difficulties reading in low light in glaucoma, but only an aggregate measure for the task (and not

scores at each level of illumination) are reported. Paucity of data on how luminance levels affect reading among people with glaucoma contrasts markedly with AMD research, where the effects of differing luminance levels on reading performance has been explored in both cross-sectional[82] and case-control[83] studies. An additional research gap concerns how glaucoma patients' visual acuity may change according to background luminance levels; in this review, only Bhorade et al (2013)[48] specifically explored glaucoma participants' visual acuity in different lighting conditions. Furthermore, while there were descriptive findings regarding adaptation strategies, no research was identified evaluating how low vision aids, assistive technologies or rehabilitation initiatives may support people with glaucoma to cope with lighting and glare difficulties.

Although no studies were formally excluded on the basis of insufficient quality, some common study limitations were identified. Only a minority of studies reported the treatments of the glaucomatous participants involved. When treatment status was reported, many patients were being treated with drops: medications that are associated with ocular surface changes and which may be associated with glare symptoms and generally reduced visual function.[84] Treatment with topical beta antagonists and glaucoma surgery are also associated with increased cataract.[85 86] This may therefore limit the extent to which lighting issues caused by glaucoma may be clearly distinguished from treatment side effects and co-pathology. Studies employing the GQL-15 clearly suggests dark adaptation and glare are the most frequently encountered issue, even in early-stage glaucoma; this may not meaningfully reflect the clinical experience, where glaucoma is commonly seen as asymptomatic. This implies that there may be discrepancy between patients' self-reports when they consider individual isolated symptoms, and their overall visual

performance where lighting may have a relatively insignificant impact. Finally, there is heterogeneity in the definition of key concepts across studies. For example, the included psychophysics studies consider dark adaptation as a process taking many minutes, while the GQL-15 domain for dark adaptation and glare is based on items such as “going from a light to a dark room”, a near instantaneous process. Hence, it could be argued that ‘classical’ dark adaptation studies provide only partial insight into the underlying mechanism of glaucoma patients’ reports of disorientation when going from outside into a dark indoor space (e.g. a cinema). Similarly, in many of the included studies, distinctions between discomfort glare and disability glare are seldom clarified or specified. Furthermore, it is possible that the term ‘glare’ may be used to describe difficulty with a rapid increase in light level, or, to describe a dramatic loss in visual performance in the presence of backlight. The research landscape in lighting and glaucoma therefore appears relatively incoherent, and shows a gap in studies that integrate an understanding of the physiological and psychophysical processes with real-world clinical effects.

There are further interesting observations about the scope of the review and included articles that could be interpreted as limitations. First, as the distribution of rods is predominant mainly outside the macular area, the studies synthesised could be affected by consideration of the location of the VF damage (central or peripheral). This kind of information was rarely stated or recorded in the studies we considered; many studies provided mean deviation values as an overall measure of VF loss, but only in a small number of cases (e.g. Wolffsohn & Cochrane) was the location of participants’ VF loss thoroughly described.[50] The parallel here is the lack of attention that is often given to the actual location and spatial extent of VF loss when assessing impact on function in any lighting condition.[5] Second, the present review has not

specifically considered the mechanism of early functional deficits of glare and adaptation in glaucoma patients. For example, it has been suggested that large (M) retinal ganglion cells are selectively damaged by glaucomatous optic nerve atrophy, and these cells are known to be particularly sensitive to luminance contrast under mesopic and scotopic conditions.[39 40 87] Indeed, for several decades it had been proposed that glaucomatous loss was sensitive to stimuli that preferentially stimulate the magnocellular (M) ganglion cells relative to parvocellular (P) ganglion cells, based on the notion that M cells are selectively damaged in glaucoma.[88] More recent evidence has contradicted this notion;[89] for example, McKendrick and colleagues have identified foveal and midperipheral dysfunction of both M and P pathways among people with glaucoma.[90] Third, it is important to note that the focus of this review is investigating the effect of different lighting conditions on real-world function and vision related quality of life. Thus it should be noted that a more detailed review of psychophysical measures, such as ERG (electroretinogram) studies, is not covered by our review. Fourth, none of the included studies explored in detail how VF measurements may be affected by lighting conditions. Conventional VF testing uses bright stimuli on a dark background, which may be advantageous to detect glaucoma; however the results may be different when patients are in a bright place in their daily lives. Indeed, the outcome of VF measurement may be different when dark stimuli, instead of bright stimuli, are used.[91]

This review's methodology also has a number of limitations. First, for the purposes of data extraction and quality assessment, only studies published in peer-reviewed journals were formally included in results. This is a shortcoming not only because of publication bias, but also because many of the most relevant findings exist in a grey literature form, for example as conference abstracts (Appendix 4).

Second, the range of languages spoken in the review team only allowed for screening and inclusion of studies in English, French or Spanish (and only English articles were ultimately included). This meant that a fairly large number of seemingly relevant studies - in German (13), Japanese (5) and Russian (4) in particular - were therefore excluded. Third, while included studies were required to include at least some POAG patients, the glaucoma group in some studies involved participants with other forms of glaucoma (e.g. normal tension glaucoma, or secondary open-angle glaucoma, such as pseudoexfoliative or pigmentary glaucoma). In these studies, results were rarely disaggregated by exact glaucoma type, thereby limiting how highly specific the review's findings are to POAG. A fourth limitation relates to using the assessment criteria we chose (Kmet, Lee, & Cook, 2004) for a heterogeneous research field. Most studies were appraised as being of high methodological quality, with a mean of 0.91 (out of 1) for quantitative studies and 0.83 for qualitative studies. However, some studies scored 1 because they elegantly replicated an existing questionnaire, such as the GQL-15 in a different population; while another more novel, complex study could score relatively low if it did not meet the precise assessment criteria. Additionally, the inclusion of a study from 1929[11] presented a significant challenge for using a tool that assesses quality according to modern scientific conventions, with the result that that study was omitted for quality assessment.

In spite of these limitations, in conclusion this review provides clear evidence that lighting conditions may cause frequent, although not always hugely problematic, difficulties for the everyday visual function, QoL and daily activities of people with glaucoma. The weight of the evidence suggests these difficulties with lighting transitions and glare exceed those experienced by healthy older adults more

generally, and that the problems become worse as glaucoma severity increases. Nonetheless, tests of dark adaptation or questionnaires do not themselves allow for clear discrimination between people with glaucoma and visually healthy controls. Using naturalistic performance-based measures to assess activities of daily living under different lighting levels is becoming more feasible as a valuable area for further research. Similarly, research focussed on low vision aids and rehabilitation also emerges as a clear priority for future research, given both the lack of studies identified on this theme and the clear evidence that the majority of glaucoma patients' home lighting is inadequate. Clinicians should be aware of the impacts of illumination on glaucoma patients and how visual function as measured in the clinic may not reflect their real world visual performance, especially at night or under scotopic conditions.

Appendix 1: Search terms

Group 1: Glaucoma terms

(glaucoma OR glaucomatous OR Glaucoma, Open-Angle {MeSH} OR POAG OR glaucomatous optic neuropathy {EMBASE})

AND

Group 2: Lighting terms

(lighting OR light* OR luminescen* OR "Rod-Cone interaction" OR bright* OR dark* OR illumina* OR photopic OR mesopic OR scotopic OR glare OR lumin* OR irradian* OR fluorescen* OR sunlight OR daylight OR incandescen* OR “low level light” OR “bright light” OR shade OR shadow OR Iridescen* OR Candela OR Lux OR Lumen)

Appendix 2: Quality assessment

Table 4. Quality assessment results from quantitative studies (N=53)

Authors	Is the question / objective sufficiently described?	Is the study design evident and appropriate?	Is the method of subject/comparison group selection or source of information/input variables described and appropriate?	Are the Subject (and comparison group, if applicable) characteristics sufficiently described?	If interventional and random allocation was possible, was it described?	If interventional and blinding of investigators was possible, was it reported?	If interventional and blinding of subjects was possible, was it reported?	Are outcome and (if applicable) exposure measure(s) well defined and robust to measurement / misclassification bias? Are means of	Is the sample size appropriate?	Are the analytic methods described/justified and appropriate?	Is some estimate of variance is reported for the main results?	Controlled for confounding?	Are results reported in sufficient detail?	Are conclusions supported by the results?	Overall score
Altangerel et al (2006)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Partial (1)	Yes (2)	Yes (2)	Partial (1)	N/A	Yes (2)	Yes (2)	0.90
Ansari et al (2002)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	1.00
Arvind et al (2011)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.95

Aspinall et al (2005)	Partial (1)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	Yes (2)	Yes (2)	0.90
Aspinall et al (2008)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	N/A	N/A	N/A	Yes (2)	Partial (1)	Yes (2)	Yes (2)	N/A	Yes (2)	Yes (2)	0.90
Bhorade et al (2013)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.95
Bhorade et al (2016)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Partial (1)	Partial (1)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.91
Bierings et al (2018)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Partial (1)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.91
Bierings et al (2018)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	1.00
Bierings et al (2018)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.92
Bierings et al (2019)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.95
Brunnström et al (2004)	Yes (2)	Yes (2)	No (0)	Partial (1)	Yes (2)	N/A	N/A	Partial (1)	Yes (2)	Yes (2)	Yes (2)	No (0)	Yes (2)	Yes (2)	0.75

Carta et al. (1998)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Partial (1)	Partial (1)	Yes (2)	Partial (1)	Partial (1)	Partial (1)	Yes (2)	0.73
Chu et al (2006)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.91
Daruka et al (2018)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	Yes (2)	Yes (2)	1.00
Drum et al (1986)	Yes (2)	Yes (2)	Partial (1)	No (0)	N/A	N/A	N/A	Yes (2)	Yes (2)	Partial (1)	Partial (1)	Yes (2)	Yes (2)	Yes (2)	0.77
Glovinsky et al (1992)	Yes (2)	Yes (2)	Partial (1)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.86
Goldberg et al (2009)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Partial (1)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.95
Hertenstein et al (2016)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Yes (2)	Partial (1)	Partial (1)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.86
Hoeft et al (1981)	Partial (1)	Yes (2)	N/A	Partial (1)	N/A	N/A	N/A	Yes (2)	N/A	N/A	N/A	N/A	Partial (1)	Partial (1)	0.67

Hu et al (2014)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	N/A	N/A	N/A	Yes (2)	N/A	Yes (2)	N/A	N/A	Yes (2)	Yes (2)	0.94
Janz et al (2001)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Partial (1)	Yes (2)	0.88
Janz et al (2009)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	1.00
Jost et al (1990)	Yes (2)	Yes (2)	No (0)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.91
Khadka et al (2016)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.91
Klein et al (2015)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Partial (1)	Yes (2)	0.91
Kulkarni et al (2012)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Partial (1)	Yes (2)	Yes (2)	Partial (1)	N/A	Yes (2)	Yes (2)	0.90
Kumar et al (2019)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	Partial (1)	Yes (2)	0.95

Lahav et al (2011)	Yes (2)	Yes (2)	Partial (1)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.91
Lee et al (1998)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	1.00
Lee et al (2014)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	Partial (1)	Yes (2)	0.90
Lenoble et al (2016)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Partial (1)	Yes (2)	0.86
Lorenzana et al (2009)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Partial (1)	Yes (2)	Yes (2)	Yes (2)	N/A	Partial (1)	Yes (2)	0.90
Mbadugha et al. (2012)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.95
Mogil et al (2017)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Partial (1)	Partial (1)	0.82
Nelson et al. (1999)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	Yes (2)	Yes (2)	0.94
Nelson et al. (2003)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Partial (1)	Yes (2)	Yes (2)	N/A	Yes (2)	Yes (2)	0.95
Onakoya et al (2012)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	1.00

Roux-Sibilon et al (2018)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Partial (1)	0.91
Sencanic et al (2018)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.95
Sherwood et al (1998)	Yes (2)	Yes (2)	No (0)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	No (0)	No (0)	Yes (2)	Yes (2)	0.73
Siah et al (2018)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	1.00
Skalicky et al (2016)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.95
Tam et al (2018)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Partial (1)	Partial (1)	Yes (2)	N/A	Partial (1)	Yes (2)	Yes (2)	0.85
Tatemichi et al (2012)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.95
Turano et al (2002)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.91

Velten et al (2001)	Yes (2)	Yes (2)	Partial (1)	No (0)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	Yes (2)	0.82
Willis & Anderson (2000)	Yes (2)	Yes (2)	Partial (1)	Partial (1)	N/A	N/A	N/A	Yes (2)	Partial (1)	Yes (2)	Yes (2)	Partial (1)	Yes (2)	Yes (2)	0.90
Wolffsohn & Cochrane (1998)	Yes (2)	Yes (2)	N/A	Yes (2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Partial (1)	Yes (2)	0.90
Wren et al (2009)	Yes (2)	Yes (2)	N/A	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	Yes (2)	Yes (2)	1.00
Yonge et al (2017)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Partial (1)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	0.95
Zhou et al (2014)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	N/A	N/A	Yes (2)	Yes (2)	Yes (2)	Yes (2)	N/A	Yes (2)	Yes (2)	1.00
Zuege and Drance (1967)	Yes (2)	Yes (2)	Partial (1)	No (0)	N/A	N/A	N/A	Yes (2)	Partial (1)	Yes (2)	Partial (1)	N/A	Yes (2)	Partial (1)	0.70

Table 5. Quality assessment results from qualitative studies (N=2)

Authors	**Question / objective sufficiently described?**	**Study design evident and appropriate?**	**Context for the study clear?**	**Connection to a theoretical framework / wider body of knowledge?**	**Sampling strategy described, relevant and justified?**	**Data collection methods clearly described and systematic?**	**Data analysis clearly described and systematic?**	**Use of verification procedure(s) to establish credibility?**	**Conclusions supported by the results?**	**Reflexivity of the account?**	**Overall score**
Glen et al. (2015)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	0.95
Green et al. (2002)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	Partial (1)	Partial (1)	Yes (2)	No (0)	Yes (2)	No (0)	0.70

Appendix 3: Data extraction table

Table 6. Data extraction table.

Frequently used abbreviations: CS = Contrast sensitivity; GQL-15 = Glaucoma Quality of life Questionnaire; NEI-VFQ-25 = National Eye Institute Visual Function Questionnaire; PDG - pigment dispersion glaucoma; POAG = primary open angle glaucoma; PXG – pseudoexfoliation glaucoma; QoL = quality of life.

Authors	Study title	Study design	Domain of main outcome	Study objectives	Study population	Key outcome(s) measured	Results
Altangerel et al., 2006	Assessment of Function Related to Vision (AFREV)	Cross-sectional	ADL	To evaluate the relationship of a performance-based measure of visual functioning to clinical and subjective measures in glaucoma patients.	43 participants with POAG, mean (SD) age = 69.1 (14.3).	Scores on a novel performance-based measure, the Assessment of Function Related to Vision (AFREV), standard clinical tests of visual function, and the NEI-VFQ-25.	AFREV total scores were highly correlated with contrast sensitivity, binocular visual acuity, better-eye visual acuity, worse-eye visual acuity, and Estermann visual field efficiency scores as well as with NEI-VFQ scores. The Rasch person-item map demonstrates that of AFREV activities, the “putting stick into holes” and “reading small print” tests require the most visual ability.

Ansari et al., 2002	Psychophysical characterisation of early functional loss in glaucoma and ocular hypertension	Case-control	Psychophysics	To determine relative damage to the magnocellular and parvocellular pathways.	16 participants with early to moderate glaucomatous visual field loss (mean (SD) age: 68.1 (5.1)); 16 healthy controls (mean (SD) age: 61.1 (9)); 16 age-matched patients with ocular hypertension (mean (SD) age: 59.3 (13.5)).	Contrast sensitivity was for the detection of luminance modulated gratings at a range of spatial (0.5, 2, 8 cycles /degree) and temporal (0, 16 Hz) frequency combinations.	Foveally, compared to the normal group, the thresholds for the glaucoma patients were significantly elevated at all spatial and temporal frequencies ($p<0.0001$), but this reduction was not significantly different at any particular spatial or temporal frequency ($p>0.1$). There was no difference in contrast sensitivity between the controls and OHTs ($P > 0.10$). At the periphery, thresholds of the glaucoma patients were elevated compared to the normal controls ($P < 0.01$). The contrast sensitivity in normal and OHT groups was not significantly different ($P > 0.10$).
Arvind et al., 2011	Low-Luminance Contrast Stimulation Is Optimal for Early Detection of Glaucoma Using Multifocal Visual Evoked Potentials	Case-control	Psychophysics	To elucidate the mechanism responsible for the enhanced performance of the blue-on-yellow multifocal visual evoked potential (BonY mfVEP) stimulus in identifying early glaucoma.	30 healthy controls (mean (SD) age = 65.1 (10.1)) and 23 participants with early glaucoma (mean deviation [MD] < 6 dB ; mean (SD) age = 66.8 (7.06)).	Multifocal pattern-onset VEPs were recorded in response to BonY, high-luminance contrast achromatic (HLA) and low-luminance contrast achromatic (LLA) stimulations.	In controls, LLA mfVEPs had significantly lower amplitudes than did BonY and HLA mfVEPs ($P < 0.001$), which were not significantly different from each other. In glaucomatous eyes, all three stimuli demonstrated significantly reduced amplitudes in comparison with those of normal eyes. Although the sensitivities of both BonY and LLA in identifying subjective visual field defects were similarly high (93% and 89.7%, respectively), HLA showed only a 79.3% detection rate. BonY and LLA demonstrated significantly higher defect severity scores than did HLA ($P < 0.05$ for both). Specificities for BonY and LLA were similar (96%).

Aspinall et al., 2005	Quality of Life in Patients with Glaucoma: A Conjoint Analysis Approach	Cross-sectional	Quality of life	To assess the perceived importance of visual field loss on vision-related QoL for a group of patients with glaucoma.	108 participants with glaucoma (mean (SD) age = 69.0 (8.7)).	Results on a battery of tests including clinical assessment, visual function measures, and QoL questionnaires (including choice-based conjoint analysis).	While problems with 'darkness or glare' were the most frequently reported complaints suffered by the group of subjects, their relative importance was much less than that assigned to the other attributes. Additionally, there was evidence of an increased priority for problems with glare as contrast sensitivity decreased.

Aspinall et al., 2008	Evaluation of Quality of Life and Priorities of Patients with Glaucoma	Cross-sectional	Quality of life	To investigate the quality of life and priorities of patients with glaucoma.	72 glaucoma patients. Mean (SD) age = 71.8 (11.0). 57% of patients had mild VF loss, 28% moderate VF loss and 15% severe VF loss.	Correlation between EuroQuol (EQ-5D), time tradeoff (TTO), and choice-based conjoint analysis.	The conjoint utilities showed that the two main priorities were “reading and seeing detail” and “outdoor mobility.” A principal component analysis revealed relatively independent components (i.e., low correlations) between the three different methodologies for assessing quality of life.

Bhorade et al., 2013	Differences in vision between clinic and home and the effect of lighting in older adults with and without glaucoma.	Case-control	Functional vision	The purpose of this report was to 1) compare vision between clinic and home and 2) evaluate factors, including lighting, associated with differences in vision between clinic and home in older adults with mild, moderate, and advanced glaucoma and no ocular disease.	126 glaucoma patients (mean (SD) age = 72.5 (7.7)) and 49 controls with no glaucoma (mean (SD) age = 70.7 (8.2)).	Participants underwent a clinic and home visit randomized to order of completion. At each visit, masked and certified examiners measured binocular distance visual acuity (DVA) with a non-backlit chart, near visual acuity (NVA), contrast sensitivity (CS), CS with glare, and lighting. Main outcome measure was the difference in vision between clinic and home.	Mean scores for all vision tests were significantly better in the clinic than home for glaucoma and non-glaucoma patients (P <0.05). For the entire sample, 21% of participants read ≥2 lines better in clinic than home for NVA and 49% read ≥2 triplets better in clinic for CS with glare. Lighting was the most significant factor associated with differences in vision between clinic and home for DVA, NVA, and CS with glare testing (p<0.05 multiple regression model). Median home lighting was 4.3 times and 2.8 times lower than clinic lighting in areas tested for DVA and NVA, respectively. Home lighting was below that recommended for ≥ 85% of participants.
Bhorade et al., 2016	On-road Driving Performance of Patients With Bilateral Moderate and Advanced Glaucoma	Case-control	ADL	To compare on-road driving performance of patients with moderate or advanced glaucoma to controls and evaluate factors associated with unsafe driving.	21 patients with bilateral moderate or advanced glaucoma (mean (SD) age = 71.5 (8.5)); 38 controls (mean (SD) age = 70.2 (8.4)).	Participants underwent a clinical evaluation and an on-road driving evaluation. Overall driving performance of pass vs. marginal/fail, and number of wheel and/or brake	52% of glaucoma participants scored a marginal/fail compared to 21% of controls. Glaucoma participants had a higher risk of wheel interventions than controls. There were no differences detected between glaucoma participants who scored a pass vs. marginal/fail for visual field mean deviation of the better or worse eye, binocular distance or near visual acuity, contrast sensitivity or glare.

						interventions, were recorded.	
Bierings et al., 2018	Visual complaints of patients with glaucoma and controls under optimal and extreme luminance conditions	Case-control	Functional vision	To determine (i) whether, compared to controls, visual complaints of glaucoma patients are more pronounced under extreme luminance conditions than in the optimal luminance conditions and (ii) whether complaints belonging to different extreme luminance conditions are associated.	178 people with glaucoma (mean (SD) age = 72.2 (10.0)), 182 controls (mean (SD) age = 65.7 (10.8)). Glaucoma participants with POAG, PXG or PDG were eligible.	Visual performance for daily activities under five different luminance conditions (optimal; low; high; sudden luminance decrease; sudden luminance increase)	Percentages of patients and controls with visual complaints were 4 versus 0% (P = 0.02) for optimal luminance and 48 versus 6% (P < 0.001), 22 versus 1% (P < 0.001), 32 versus 1% (P < 0.001) and 25 versus 3% (P < 0.001) for low, high, sudden decrease and sudden increase in luminance.
Bierings et al., 2018	Visual Performanc e as a Function of Luminance in Glaucoma: The De Vries-Rose, Weber's, and Ferry-	Case-control	Psychoph ysics	To determine whether the De Vries-Rose, Weber's, and Ferry-Porter's law, which describe visual performance as a function of luminance, also	19 participants with glaucoma (median (IQR) age = 71 (64-73)), 45 controls (median (IQR) age = 54 (47-65)).	Foveal and peripheral CS, and foveal and peripheral critical fusion frequency (CFF) as a function of luminance (0.02 to 200 cd/m2).	Foveally, glaucoma patients had a 0.4 log unit lower logCS than controls (P < 0.001), independent of luminance. Peripherally, the difference was more pronounced at lower luminances (P = 0.007). Glaucoma patients had a lower CFF compared with controls (P < 0.001).

	Porter's Law			apply to patients with glaucoma.			
Bierings et al., 2018	Foveal light and dark adaptation in patients with glaucoma and healthy subjects: A case-control study	Case-control	Psychophysics	To determine whether foveal light and dark adaptation are affected in glaucoma.	23 participants with glaucoma (median (IQR) age = 69 (61-73)) and two different groups of controls. 51 controls for 5 log unit step condition (median (IQR) age = 57 (49-65)) and 52 controls for 6.5 log unit step condition (median (IQR) age = 58 (49-66)).	Light and dark adaptation were measured twice. After 10 minutes pre-adaptation to 0.0032 cd/m2, the background luminance increased stepwise to 320 (5 log unit step) or 10,000 cd/m2 (6.5 log unit step) for 10 minutes, then it decreased back to 0.0032 cd/m2 for 30 minutes. Foveal contrast sensitivity [CS]) as a function of time was determined.	After light adaptation to 320 and 10,000 cd/m2, glaucoma patients had a 0.22 ($P < 0.001$) and 0.13 ($P = 0.010$) log unit lower CS plateau than controls, respectively. After dark adaptation, this difference was 0.21 ($P = 0.018$) and 0.30 ($P<0.001$) log unit, respectively. Light adaptation occurred too fast to determine an accurate light adaptation time. Dark adaptation times of glaucoma patients and controls were similar, for both the 5 (7.2 versus 5.5 minutes; $P = 0.10$) and the 6.5 (18.2 versus 16.6 minutes; $P = 0.14$) log unit step conditions.

Bierings et al., 2019	Spatial contrast sensitivity from star- to sunlight in healthy subjects and patients with glaucoma	Case-control	Psychophysics	The aims of this study were (i) to determine whether Weber's law also holds under extremely high luminance conditions and how this depends on spatial frequency, and (ii) to compare CS as a function of spatial frequency and luminance between glaucoma patients and healthy subjects.	22 people with glaucoma (median (IQR) age = 68 (60-73)), 51 controls (median (IQR) age = 58 (49-66)).	Monocular contrast sensitivity (CS) at 1, 3, and 10 cycles per degree (cpd); mean luminance ranged from 0.0085 to 8500 cd/m2. Authors analysed the effect of glaucoma, luminance, and spatial frequency on logCS.	The logCS versus log luminance curves did not differ grossly between patients and controls (P=0.14; typically 0–0.2 log units); the difference became larger with decreasing luminance (P=0.003) but did not depend clearly on spatial frequency (P=0.27).
Brunnström et al., 2004	Quality of light and quality of life–the effect of lighting adaptation among people with low vision	Randomised controlled trial	ADL	The study has investigated the effect of lighting on the daily activities (ADL) of the visually impaired in their homes by comparison before and after light adjustments were made in the kitchen, hall and bathroom. It has also investigated the additional	46 test subjects who were visually impaired (VA ≤ 0.3) and were from five diagnostic groups: macular degeneration, dry form (n = 12), macular degeneration, wet form (n = 16), retinitis pigmentosa (n = 2), glaucoma (n= 5), other diagnoses (n =11).	Lighting standards and psychosocial factors were charted. Participants were randomly divided into two groups, an intervention and a comparison group. Follow-up interviews to determine ADL and quality of life were performed 6 months after lighting adaptation.	A marked effect on quality of life of the lighting in the living room was found for the intervention group. The effect on ADL of the basic lighting adaptation in kitchen, hall and bathroom for both groups was significant for tasks carried out on the working surface in the kitchen. Other activities in the kitchen and in the bathroom tended to improve but changes were not significant.

				effects on the quality of life after providing task lighting in the living room.			
Carta et al., 1998	Self-assessment of the quality of vision: association of questionnaire score with objective clinical tests	Cross-sectional	Functional vision	To investigate the association of a quality of life visual function questionnaire with an objective clinical test of visual function.	120 participants with different eye diseases (33 with POAG). Mean (SD) age overall was 65.8 (10.1), and mean (SD) age for POAG participants was 65.4 (11.3).	Questionnaire scores, and their association with results of psychophysical tests commonly used in clinical practice to assess visual function.	The total questionnaire score was significantly associated with the results of all visual function tests with the exception of glare.
Chu et al., 2006	Glaucoma Detection Is Facilitated by Luminance Modulation of the Global Flash Multifocal Electroretinogram	Case-control	Psychophysics	To investigate the variation of retinal electrophysiological function in glaucoma by using the global flash multifocal electroretinogram (mfERG) stimulation with altered differences in the stimulus luminance of the multifocal flashes, in an attempt to alter the levels of	30 healthy participants (mean (SD) age = 36.9 (12.2)); 30 POAG participants (mean (SD) age = 39.4 (11.5)).	The mfERG was assessed with a visual stimulus in steps of four video frames, which consisted of 103 scaled hexagonal elements followed by a dark frame, global flash, and dark frame. The localized luminance difference was set at 96%, 65%, 49%, or 29% stimulus contrast.	This stimulus induces complex local first-order responses with an early direct component (DC) and a later induced component (IC). An “adaptive index” was calculated from the luminance-difference dependence of the peripheral DC, and it showed a sensitivity of 93%, with a specificity of 95% for differentiating normal from glaucomatous eyes, and also had a significant correlation (r = 0.58) with the glaucomatous visual field defect.

				inner retinal contributions.			
Daruka et al., 2018	Correlation of central field index (10-2 visual field analysis) and activity limitation with increasing severity of glaucoma using glaucoma activity limitation-9 questionnaire.	Cross-sectional	Quality of life	To investigate the relationship between vision-related QoL, as measured by the GAL-9 questionnaire, and the central field index (CFI) in patients with advanced glaucoma.	50 glaucoma patients (mean (SD) age = 63.54 (12.35)).	Correlation between the CFI and the GAL-9 scores.	There was a moderate correlation between CFI of better eye (r = −0.431, confidence interval “CI” −0.619 to −0.173, P < 0.002) and worse eye (r = −0.342, CI: −0.575 to − 0.058, P < 0.015) with GAL-9, the better eye showing a stronger correlation. Subscales of GAL-9 questionnaire also correlated with better eye status. “Finding dropped objects” had the strongest correlation to CFI of better eye (r = −0.676) and “adjusting to dim lights” had the weakest correlation (r = −0.052).
Derby et al., 1929	The light sense in early glaucoma: the smallest difference in brightness perceptible to the light adapted eye (light difference).	Case-control	Psychophysics	To investigate the ability of the eye to detect a difference in the degree of brightness to discover if this might be significant as a diagnostic sign in early glaucoma.	89 participants with suspected glaucoma; 29 controls; 38 participants with established glaucoma. All in the age range 50-70 years.	Dark adaptation readings among people with glaucoma and healthy controls.	The smallest perceptible increase in brightness was 2 per cent for clinical group 1 (healthy eyes, no sign of glaucoma), 2.8% for group 2, 3% for group 3, 3.5% for group 4, 6.1% for group 5 and 6.5% for group 6 (advanced glaucoma). There was wide variation in readings of light difference percentages in each clinical group and much overlapping between the groups.

Drum et al., 1986	Scotopic Sensitivity Loss in Glaucoma	Case-control	Psychophysics	To compare measurements of photopic and scotopic sensitivity for patients with open angle glaucoma, patients suspected of having glaucoma and normal control subjects at six selected positions in the nasal visual field.	31 healthy control participants (10 under 40, 15 in 40-60 range, 6 over 60); 39 participants with suspected glaucoma (6 under 40, 22 in 40-60 range, 11 over 60); 39 participants with confirmed open angle glaucoma (6 under 40, 17 in 40-60 range, 16 over 60).	Photopic and scotopic thresholds at three eccentricities (5◦, 10◦ and 15◦).	Both photopic and scotopic thresholds were elevated significantly for both the suspect and glaucoma groups. The average photopic and scotopic threshold elevations were the same for the suspect group, but scotopic threshold elevations were substantially greater than photopic threshold elevations for the glaucoma group.
Glen et al., 2015	Living with glaucoma: a qualitative study of functional implications and patients' coping behaviours	Qualitative	Qualitative	This study aimed to identify different strategies used by patients with glaucoma to cope with vision loss during everyday activities.	16 participants living with glaucoma (median (IQR) age = 71 (68 – 77)).	Different strategies used by patients with glaucoma to cope with vision loss during everyday activities.	In order to maintain independence, some patients increased confidence by making practical changes such as adjusting lighting, using handrails and magnifying glasses, or actively changed aspects of their behaviour such as moving their head and eyes towards known areas of vision loss.
Glovinsky et al., 1992	A Whole-Field Scotopic Retinal Sensitivity Test for the Detection of Early	Case-control	Psychophysics	Evaluate a new psychophysical test that utilises a whole-field light stimulus under dark-adapted conditions.	35 healthy participants; 21 participants with glaucoma; 77 glaucoma-suspect participants. All were over 35.	Four retinal sensitivity measurements - one absolute retinal sensitivity (ARS) and three incremental retinal sensitivities.	Glaucomatous eyes were discriminated from normal with a diagnostic power of 0.91 as judged by receiver operating characteristic analysis, and specificity and sensitivity were 91% and 86%, respectively. Glaucoma suspects with an abnormal response to the whole-field scotopic test were more likely to have other signs indicating early optic nerve injury.

	Glaucoma Damage						
Goldberg et al., 2009	Assessing quality of life in patients with glaucoma using the Glaucoma Quality of Life-15 (GQL-15) questionnaire.	Case-control	Quality of life	To measure and compare quality of life in patients with and without glaucoma using the Glaucoma Quality of Life-15 Questionnaire, and to determine the association between glaucoma-related quality of life and clinical indices of glaucoma.	121 participants with glaucoma (mean (SD) age = 70 (9.1)) and 31 control participants (mean (SD) age = 63 (8.9)). Of the glaucomatous participants, 49 had mild, 34 moderate, and 38 severe glaucoma.	GQL-15 scores, and the relationship between the likelihood of reporting vision-related dysfunction and glaucoma severity.	Patients with glaucoma had significantly poorer glaucoma-related quality of life than controls ($P<0.001$). Summary scores differed significantly among patients with mild, moderate, and severe glaucoma demonstrating a trend of poorer quality of life with increasing disease severity. Activities involving glare and dark adaptation were most problematic for all, but patients with glaucoma felt significantly more compromised in central and near vision, peripheral vision, and outdoor mobility (all $P < 0.001$).
Green et al., 2002	Learning to live with glaucoma: a qualitative study of diagnosis and the impact of sight loss	Qualitative	Qualitative	To identify triggers to self-referral for glaucoma symptoms in a UK sample from Britain, and to explore the meaning of symptoms for people living with moderate to severe glaucoma.	28 participants with moderate or severe open-angle glaucoma.	Different kinds of experiences discussed, including lighting and glare.	Participants reported low levels of awareness of glaucoma prior to their diagnosis, and had assumed that symptoms were the 'normal' deterioration of eyesight expected with other morbidity or advancing age. Participants reflected on problems with light and seeing 'halos' around lights as one of the possible early symptoms.

Hertenstein et al., 2016	Marked dissociation of photopic and mesopic contrast sensitivity even in normal observers	Case-control	Psychophysics	To investigate if photopic CS can act as a surrogate measure for mesopic CS, potentially for screening purposes.	47 healthy controls, 23 participants with glaucoma, and 3 participants with cataract. No age means were reported. Age ranges were: Controls 20–61, glaucoma 37–80, cataract 63–76.	Photopic contrast sensitivity, assessed with both the Freiburg Acuity and Contrast Test (FrACT) and the Mars Letter Contrast Sensitivity Charts. Mesopic contrast sensitivity, without and with glare, was measured with the Mesoptometer IIb.	While mesopic and photopic contrast sensitivities correlate significantly ($r = 0.51$, $P < 0.01$), only 27 % of the variance is in common. In particular, subjects with high photopic results may be nearly as likely to have low as well as high mesopic results.
Hoeft et al., 1981	A comparative study of low-vision patients: Their ocular disease and preference for one specific series of light transmission filters	Descriptive case series	Functional vision	Find out eye disease patients' preferences for light filters.	100 low vision patients with sensitivity to light, of whom 13 had glaucoma. The 100 patients ranged from 18 to 80 years, with majority in 42-61 range. No means, or age data for the glaucoma group.	Filter preference out of 5 filters.	More than 85% of glaucoma patients chose the two filters with the greatest light transmission.

Hu et al., 2014	What Do Patients With Glaucoma See? Visual Symptoms Reported by Patients With Glaucoma	Cross-sectional	Functional vision	To improve understanding of how glaucoma affects vision from the patients' point of view by asking specific detailed questions about how they see. A secondary objective of the study was to correlate severity of VF loss with visual symptoms reported.	99 glaucoma patients. 47 with early glaucoma (mean (SD) age = 67 (13)); 26 with moderate glaucoma (mean (SD) age = 76 (13); 14 with advanced glaucoma (mean (SD) age = 68 (10)); 7 with severe glaucoma 78 (14); 5 with end-stage glaucoma (mean (SD) age = 81 (13)). 67% with POAG.	Most common visual symptoms reported by all patients, and any association between glaucoma severity and visual symptoms reported.	The most common symptoms reported by all patients, including patients with early or moderate glaucoma, were needing more light and blurry vision. Patients with a greater amount of field loss (Octopus mean defect .+9.4 dB) were more likely to report difficulty seeing objects to one or both sides, as if looking through dirty glasses and trouble differentiating boundaries and colours.

Janz et al., 2001	Quality of life in newly diagnosed glaucoma patients: The Collaborative Initial Glaucoma Treatment Study	Cross-sectional	Quality of life	To describe the QoL measurement approach of the Collaborative Initial Glaucoma Treatment Study, instruments included, and the CIGTS participants' QoL findings at the time of diagnosis.	607 patients with glaucoma. 147 (24.2%) in the 29–49 age range, 269 (44.3%) in the 50–64 age range, and 191 (32.5%) in the 65–75 age range.	Quality of life, incorporating both disease-specific and generic measures.	The correlations between QoL measures and clinical outcomes were in the expected direction, but relatively weak. At initial diagnosis, difficulty with bright lights and with light and dark adaptation were the most frequently reported symptoms related to visual function, whereas visual distortion was the most bothersome.

Janz et al., 2009	Evaluating Clinical Change and Visual Function Concerns in Drivers and Nondrivers with Glaucoma	Longitudinal	ADL	To compare drivers and nondrivers, and to describe the specific concerns of drivers, among individuals with glaucoma.	471 drivers and 84 nondrivers, all with glaucoma. Age ranges: 25–49: Drivers 119 (25.3%), non-drivers 12 (14.3%) 50–64: Drivers 198 (42.0%), non-drivers 42 (50.0%) 65–74: Drivers 149 (31.6%), non-drivers 28 (33.3%)	Driving status (drivers versus non-drivers) and patient-reported visual function, as determined by the Visual Activities Questionnaire and the National Eye Institute Visual Function Questionnaire.	More than 50% of drivers reported at least “some” difficulty performing tasks involving glare, whereas 22% reported at least “some” difficulty with tasks requiring peripheral vision. At 54 months, drivers with moderate/severe bilateral visual field loss (VFL) reported greater difficulty with night driving and tasks involving visual search and visual processing speed than drivers with less bilateral VFL (all $P < 0.05$).

Jonas et al., 1990	Dark adaptation in glaucomatous and nonglaucomatous optic nerve atrophy	Case-control	Psychophysics	To evaluate dark adaptation in healthy participants and patients with optic nerve damage, and compare for differences between the groups.	14 healthy control participants (mean (SD) age = 37.7 (19.6)); 19 patients with POAG (mean (SD) age = 57.4 (14.4)); 4 patients with non-glaucomatous descending optic nerve atrophy (mean (SD) age = 32.7 (11.4)).	Dark adaptation threshold, evaluated for each eye separately.	In the healthy participants, light thresholds and time of the shoulder in the dark adaptation curve increased significantly with age. In eyes with glaucomatous or nonglaucomatous optic nerve damage light sensitivity was lower than in normal eyes of age-matched control groups.
Khadka et al., 2016	Item Banking Enables Stand-Alone Measurement of Driving Ability	Cross-sectional	ADL	To explore whether large item sets, as used in item banking, enable important latent traits, such as driving, to form stand-alone measures.	293 participants with glaucoma. Median age = 71 (range = 21-93 years). 54.5% of participants had POAG. Other included glaucoma types were angle closure glaucoma; PXF and normal-tension glaucoma.	The 88-item activity limitation (AL) domain of the glaucoma module of the Eye-tem Bank was interviewer administered to patients with glaucoma.	These findings indicate that driving items in the AL domain of the glaucoma module were perceived and responded to differently from the other AL items, but the reading and luminance items were not. Therefore, item banking enables stand-alone measurement of driving ability in glaucoma.

Klein et al., 2015	The Effect of Cataract on Early Stage Glaucoma Detection Using Spatial and Temporal Contrast Sensitivity Tests	Case-control	Psychophysics	To investigate the effect of cataract on the ability of spatial and temporal contrast sensitivity tests used to detect early glaucoma.	27 glaucoma participants with early cataract (mean (SD) age = 60 (10.2)) which constituted the test group were recruited together with 27 controls (cataract only) (mean (SD) age = 59.03 (9.0)).	Contrast sensitivity to flickering gratings at 20 Hz and stationary gratings with and without glare, were measured for 0.5, 1.5 and 3 cycles per degree (cpd) in central vision. Perimetry and structural measurements with the Heidelberg Retinal Tomograph (HRT) were also performed.	After considering the effect of cataract, contrast sensitivity to stationary gratings was reduced in the test group compared with controls with a statistically significant mean difference of 0.2 log units independent of spatial frequency. A significant correlation was found between the reduction of contrast sensitivity caused by glare and the Glaucoma Probability Score (GPS) as measured with the HRT (P <0.005).
Kulkarni et al., 2012	Visual Field Staging Systems in Glaucoma and the Activities of Daily Living	Cross-sectional	ADL	To compare 8 clinically relevant methods of staging visual field (VF) damage in glaucoma with a performance-based measure of the activities of daily living and self-reported quality of life.	192 glaucoma patients, mean (SD) age = 67.1 (12.9). 140 (72.9%) of the sample had POAG.	Results from visual field tests, ADREV scores and NEI-VFQ-25 scores.	ADREV scores and NEI-VFQ-25 scores were associated most closely with the VF score in the better eye and the binocular VF scoring systems.
Kumar et al., 2019	The impact of primary open-angle glaucoma: Comparison of vision-	Cross-sectional	Quality of life	To compare a general vision-specific patient-reported outcomes (PRO) instrument,	140 participants with POAG. 49 with mild POAG (mean (SD) age = 60.15 (7.45)), 55 with	This study was designed to compare two disease-specific instruments (GQL-15 and	There was a statistically significant difference between patients with mild, moderate, and severe POAG with all instruments (P ≤ 0.001). The instruments correlated well across several parameters especially the peripheral vision and

	specific (National Eye Institute Visual Function Questionnaire-25) and disease-specific (Glaucoma Quality of Life-15 and Viswanathan 10) patient-reported outcome (PRO) instruments.			National Eye Institute Visual Function Questionnaire-25 (NEIVFQ-25) with two disease-specific PRO instruments, Glaucoma Quality of Life-15 (GQL-15), and Viswanathan 10 in patients with varying severity of primary open angle glaucoma (POAG)	moderate POAG (mean (SD) age = 62.65 (8.13)), 36 with severe POAG (mean (SD) age = 62.53 (6.12)).	Viswanathan 10) with one vision-specific instrument (NEIVFQ-25) for QoL assessment in Indian POAG patients.	glare/dark adaptation. The disease-specific scales however are simpler and faster to administer.
Lahav et al., 2011	Reduced Mesopic and Photopic Foveal Contrast Sensitivity in Glaucoma	Case-control	Psychophysics	To demonstrate differences in foveal constrast sensitivity (CS) between glaucomatous and nonglaucomatous eyes using a simple, rapid computerized test.	27 participants with glaucoma (mean (SD) age = 64.4 (9.9)) and 23 control participants (mean (SD) age = 62.6 (10.6)).	Contrast sensitivity (CS), examined by means of 2 computerized psychophysical tests. The tests were conducted under photopic and mesopic conditions.	Significantly lower foveal CS was found in glaucomatous eyes under photopic and mesopic conditions for all spatial frequencies ($P < .01$). All transient photopic and mesopic CSs were significantly correlated with cup to disc ratio ($P < .05$). The static photopic spatial frequency of 6 cycles per degree was significantly correlated with the severity of the glaucomatous damage.
Lee et al., 1998	The Glaucoma Symptom	Case-control	Quality of life	To develop a brief symptom survey specific for	147 participants with glaucoma among a broad range of	A modified version of the Ocular Hypertension	The GSS has 2 underlying domains that demonstrate sufficient internal consistency reliability for between-group comparisons. The

	Scale: A Brief Index of Glaucoma-Specific Symptoms			persons with glaucoma, the Glaucoma Symptom Scale.	treatment categories and 44 controls. Average age of glaucoma patients was 64 years and average age of controls was 49 years.	Treatment Study 10-item symptom checklist. Participants also completed 2 vision-specific measures, the NEI-VFQ and the VF-14.	GSS discriminates well between persons with and without glaucoma. 120 of the glaucomatous participants (82%) reported problems seeing in the dark, versus 14 (32%) participants in the control group.
Lee et al., 2014	The association between clinical parameters and glaucoma-specific quality of life in Chinese primary open-angle glaucoma patients.	Cross-sectional	Quality of life	To investigate the correlations between clinical parameters and glaucoma-specific QoL in Chinese patients with bilateral POAG.	51 POAG patients, with varying degrees of glaucoma severity. Mean (SD) age = 65.8 (12.1) years.	Scores on a Chinese translation of the Glaucoma Quality of Life–15 questionnaire, and clinical parameters (e.g. visual field, best-corrected visual acuity, IOP, RNFL thickness, and the number of topical anti-glaucoma medications being used.	There was a significant correlation and linear relationship between a poorer Glaucoma Quality of Life–15 score and a lower visual field index ($r = 0.3$, $r^2 = 0.1$, $P = 0.01$) and visual acuity ($r = 0.3$, $r^2 = 0.1$, $P = 0.03$). The three most problematic activities affecting quality of life were “adjusting to bright lights”, “going from a light to a dark room or vice versa”, and “seeing at night”.
Lenoble et al., 2016	Visual object categorisation in people with glaucoma	Case-control	Functional vision	To determine whether glaucoma affects the ability to categorise briefly presented visual objects in central vision.	14 people with glaucoma (POAG and pre-perimetric), mean (SD) age = 68 (7); and 15 age-matched controls, mean (SD) age = 66 (5).	Visual categorisation performance, assessing both accuracy and response times.	On average, accuracy was significantly decreased by 7% (P =0.046) for the medium contrast stimuli in patients with glaucoma compared with controls. Group average response times were significantly slower for the patients relative to the control group. Performance was equivalent in the two groups when the picture contrast was 100%.

Lorenzana et al., 2009	A New Method of Assessing Ability to Perform Activities of Daily Living: Design, Methods and Baseline Data	Cross-sectional	ADL	To determine the relationship between ADREV (Assessment of Disability Related to Vision) evaluations and both clinical and subjective measures in glaucoma patients.	194 glaucoma patients, mean (SD) age = 67.1 (12.9). 140 (72.2%) of the sample had POAG.	Performance on the ADREV, which includes nine tasks to simulate daily living activities, and scores on the NEI-VFQ-25.	While ADREV score ranges from 0 (total disability) to 63 (no disability), total ADREV score ranged from 3.0 to 61.7. Total NEI VFQ-25 score ranged from 17.8 (low score indicates incapable) to 100 (high score indicates not hindered).
Mbadugha et al., 2012	A comparison of the NEI-VFQ-25 and GQL-15 questionnaires in Nigerian glaucoma patients.	Case-control	Quality of life	To compare two vision-specific QoL instruments – the disease-specific 15-item Glaucoma Quality of Life questionnaire (GQL-15) and the non glaucoma-specific 25-item National Eye Institute Visual Function Questionnaire (NEI-VFQ-25).	132 glaucoma participants and 132 controls. Mean age was 52.81 for participants with mild glaucoma (N= 44), 59.11 for participants with moderate glaucoma (N = 44) and 62.67 for participants with severe glaucoma (N = 44).	The range, mean, median, and standard deviation of QoL scores for the two questionnaires were calculated and compared for the subgroups of participants. Spearman's rank correlation coefficients were used to assess the correlation between the GQL-15 and the NEI-VFQ-25.	Patients had the greatest difficulty with activities affected by glare and dark adaptation in the GQL-15. Driving and general vision were the factors most affected in the NEI-VFQ-25. The Spearman rho values showed strong correlations (rho: 0.55) between the NEI-VFQ-25 and GQL-15 QoL scores for the total number of participants (rho: −0.75), total number of cases (rho: −0.83), and the mild (rho: -0.76), moderate (rho: −0.75), and severe (rho: −0.84) cases.

Mogil et al., 2017	Glaucoma Patient–Reported Concerns and Associated Factors	Cross-sectional	Quality of life	To assess the character and degree of concerns of glaucoma patients and identify demographic/clinical factors affecting the concerns.	152 participants with glaucoma (mean (SD) age = 69 (14)). 97 participants with POAG, 18 with exfoliation glaucoma, 4 with pigmentary glaucoma, and 33 with chronic angle-closure glaucoma.	Severity of concerns, scored with a scale of 0–5 (in order of increasing severity).	Severity of concern was greatest for general eyesight (2.92/5.00) and visual symptoms (2.78/5.00), followed by activities (2.20/5.00) and socioeconomic factors (2.13/5.00), and then ocular symptoms (1.69/5.00) (P < .001). The most common concerns within each domain were blurry vision (32%), reading small print (34%), medical costs (26%), and dryness (32%).
Nelson et al., 1999	Patients' perception of visual impairment in glaucoma: a pilot study	Cross-sectional	Quality of life	To identify the most commonly perceived disabilities in the daily life of glaucoma patients by means of a questionnaire, to rank the perceived problems with regard to frequency, to group related visual problems and assess their impact on daily life activities, and to examine the relation between perceived visual difficulties and the	63 glaucoma patients (mean (SD) age = 70 (14) years). 80% of participants had POAG, while the remaining 20% had other chronic types of glaucoma such as normal-tension, chronic angle-closure or pseudoexfoliative glaucoma.	The relationship between a measure of the severity of visual field loss and subjective visual disability.	The most frequently reported problems were grouped into the following four categories: outdoor mobility, glare and lighting conditions and activities demanding functional peripheral vision, household tasks, and personal care. These four factors accounted for 72% of the variability in the patients' questionnaire responses. With increasing severity of binocular visual field loss there was an increase in the number of self-reported visual problems.

				severity of visual field loss.			
Nelson et al., 2003	Quality of Life in Glaucoma and Its Relationship with Visual Function	Case-control	Quality of life	(a) To explore patients' self-reported visual disability resulting from glaucoma by means of a questionnaire; (b) To identify activities strongly associated with a measure of visual field loss, (c) to quantify different psychophysical aspects of visual function; (d) to assess the relationship between objective measures of visual function	47 glaucoma patients and 19 controls. Mean (SD) age = 67.72 (7.45) for the 18 patients with mild VF loss; 67.21 (7.61) for the 19 patients with moderate VF loss; 71.70 (6.97) for the 10 patients with severe VF loss; and 66.50 (4.35) for the controls.	Questionnaire responses (vision-related quality of life, general health and psychosocial variables), visual acuity, visual fields, Esterman binocular disability scores, contrast sensitivity, critical flicker frequency, colour vision, dark adaptation, glare disability (brightness acuity), and stereoacuity scores were measured.	Fifteen of the 50 questions were noted to have a strong significant relationship with a measure of visual field loss and were included in a new questionnaire scale, the Glaucoma Quality of Life – 15 (GQL-15). A significant relationship was found between the questionnaire summary performance measure and psychophysical tests: Pelli-Robson contrast sensitivity ($r = -0.45$, $P < 0.001$), glare disability ($r = -0.41$, $P < 0.001$), Esterman binocular visual field test ($r = -0.39$, $P < 0.001$), dark adaptation ($r = 0.34$, $P = 0.007$), and stereopsis ($r = 0.26$, $P = 0.04$).

				and patients' perception of their vision-related QoL.			
Onakoya et al., 2012	Quality of Life of Primary Open Angle Glaucoma Patients in Lagos, Nigeria: Clinical and Sociodemographic Correlates	Case-control	Quality of life	To evaluate the QoL of POAG patients attending a tertiary eye institution in Lagos, Nigeria and identify clinical and sociodemographic factors affecting it.	132 glaucoma cases and 132 controls. Mean (SD) age was 58.58 (10.5 for glaucoma participants, and 58.61 (10.56) for controls.	QoL, as measured by the NEI-VFQ-25 and the GQL-15. Also clinical and sociodemographic variables (e.g. colour vision, age etc).	Early or mild glaucoma was associated with reduced QoL compared with the controls. Glaucoma patients had the greatest difficulty with glare and dark adaptation subscale of the GQL-15. Increasing severity of disease defined by increasing visual field deficit (mean deviation values) correlated significantly with worsening QoL [Spearman r (r) values ranging from 0.32 to 0.43]. Contrast sensitivity correlated moderately with QoL (r ranges from 0.43 to 0.47; P=0.001). Age had a negative impact on QoL (r= 0.30 for the NEIVFQ25 and 0.30 for the GQL-15) and affected all the subscales of the GQL-15 and most subscales of the NEI-VFQ-25.

Roux-Sibilon et al., 2018	Scene and human face recognition in the central vision of patients with glaucoma	Case-control	Functional vision	To assess visual abilities of scene and human face recognition in the central vision of POAG patients.	22 participants with POAG. POAG participants were subdivided into those with a central vision defect (mean (SD) age = 67.9 (10)) and those with no central defect (mean (SD) age = 67.1 (9)). 25 controls (mean (SD) age = 68.0 (6)).	Performance on two different tasks where low-contrast stimuli were presented in the central 6º of the visual field. A categorization task of scene images and human face images assessed high-level visual recognition abilities. In contrast, a detection task using the same stimuli assessed low-level visual function.	Compared to controls, patients with a central visual defect showed a deficit in both detection and categorization of all low-contrast images. However, the deficit was greater for categorization than detection. Patients without a central defect showed similar performances to the controls concerning the detection and categorization of faces. However, while the detection of scene images was well-maintained, these patients showed a deficit in scene categorization.
Sencanic et al., 2018	Validation of the Glaucoma Quality of Life-15 Questionnaire in Serbian language	Cross-sectional	Quality of life	To translate the GQL-15 into Serbian, and assess its validity and reliability in the population of Serbian patients.	177 glaucoma patients (mean (SD) age = 62.83 (13.60)). 101 had mild glaucoma, 38 had moderate glaucoma and 38 had severe glaucoma.	All patients filled out the GQL-15 and NEI-VFQ-25. The psychometric properties of the translated GQL-15 were assessed by using classical test theory and Rasch analysis.	The mean total score for the GQL-15 was 20.68±7.31. The GQL-15 effectively discriminated advanced from mild and moderate glaucoma. Of the 4 domains, the glare and dark adaptation subscale showed the worse score, with no significant difference between mild and moderate glaucoma stages, but with advanced glaucoma participants showing significantly worse scores.

Sherwood et al., 1998	Glaucoma's Impact on Quality of Life and Its Relation to Clinical Indicators	Case-control	Quality of life	To compare QoL of patients with glaucoma and control subjects, and to determine the relationships between QoL and demographic and clinical variables in patients with glaucoma.	54 healthy participants (mean (SD) age = 62 (11.1)); 56 participants with glaucoma (mean (SD) age = 65.4 (10.5)). An additional 12 glaucoma participants were later included to examine relationships between glaucoma, therapy and QoL.	The Medical Outcomes Study (MOS) scores, Activities of Daily Vision Scale (ADVS) scores, visual acuity, visual fields, and demographic variables were measured.	Patients scored significantly lower than did the control subjects in all MOS-20 categories except pain. In patients, current medications and previous surgeries correlated with ADVS subscales night vision, near vision, and glare; visual acuity and fields correlated with MOS subscales physical, role and health, and all ADVS subscales.
Siah et al., 2018	Macular pigment is associated with glare-affected visual function and central visual field loss in glaucoma	Cross-sectional	Psychophysics	To evaluate the relationship between macular pigment optical density (MPOD) and glare disability in open-angle glaucoma.	88 participants with POAG (median age = 67, range 36-84 years).	MPOD at 0.25°, 0.5° and 1° of retinal eccentricity, measured using customised heterochromatic flicker photometry. Mesopic contrast sensitivity with glare (mCSg), photostress recovery time (PRT) and self-reported glare symptoms were evaluated.	Low spatial frequency mCSg was significantly correlated with MPOD at 0.25° (3 cycles per degree (cpd): r =0.25, P = 0.04) and 0.5° (3 cpd: r=0.23, P = 0.04) of retinal eccentricity. The depth of central 10° field loss was related to MPOD at all eccentricities (P <0.01 for all). Those who reported glare symptoms had a significantly lower MPOD at all retinal eccentricities (0.25° and 1°: P = 0.05 each; 0.5°: P = 0.04), including those with foveal involvement (0.25°: P = 0.05; 0.5°: P <0.01; 1°: P = 0.01).

Skalicky et al., 2016	Impact of age-related macular degeneration in patients with glaucoma: understanding the patients' perspective	Case-control	Quality of life	To measure the impact of age-related macular degeneration (AMD) on vision-related activity limitation and preference-based status for glaucoma patients.	200 glaucoma patients, of whom 73 had AMD. Participants consisted of controls, who had glaucoma without AMD (mean (SD) age = 70.4 (9.6)); cases with glaucoma and low-risk AMD (mean (SD) age = 76.4 (8.5); and cases with glaucoma and high-risk AMD (mean (SD) age = 82.2 (7.1)).	Vision-related activity limitation (as measured by the Glaucoma Activity Limitation-9 questionnaire) and preference-based status (measured by the Visual Function Questionnaire Utility Index), for those with and without AMD.	Lower better eye mean deviation (β: 1.42, 95% confidence interval: 1.24–1.63, $P < 0.001$) and AMD (β: 1.26 95% confidence interval: 1.10–1.44, $P = 0.001$) were independently associated with worse vision-related activity limitation. Glaucoma patients with AMD found using stairs, walking on uneven ground and judging distances of foot to step/curb significantly more difficult than those without AMD.
Tam et al., 2018	Self-perceived Impact of Glaucomatous Visual Field Loss and Visual Disabilities on Driving Difficulty and Cessation	Cross-sectional	ADL	To investigate if glaucoma severity and the presence of self-reported glare and difficulty with dark adaptation are associated with driving difficulty or cessation.	99 participants with glaucoma. 53 participants had mild glaucoma (mean (SD) age = 69.0 (8.8)) and 46 had moderate glaucoma (mean (SD) age = 74.4 (7.5)).	Patient responses to the glare and dark adaptation subscales in Glaucoma Quality of Life-15 questionnaire were used to measure relevant visual disability. Associations were assessed utilizing prevalence ratios (PR).	19% of participants (19/99) reporting driving cessation. Patients with moderate/severe glaucoma when compared with mild glaucoma reported a significantly higher percentage of driving cessation (33% vs. 8%; P=0.002), presence of glare (27% vs. 6%; P=0.012), and difficulty with dark adaptation (31% vs. 10%; P= 0.011). Individuals with self-perceived difficulty with dark adaptation were about 4 times more likely than those without to have difficulty driving at night (adjusted PR=3.94; $P < 0.0001$) or in poor driving conditions (adjusted PR=4.09; P=0.0002). Self-reported glare was associated with an increased risk of driving difficulty in poor driving conditions (PR=4.17; P= 0.05).

Tatemichi et al., 2012	Symptoms related to glaucomatous visual field abnormalities (VFAs) among male Japanese workers in a population-based setting	Cross-sectional	Functional vision	To identify symptoms potentially related to VFAs in a population-based setting, and to assess the applicability of using these symptoms to identify persons at risk of developing glaucoma.	10,214 Japanese male general workers (mean (SD) age = 45.3 (8.8)). 9767 participants had no VFAs, 447 participants had VFAs as determined by the frequency doubling technology (FDT), and 227 participants had confirmed glaucomatous VFAs.	Scores on a self-administered questionnaire, which inquired about whether the participant was suffering from any of nine symptoms.	Responses citing the symptoms 'feeling of something in the front of the eye' and 'feeling of hardness to see in dark places' were significantly ($P < 0.05$) more frequent in participants with FDT- and glaucomatous VFAs than among normal participants. However, the respective areas under the ROC curve of summed scores for the nine total items and for the two items which showed significant differences for the glaucoma groups were 0.57 (95% confidence interval = 0.53–0.60) and 0.58 (95% confidence interval = 0.54–0.61).
Turano et al., 2002	A Self-Assessment Instrument Designed for Measuring Independent Mobility in RP Patients: Generalizability to Glaucoma Patients	Cross-sectional	ADL	To determine whether the patient-based assessment of difficulty in mobility, developed and validated in a group of patients with retinitis pigmentosa (RP), is valid for measuring perceived visual ability for independent mobility in patients with glaucoma.	83 glaucoma patients (mean (SD) age = 61.7 years (12.3).	Participants' ratings of the perceived difficulty of walking independently in each of 35 mobility situations. A Rasch analysis of the ordinal difficulty ratings was used to estimate interval measures of perceived visual ability for independent mobility.	Patients with glaucoma had, on average, higher perceived visual ability for independent mobility than those with RP. Glaucoma patients reported changes in lighting at night causing more mobility difficulties than the RP patients.

Velten et al., 2001	The b-wave of the dark adapted flash electroretinogram in patients with advanced asymmetrical glaucoma and normal subjects	Case-control	Psychophysics	To evaluate whether the b-wave of the dark adapted flash electroretinogram (ERG) is affected by glaucomatous damage.	35 patients with advanced asymmetrical open angle glaucomas, primary and secondary (pseudoexfoliation syndrome and pigmentary dispersion) open angle and low tension glaucomas. 17 healthy control subjects, matched for age and sex. Mean (SD) age = 56 (10).	The b-wave amplitudes and implicit times of all flash intensities tested and parameters Vmax, n, and K of the two models of the Naka-Rushton equation were compared between the normal subjects and those with glaucoma using the unpaired t test.	Implicit times were significantly longer ($p<0.005$) in the glaucoma patients than in the normal group for flash intensities of 9.4, 5.3, 1.7, 0.53, and 0.17 cd/s/m2. b-Wave amplitudes did not differ significantly between the two study groups.
Willis et al., 2000	Effects of Glaucoma and Aging on Photopic and Scotopic Motion Perception	Case-control	Functional vision	To examine the effects of primary open-angle glaucoma and normal aging on visual sensitivity for targets known to bias responses from the magnocellular visual processing stream.	15 patients with POAG (mean (SD) age = 58.7 (11.9)); 14 age-matched controls (mean (SD) age = 55.8 (10.5)); 10 young controls (mean (SD) age = 24.4 (2.1)).	Contrast sensitivity was measured for the detection and direction discrimination of low-spatial-frequency (0.5 cyc/deg), drifting (4–24 Hz) sinusoidal gratings As a control, sensitivity was measured for the detection of stationary stimuli. Tests took place under both photopic and	Across a wide range of conditions, the ability to detect and discriminate visual motion declined significantly ($P < 0.05$) with increasing age, whereas the ability to detect stationary patterns was generally unaffected. There were no significant differences in mean sensitivity between glaucoma and age-matched control groups for any of the conditions used.

						scotopic levels of lighting.	
Wolffsohn et al., 1998	Low vision perspectives on glaucoma	Descriptive case series	Functional vision	The aim of this paper is to examine the demographics of patients with glaucoma-induced visual impairment.	The study involved a total of 590 patients with visual impairment. Glaucoma was the primary cause of visual loss in 8.5% of patients and was a secondary contributor to visual impairment in 5.9%.	Data collected included age, subjective assessment of glare, mobility and visual needs, visual acuity (at distance and near), contrast sensitivity, visual field loss or disruption and magnifiers prescribed.	Of patients whose primary cause of visual impairment was glaucoma, 34% reported being greatly affected by glare with a further 38% moderately affected. 64% of glaucoma patients had magnifiers prescribed to help them achieve their visual needs, which were to read newspapers in the majority of cases.

Wren et al., 2009	Contrasting the Use of Two Vision-Specific Quality of Life Questionnaires in Subjects with Open-Angle Glaucoma	Cross-sectional	Quality of life	To compare two vision-specific functional status measures to each other and to clinical parameters in the Collaborative Initial Glaucoma Treatment Study (CIGTS).	426 participants with glaucoma. The average age of CIGTS participants who provided complete data at 54 months was 57.8 years.	Scores on the Visual Activities Questionnaire (VAQ) and the NEI-VFQ-25, as well as visual field and visual acuity measures.	The VAQ subscales (range, 0 to 100) that assessed light-dark adaptation (mean=66.1), glare disability (66.4), and acuity/spatial vision (67.7) indicated vision-related functions that CIGTS participants found most difficult. On the NEI-VFQ, subjects reported high levels of visual functioning, with mean Z90 (out of 100) on the total score and in 9 of 12 subscales. Increasing VF loss was associated with a significant decrease in the overall and peripheral vision subscale scores from both questionnaires, and also several other subscales.
Yonge et al., 2017	Quantifying Fall-Related Hazards in the Homes of Persons with Glaucoma	Cross-sectional	ADL	To characterize fall-related hazards in the homes of persons with suspected or diagnosed glaucoma, and to determine whether those with worse visual field (VF) damage have fewer home hazards.	174 participants with glaucoma. Mean (SD) age = 71.1 (7.6).	Total number of home hazards.	The mean number of items graded per home was 85.2 (SD = 13.2), and an average of 32.7 (38.3%) were identified as hazards. The bathroom contained the greatest number of hazards (mean = 7.9; 54.2% of graded items classified as hazardous), and the most common hazards identified in at least 1 room were ambient lighting <300 lux and exposed light bulbs. Only 27.9% of graded rooms had adequate lighting.

Zhou et al., 2014	Quality of life of glaucoma patients in China: sociodemographic, clinical, and psychological correlates—a cross-sectional study	Cross-sectional	Quality of life	To assess vision-related quality of life (VRQoL) in Chinese glaucoma patients and explore its sociodemographic, clinical and psychological correlates, and determine which of them explain the largest variation.	508 glaucoma patients (mean (SD) age = 55.4 (15.2)). 52.0% of participants had POAG and normal-tension glaucoma, 35.0% had primary angle closure glaucoma and 13.0% had secondary glaucoma.	Chinese-version Glaucoma Quality of Life-15 questionnaire (CHI-GQL-15) and Hospital Anxiety and Depression Scales were used to evaluate their VRQoL and psychological distresses respectively. Habitual-corrected visual acuity (HCVA), IOP, and mean defect (MD) of visual field) were assessed.	The mean summary score for CHI-GQL-15 was 28.79 ± 12.74. Patients exhibited the greatest difficulty in activities involving glare and dark adaptation (28.19 ± 22.86), followed by central and near vision (26.18 ± 26.56), peripheral vision (18.03 ± 21.37), and the least difficulty for outdoor mobility (15.06 ± 24.57).
Zuege et al., 1967	Studies of Dark Adaptation of Discrete Paracentral Retinal Areas in Glaucomatous Subjects	Cross-sectional	Psychophysics	To explore whether rod adaptation of the paracentral areas could be used in separating nonglaucomatous eyes from glaucoma eyes with field defects.	67 patients with glaucoma, in the age range 20-81.	The ratio of the dark-adaptation threshold at 30 minutes, 15/30 degrees from fixation.	The ratio is well below unity and only very few non-glaucomatous eyes had a ratio which was above unity. The eyes with glaucoma fields, on the other hand, in the area of their visual field defect, were abnormal with the exception of the three eyes previously described.

Appendix 4: Relevant abstracts

Table 7. Abstracts relevant to this review (ordered alphabetically by first author)

Author(s)	Year	Abstract title	Key findings
Blumberg DM Liebmann JM Hiriji SH Hood DC	2019	Diffuse Macular Damage in Mild to Moderate Glaucoma is Associated with Decreased Visual Function Scores under Low Luminance Conditions[92]	"82 (65%) of the 126 better eyes (defined by 24-2 VF MD) had evidence of macular damage, while the remaining 44 did not have macular damage. Of the 82 with damage, 33 (40%) had diffuse damage and 49 (60%) had focal damage. After adjusting for 24-2 MD and age in the multivariable regression, diffuse macular damage remained a significant predictor of the Low Luminance Questionnaire (LLQ) subscales 'difficulty with extreme lighting' (p=0.0024), ''difficulty with low lighting' (p=0.037), and 'diminished mobility'; (p=0.042). In contrast, there was no significant difference in LLQ scores in any subscale between participants with focal macular damage and those without macular damage."
Dintsios CM Scheibler FF Janssen I Gerber A Chernyak N Finger R	2011	How Do Glaucoma Patients Assess Different Aspects of Their Treatment: An Elicitation of Patients' Preferences Using the Analytic Hierarchy Process[93]	Patients rated the importance of different aspects of glaucoma treatment by a pairwise comparison. Of six domains, "Darkness and glare" was rated the third highest priority, after "Autonomy" and "Reading and seeing details". The other three aspects, considered a lower patient priority, were "Peripheral vision", "Side effects" and "Treatment-related burden".
Hattori M Morikawa S Tsuneoka H	1979	Night visual acuity of open angle glaucoma[94]	The authors evaluated the night visual acuity in 6 cases with ocular hypertension and in 10 cases with open angle glaucoma with defective visual field. All the cases with ocular hypertension showed normal night visual acuity. Cases with glaucoma, on the other hand, showed impaired night visual acuity. There was no correlation between the impaired night visual acuity and retarded dark adaptation in glaucoma subjects.
Htoon HM Baskaran M Chay J Aw AT Aung T	2014	Preliminary Estimation and Validation of the Glaucoma Utility Index-Singapore[95]	"70 primary glaucoma patients (72.9% with primary open angle) responses were collected: mean age 68.2 years (±9.1), female (27.1%), glaucoma severity; (48.6% mild, 34.3% moderate, 17.1% severe). The significant estimated utility values comparing 'no difficulty' with 'some/severe

Lamoureux EL Finkelstein EA			difficulty' in each of the dimensions were: central near vision (0.13, p=0.001), lighting and glare (0.20, p<0.001), mobility (0.32, p<0.001), psychosocial dimensions (0.19, p<0.001)."
Lappas A Foerster AM Schild AM Rosentreter A Dietlein TS	2011	Quantification of subjective visual quality of life in glaucoma patients : first results of a German version of the GQL-15 questionnaire[96]	A total of 31 patients were evaluated. It could be demonstrated that the QoL summary scores correlated with visual field loss. Evaluation of subscale scores of visual function revealed that glare and dark adaptation were correlated with glaucoma severity especially in the early stages of the disease.
Mihailovic A Friedman DS West S Gitlin L Ramulu P	2017	Gait changes across lighting conditions in persons with glaucoma[97]	Glaucoma patients with worse integrated visual field sensitivity demonstrate more pronounced gait changes between normal and bright/dim lighting, suggesting greater challenges in mobility under the extremes of lighting.
Mukherjee MR Mihailovic A Friedman DS West S Ramulu P	2017	Initiation of walking in glaucoma[98]	Glaucoma patients with worse vision take longer to initiate walking during bright-to-dim and obstructed pathway walking, and specific attention should be devoted to these scenarios when rehabilitating mobility in glaucoma.
Ramsey DJ Alwreikat AM Cooper ML Roh S Bhardwaj MK, Kent-Gasiorowski A Bowen SA Cotran PR	2019	Dark Adaptation Survey as a Predictive Tool for Primary Open-Angle Glaucoma[99]	This pilot study revealed that problems with dark adaptation and vision under low luminance are commonly encountered by patients with POAG. These areas of visual disability are not assessed routinely in glaucoma care. A questionnaire assessing vision under low luminance and light–dark transitions may serve as a proxy for functional impairment in glaucoma. When paired with risk factors such as structural features of the optic nerve and family history, this survey instrument may be suitable to screen for patients with POAG.
Zenouda A Lombardi M Gutman E Brasnu E Hamard P Baudouin C Labbe A	2016	Consequences of glaucoma on activities of daily living: Evaluation in an artificial street[100]	Low light condition decreased mobility performance for all subjects (*P* <0.01). The influence of light condition was not different between the glaucoma and control group (*P* =0.16). The number of mobility incidents was not different between both groups (*P* =0.65). There was no difference in average movement onset (MO) time between the two groups (p=0,086) but glaucoma patients had a significantly longer overall movement (OM) time as compared to control subjects (OM delay: 151 ms, *P* <0.01). Low light condition increased the MO time by 4 to 20% (1.057 +/- 0.05 sec; 1.217 +/- 0.07 sec) for all subjects without difference between the two groups.

Zenouda A Lombardi M Gutman E Brasnu E Hamard P Sahel JA Baudouin C Labbe A	2016	Effect of different lightning conditions on daily living activities of glaucoma patients[71]	Glaucoma patients had decreased performance in mobility and motor control tasks. The influence of light condition was not different between the glaucoma and control group.

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