Global causes of blindness and distance vision impairment 1990–2020: a systematic review and meta-analysis

Seth R Flaxman, Rupert R A Bourne*, Serge Resnikoff, Peter Ackland, Tasanee Braithwaite, Maria V Cicinelli, Aditi Das, Jost B Jonas, Jill Keeffe, John H Kempen, Janet Leasher, Hans Limburg, Kovin Naidoo, Konrad Pesudovs, Alex Silvester, Gretchen A Stevens, Nina Tahhan, Tien Y Wong, Hugh R Taylor, on behalf of the Vision Loss Expert Group of the Global Burden of Disease Study†*

Summary

Background Contemporary data for causes of vision impairment and blindness form an important basis of recommendations in public health policies. Refreshment of the Global Vision Database with recently published data sources permitted modelling of cause of vision loss data from 1990 to 2015, further disaggregation by cause, and forecasts to 2020.

Methods In this systematic review and meta-analysis, we analysed published and unpublished population-based data for the causes of vision impairment and blindness from 1980 to 2014. We identified population-based studies published before July 8, 2014, by searching online databases with no language restrictions (MEDLINE from Jan 1, 1946, and Embase from Jan 1, 1974, and the WHO Library Database). We fitted a series of regression models to estimate the proportion of moderate or severe vision impairment (defined as presenting visual acuity of <6/18 but ≥3/60 in the better eye) and blindness (presenting visual acuity of <3/60 in the better eye) by cause, age, region, and year.

Findings We identified 288 studies of 3 983 541 participants contributing data from 98 countries. Among the global population with moderate or severe vision impairment in 2015 (216·6 million [80% uncertainty interval 98·5 million to 359·1 million]), the leading causes were uncorrected refractive error (116·3 million [49·4 million to 202·1 million]), cataract (52·6 million [18·2 million to 109·6 million]), age-related macular degeneration (8·4 million [0·9 million to 29·5 million]), glaucoma (4·0 million [0·6 million to 13·3 million]), and diabetic retinopathy (2·6 million [0·2 million to 9·9 million]). Among the global population who were blind in 2015 (36·0 million [12·9 million to 65·4 million]), the leading causes were cataract (12·6 million [3·4 million to 28·7 million]), uncorrected refractive error (7·4 million [2·4 million to 14·8 million]), and glaucoma (2·9 million [0·4 million to 9·9 million]). By 2020, among the global population with moderate or severe vision impairment (237·1 million [101·5 million to 399·0 million]), the number of people affected by uncorrected refractive error is anticipated to rise to 127·7 million (51·0 million to 225·3 million), by cataract to 57·1 million (17·9 million to 124·1 million), by age-related macular degeneration to 8·8 million (0·8 million to 32·1 million), by glaucoma to 4·5 million (0·5 million to 15·4 million), and by diabetic retinopathy to 3·2 million (0·2 million to 12·9 million). By 2020, among the global population who are blind (38·5 million [13·2 million to 70·9 million]), the number of patients blind because of cataract is anticipated to rise to 13·4 million (3·3 million to 31·6 million), because of uncorrected refractive error to 8·0 million (2·5 million to 16·3 million), and because of glaucoma to 3·2 million (0·4 million to 11·0 million). Cataract and uncorrected refractive error combined contributed to 55% of blindness and 77% of vision impairment in adults aged 50 years and older in 2015. World regions varied markedly in the causes of blindness and vision impairment in this age group, with a low prevalence of cataract (<22% for blindness and 14·1–15·9% for vision impairment) and a high prevalence of age-related macular degeneration (>14% of blindness) as causes in the high-income subregions. Blindness and vision impairment at all ages in 2015 due to diabetic retinopathy (odds ratio 2·52 [1·48–3·73]) and cataract (1·21 [1·17–1·25]) were more common among women than among men, whereas blindness and vision impairment due to glaucoma (0·71 [0·57–0·86]) and corneal opacity (0·54 [0·43–0·66]) were more common among men than among women, with no sex difference related to age-related macular degeneration (0·91 [0·70–1·14]).

Interpretation The number of people affected by the common causes of vision loss has increased substantially as the population increases and ages. Preventable vision loss due to cataract (reversible with surgery) and refractive error (reversible with spectacle correction) continue to cause most cases of blindness and moderate or severe vision impairment in adults aged 50 years and older. A large scale-up of eye care provision to cope with the increasing numbers is needed to address avoidable vision loss.

Funding Brien Holden Vision Institute.

Lancet Glob Health 2017; 5: e1221–34

Published Online October 11, 2017 http://dx.doi.org/10.1016/S2214-109X(17)30393-5

See Comment page e1164

*Contributed equally

†Members listed at http://www.anglia.ac.uk/epidemiology-members

Department of Mathematics and Data Science Institute, Imperial College London, London, UK (S R Flaxman PhD); **Vision and Eye Research Unit, Anglia Ruskin University, Cambridge, UK** (Prof R R A Bourne MD); **Brien Holden Vision Institute, Sydney, NSW, Australia** (Prof S Resnikoff MD, K Naidoo PhD, N Tahhan PhD); **School of Optometry and Vision Science, University of New South Wales, Sydney, NSW, Australia** (Prof S Resnikoff, N Tahhan); **International Agency for the Prevention of Blindness, London, UK** (P Ackland MPhil); **Moorfields Eye Hospital NHS Foundation Trust, London, UK** (T Braithwaite MPH); **San Raffaele Scientific Institute, Milan, Italy** (M V Cicinelli MD); **York Hospital, York, UK** (A Das MD); **Department of Ophthalmology, Universitätsmedizin, Mannheim, Germany, and Medical Faculty Mannheim, Heidelberg University, Mannheim, Germany** (Prof J B Jonas MD); **L V Prasad Eye Institute, Hyderabad, India** (Prof J Keeffe PhD); **Department of Ophthalmology, Massachusetts Eye and Ear Infirmary, Harvard Medical School, Boston, MA, USA, Discovery Eye Center, Addis Ababa, Ethiopia, and MyungSung Christian Medical Center, Addis Ababa, Ethiopia** (J H Kempen MD); **Nova**

Southeastern University, Fort Lauderdale, FL, USA (Prof J Leasher OD); **Health Information Services, Grootebroek, Netherlands** (H Limburg PhD); **African Vision Research Institute, University of Kwazulu-Natal, Glenwood, Durban, South Africa** (K Naidoo); **National Health and Medical Research Council Centre for Clinical Eye Research, Flinders University, Adelaide, SA, Australia** (Prof K Pesudovs PhD); **SpaMedica Research Institute, Bolton, UK** (A Silvester MD); **Department of Information, Evidence and Research, World Health Organization, Geneva, Switzerland** (G A Stevens D.Sc); **Singapore Eye Research Institute, Duke-National University of Singapore Graduate Medical School, National University of Singapore, Singapore** (Prof T Y Wong PhD); **and Melbourne School of Population and Global Health, University of Melbourne, Melbourne, VIC, Australia** (H R Taylor MD)

Correspondence to:
Prof Rupert R A Bourne, Vision and Eye Research Unit, Anglia Ruskin University, Cambridge CB1 1PT, UK
rb@rupertbourne.co.uk

Research in context

Evidence before this study

Using data from studies published between 1980 and 2012, as well as unpublished studies, the Vision Loss Expert Group previously calculated estimates for global prevalence of causes of vision impairment and blindness for 2010. The proportions of vision impairment and blindness due to cataract and trachoma decreased over the study period of 20 years; those due to glaucoma, macular degeneration, diabetic retinopathy, and uncorrected refractive error increased.

Added value of this study

This study updates the estimates of the global and regional prevalence of causes of blindness and vision impairment. The new analysis of the Global Vision Database by the Vision Loss Expert Group incorporates 61 new studies from 35 different countries and where available includes more precise disaggregated data supplied by study investigators than are available in their published outputs. This database contains data for both presenting and best-corrected visual acuity and causes of vision impairment from 3 983 541 participants examined in 288 population-based studies from a systematic review of the published literature and analysis of unpublished literature. Furthermore, it uses an improved statistical analysis and provides projections of blindness and vision impairment, by cause, to 2020. In 2015, cataract or uncorrected refractive error were responsible for 77% of the global vision impairment burden and 55% of the blindness burden in adults aged 50 years and older, both of which are completely treatable causes. Glaucoma, age-related macular degeneration, corneal opacity, diabetic retinopathy, and trachoma were less frequent causes of blindness and vision impairment than were cataract and uncorrected refractive error, some of which are also preventable. Crude global prevalence (all ages) of blindness and vision impairment of each cause decreased markedly between 1990 and 2015, except for diabetic retinopathy, which increased. However, the number of people affected by blindness and vision impairment is increasing, which is attributable to population growth and ageing. The proportion with preventable or treatable blindness decreased from 81·7% in 2010 to 81·2% in 2015 and is projected to decrease to 80·8% in 2020. The predicted increase in the number of people with avoidable vision impairment (defined as vision impairment that could be either treated or prevented by known, cost-effective means) to 2020 is mainly driven by south Asia and east Asia.

Implications of all the available evidence

This projection to 2020 of numbers of people affected by blindness and vision impairment indicates a continued increase in the need for care. Given this evidence, urgent action is called for to address this largely preventable global problem and provide adequate eye care services.

Introduction

Contemporary and accurate data for the cause-specific prevalence of vision impairment and blindness are a fundamental basis of public health policies, such as allocation of resources and health service planning, and are important for prioritisation of scientific advances and industry research. The Vision Loss Expert Group reported estimates of vision impairment resulting from a systematic review of published literature and available unpublished data from population-based studies of the prevalence of blindness and vision impairment dating from 1980 to 2015,[1] using a continuously updated database of population-based studies (the Global Vision Database; the Vision Atlas contains online maps created with data from the Global Vision Database). Unpublished data were principally those of rapid assessment methods, with some older reports held at WHO. Globally, 36·0 million people were estimated to be blind in 2015, whereas 216·6 million people had moderate or severe vision impairment. Although a decrease occurred in the age-standardised prevalence of blindness and moderate or severe vision impairment between 1990 and 2015 (the global age-standardised all-age prevalence of blindness decreased from 0·75% [80% uncertainty interval (80% UI) 0·25–1·41] in 1990 to 0·48% [0·17–0·87] in 2015), and the global age-standardised all-age prevalence of moderate or severe vision impairment decreased from 3·83% (1·66–6·42) to 2·90% (1·31–4·80), the number of people vision impaired was little changed as a result of growth and ageing of the total population.

Since the Vision Loss Expert Group last published prevalence estimates of cause of moderate or severe vision impairment or blindness up to 2010,[2] the systematic review has been extended to include the more recent population-based data to derive cause-specific estimates. New data from additional studies allowed more precise estimates of emerging causes of blindness and moderate or severe vision impairment than previously. For example, a limitation of the previous meta-analysis of causes was the inability to disaggregate age-related macular degeneration from other causes of macular degeneration (eg, myopic macular degeneration or hereditary causes) and the absence of sufficient data to model corneal opacity, which is an important cause in low-income and middle-income countries.[3,4] This study provides global estimates of the leading causes of vision impairment and blindness for 2015, examines trends since 1990, and provides projections to 2020.

For the **Global Vision Database** see www.globalvisiondata.org

For the **Vision Atlas** see http://atlas.iapb.org

Methods

Search strategy and selection criteria

In this systematic review and meta-analysis, we included distance vision impairment data from population-based studies identified through a systematic review of studies

published before July 8, 2014, by searching online databases with no language restrictions (MEDLINE from Jan 1, 1946, and Embase from Jan 1, 1974, and the WHO Library Database). A full list of data sources for each cause and the number of studies reporting each pair of causes are given in the appendix. We extracted data from published reports. Unpublished data were principally those of rapid assessments. The methods for the data search including search terms and search strategy have been published in detail.[1]

Data analysis

Our analysis proceeded as follows: data identification and access, statistical estimation of the proportion of blindness or moderate or severe vision impairment for each cause separately by age and region, and application of this estimation to the overall blindness and moderate or severe vision impairment prevalence. We estimated causes of vision impairment over time by age and geographical region, using the 21 Global Burden of Disease regions (appendix). We estimated the prevalence of moderate or severe vision impairment (defined as presenting visual acuity of <6/18 but ≥3/60 in the better eye) and blindness (presenting visual acuity of <3/60 in the better eye) attributable to cataract, glaucoma, age-related macular degeneration, diabetic retinopathy, corneal opacity, trachoma, uncorrected refractive error, and other causes for 1990–2015 (projected in 2015), and made projections to 2020. Descriptions of the causes are given in the panel.

Details of our Bayesian hierarchical modelling approach, the Stan modelling code, and the covariates used for each model are given in the appendix. We fitted six separate mixed-effects models for the following causes: cataract, glaucoma, age-related macular degeneration, diabetic retinopathy, corneal opacity, and other. The models include terms adjusting for age, sex, best-corrected versus presenting vision, urban, and whether or not the study was nationally representative.

We fitted the model for the vision impairment cause that we term "other" to data extracted from surveys reporting cataract and age-related macular degeneration and based it on the number of respondents with blindness or moderate or severe vision impairment who were reported as having unspecified causes of vision impairment. Unlike the other models, the models that we fitted for these data had no year trend. Our concern was that addition of a year covariate would have confounded a true change over time with a systematic change in how surveys reported a non-cause-specific category—eg, a tendency towards more detailed reporting on the causes of vision impairment and blindness in more recent surveys than in older surveys.

We derived estimates of uncorrected refractive error from the vision prevalence model published separately,[1] in which we explicitly modelled the contribution of uncorrected refractive error to blindness and vision impairment. This analysis used the same database as in this study, and the analysis was able to include all studies from the database (even studies for which estimates of only either best-corrected or presenting were reported) to estimate uncorrected refractive error. Because of data availability issues for blindness and vision impairment from trachoma, we used previously published estimates of trachoma-attributable blindness and moderate or severe vision impairment.[2,5] To combine the separate causal estimates, we used the overall prevalence estimates at the region level by year as an envelope. We left the uncorrected refractive error estimates fixed and then apportioned the remaining prevalence to the various causes, normalising so that these causes fitted within the envelope by dividing each cause by the sum of the causes.

We fitted this statistical model for the six causes with fully Bayesian inference through Markov Chain Monte Carlo sampling implemented in the probabilistic programming language Stan version 2.15.1. With data sparsity across countries and over time, a hierarchical Bayesian model allowed us to borrow strength within regions and over time, better informing the estimates in a data-driven way than without this approach. Fully Bayesian inference meant that diagnosis of problems with the model was easier and uncertainty estimates had better calibration than without this approach. Diagnostic checks and statistical models used to predict the

***Panel:* Definitions of causes of blindness and vision impairment**

Cataract
- Cataract of any cause

Uncorrected refractive error (including aphakia)
- Estimated as the difference between visual acuity at presentation and best-corrected sight

Glaucoma
- All types of glaucoma combined leading to central vision loss

Age-related macular degeneration
- Early and late
- Excludes other causes of macular disease, such as myopic macular degeneration, macular holes, and dystrophies

Diabetic retinopathy
- Diabetic retinopathy and sequelae

Corneal opacity
- Corneal opacity not ascribed to trachoma

Trachoma
- Trachoma-related corneal scarring

Other
- All other causes, including unidentified causes or specified causes that did not fit into the categories above

See Online for appendix

	Uncorrected refractive error	Cataract	Glaucoma	Age-related macular degeneration	Diabetic retinopathy	Corneal opacity	Trachoma	Other
1990								
High-income Asia Pacific	13·09% (11·36–14·79)	24·08% (17·94–30·48)	13·95% (5·82–23·78)	18·67% (7·23–32·84)	3·06% (0·70–6·29)	3·27% (0·32–7·91)	0	23·88% (10·33–39·94)
Central Asia	12·52% (10·62–14·37)	29·77% (22·36–37·73)	13·40% (4·00–26·55)	16·44% (4·21–32·89)	2·23% (0·26–5·04)	5·21% (0·47–12·28)	0	20·44% (4·83–40·56)
East Asia	12·76% (10·97–14·50)	42·59% (35·35–49·66)	6·92% (2·70–12·44)	7·04% (1·78–14·69)	0·38% (0·08–0·80)	5·81% (1·13–12·38)	7·21% (6·82–7·61)	17·29% (5·98–31·44)
South Asia	35·54% (32·29–38·41)	38·79% (32·99–44·43)	5·93% (2·20–10·85)	3·10% (0·83–6·32)	0·10% (0·02–0·21)	3·91% (0·73–8·47)	0·20% (0·18–0·23)	12·42% (4·42–22·80)
Southeast Asia	12·21% (10·29–14·08)	48·25% (40·37–55·88)	7·15% (2·71–12·94)	6·13% (1·47–12·91)	0·29% (0·05–0·60)	6·49% (1·25–13·89)	0·67% (0·65–0·68)	18·82% (6·52–34·21)
Australasia	13·04% (11·32–14·73)	24·16% (17·98–30·58)	13·82% (5·77–23·52)	19·16% (7·51–33·49)	2·95% (0·67–6·04)	3·31% (0·32–8·04)	0	23·58% (10·19–39·45)
Caribbean	12·37% (10·48–14·21)	29·42% (23·42–35·36)	10·56% (4·07–18·89)	8·50% (2·26–17·34)	0·68% (0·13–1·47)	2·62% (0·26–6·37)	0·02% (0·02–0·02)	35·83% (18·24–52·15)
Central Europe	12·85% (11·02–14·62)	28·24% (20·99–36·09)	13·79% (4·20–27·06)	18·57% (5·01–36·42)	2·41% (0·29–5·45)	4·91% (0·43–11·53)	0	19·23% (4·45–38·54)
Eastern Europe	12·78% (10·99–14·55)	24·85% (17·95–32·38)	13·83% (4·13–27·09)	21·65% (6·45–40·25)	3·66% (0·46–8·41)	4·79% (0·38–11·43)	0	18·44% (4·29–36·87)
Western Europe	13·06% (11·34–14·75)	24·84% (18·52–31·39)	13·75% (5·75–23·46)	19·16% (7·58–33·44)	2·42% (0·53–4·99)	3·34% (0·32–8·16)	0	23·43% (10·10–39·22)
Andean Latin America	12·40% (10·50–14·26)	32·66% (26·42–38·79)	10·15% (3·84–18·29)	4·92% (1·00–10·71)	0·29% (0·05–0·61)	2·63% (0·27–6·44)	0	36·95% (18·84–53·71)
Central Latin America	12·39% (10·51–14·20)	30·15% (24·11–36·09)	10·46% (4·06–18·61)	7·19% (1·74–15·13)	0·53% (0·10–1·14)	2·65% (0·28–6·46)	0	36·63% (18·72–53·16)
Southern Latin America	12·91% (11·18–14·64)	27·07% (20·39–34·03)	14·00% (5·80–23·99)	15·72% (5·59–28·89)	2·08% (0·46–4·26)	3·39% (0·34–8·17)	0	24·83% (10·73–41·56)
Tropical Latin America	12·72% (10·91–14·47)	28·39% (22·62–34·18)	10·88% (4·29–19·26)	7·70% (1·89–16·08)	0·75% (0·15–1·63)	2·51% (0·27–6·01)	0	37·05% (18·93–53·77)
North Africa and Middle East	11·91% (9·91–13·86)	32·71% (25·99–39·65)	6·76% (2·25–12·82)	3·48% (0·38–8·53)	0·75% (0·13–1·67)	6·65% (1·21–14·34)	6·72% (6·54–6·90)	31·03% (13·19–50·03)
High-income North America	12·99% (11·26–14·67)	23·40% (17·34–29·72)	13·55% (5·65–23·08)	20·56% (8·44–35·20)	3·14% (0·70–6·46)	3·36% (0·32–8·24)	0	23·01% (9·94–38·47)
Oceania	12·38% (10·48–14·23)	48·68% (40·69–56·46)	7·15% (2·70–12·96)	5·18% (1·17–11·04)	0·28% (0·05–0·58)	6·61% (1·31–13·96)	0	19·72% (6·87–35·73)
Central sub-Saharan Africa	12·47% (10·57–14·32)	44·83% (37·42–51·99)	13·44% (5·67–23·13)	7·50% (1·81–15·55)	0·39% (0·07–0·84)	6·02% (1·18–12·87)	0·96% (0·95–0·98)	14·39% (4·59–27·59)
East sub-Saharan Africa	11·99% (10·04–13·92)	38·88% (32·54–45·01)	10·71% (4·31–18·78)	5·48% (1·29–11·38)	0·32% (0·06–0·68)	5·13% (0·94–11·13)	15·67% (15·05–16·28)	11·83% (3·77–22·67)
Southern sub-Saharan Africa	12·20% (10·25–14·11)	36·12% (29·01–43·23)	14·49% (6·00–25·16)	14·59% (4·08–28·81)	1·38% (0·26–2·91)	5·76% (1·04–12·57)	1·69% (1·65–1·73)	13·77% (4·38–26·40)
West sub-Saharan Africa	12·08% (10·15–13·97)	40·29% (33·62–46·76)	12·08% (5·08–20·82)	6·34% (1·49–13·26)	0·37% (0·07–0·80)	5·40% (1·07–11·49)	10·32% (9·93–10·71)	13·11% (4·19–25·12)
World	19·58% (17·29–21·72)	36·67% (30·11–43·22)	8·66% (3·25–15·72)	7·93% (2·32–15·54)	0·85% (0·15–1·83)	4·75% (0·80–10·47)	2·78% (2·66–2·90)	18·78% (7·12–32·87)
2015								
High-income Asia Pacific	13·13% (11·38–14·82)	20·32% (12·91–28·40)	13·51% (4·63–24·78)	16·66% (4·84–32·72)	3·87% (0·56–8·93)	2·38% (0·18–5·85)	0	30·13% (13·01–50·24)
Central Asia	12·85% (11·07–14·60)	25·94% (17·43–35·02)	14·17% (3·50–29·80)	14·01% (2·64–30·57)	3·60% (0·34–8·59)	3·58% (0·25–8·02)	0	25·86% (6·09–51·43)
East Asia	12·90% (11·15–14·61)	43·58% (33·01–53·93)	7·06% (2·79–12·53)	5·33% (1·34–10·95)	0·51% (0·09–1·08)	4·26% (0·71–9·41)	1·81% (1·25–2·36)	24·55% (8·46–44·70)
South Asia	36·43% (33·81–38·83)	36·58% (28·55–44·67)	5·81% (2·18–10·51)	2·44% (0·71–4·83)	0·16% (0·03–0·35)	2·43% (0·45–5·34)	0·04% (0·01–0·07)	16·10% (5·71–29·58)
Southeast Asia	12·57% (10·79–14·33)	45·00% (34·22–55·54)	6·99% (2·69–12·56)	5·24% (1·27–10·81)	0·59% (0·09–1·26)	4·39% (0·73–9·72)	0·13% (0·11–0·15)	25·09% (8·66–45·62)
Australasia	13·11% (11·39–14·80)	19·65% (12·47–27·51)	13·48% (4·60–24·76)	16·52% (4·77–32·43)	4·48% (0·67–10·26)	2·35% (0·18–5·79)	0	30·40% (13·17–50·63)
Caribbean	12·59% (10·78–14·37)	25·74% (18·66–32·95)	9·61% (3·32–17·76)	5·64% (1·25–11·90)	0·79% (0·13–1·70)	1·65% (0·15–3·91)	0·00% (0·00–0·01)	43·98% (22·57–63·65)
Central Europe	12·98% (11·21–14·72)	25·42% (16·84–34·61)	14·08% (3·53–29·57)	15·92% (3·10–34·77)	3·10% (0·27–7·33)	3·63% (0·24–8·21)	0	24·87% (5·76–49·71)

(Table 1 continues on next page)

proportion of vision impairment by cause are described in the appendix.

For each cause, we ran four parallel Markov Chain Monte Carlo chains, drawing 1000 samples each. After discarding 500 samples as burn-in from each chain, we obtained 2000 samples. We report means and tenth to 90th percentiles as uncertainty intervals. We used regression models to combine raw survey data based on age and sex groups in various countries and years to produce estimates of attributable vision impairment by cause for each age-sex-country-year group. By combining these estimates with estimates of overall vision impairment by age-sex-country-year, we obtained prevalence estimates of each cause of vision loss. A straightforward aggregation of these estimates, weighting each age-sex group by its population in a given country-year, yields crude population-level estimates of the prevalence of vision impairment by cause for each country and year. As these estimates are based on the age structure of a population, countries with older populations will typically have higher crude prevalence estimates. Thus, we also report age-standardised estimates of prevalence, wherein the aggregation is done with use of an artificial population structure, the WHO standard population,[6] to enable comparability of population-level estimates of prevalence between countries with different age structures. By restricting the WHO standard population to individuals aged 50 years or older, we obtain age-standardised adult prevalence estimates.

By including a linear year term, the sign of this term indicates whether an increase or decrease occurs over time. In the Bayesian inference paradigm, we inferred a full posterior distribution over this term, so we can summarise it by asking what proportion of the time is it less than zero, indicating a decrease over time. This proportion is the posterior probability assigned by our model to a decreasing time trend.

We applied our model to forecast prevalence of blindness and moderate or severe vision impairment by cause into the future. Our model relies on health status and education as covariates and we extrapolated these covariates to the year 2020. As our model gives estimates of crude prevalence for country-years, we relied on the UN Population Division's forecasts to 2020 to derive crude numbers affected and age-standardised prevalence.[7] Thus, our estimates are also contingent on the assumptions regarding future fertility and mortality that underpin the UN Population Division estimates.

Role of the funding source

The funder had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

	Uncorrected refractive error	Cataract	Glaucoma	Age-related macular degeneration	Diabetic retinopathy	Corneal opacity	Trachoma	Other
(Continued from previous page)								
Eastern Europe	13·00% (11·25–14·71)	20·91% (13·31–29·19)	14·33% (3·48–30·10)	19·53% (4·06–41·02)	4·91% (0·46–11·93)	3·43% (0·21–7·70)	0	23·89% (5·60–47·60)
Western Europe	13·12% (11·39–14·81)	21·42% (13·68–29·87)	13·50% (4·64–24·79)	15·39% (4·38–30·42)	3·30% (0·47–7·60)	2·43% (0·18–5·93)	0	30·84% (13·35–51·36)
Andean Latin America	12·62% (10·82–14·41)	27·48% (20·20–34·81)	9·40% (3·33–17·26)	3·84% (0·78–8·18)	0·39% (0·06–0·83)	1·60% (0·16–3·82)	0	44·66% (22·83–64·82)
Central Latin America	12·71% (10·93–14·46)	23·97% (17·25–30·90)	9·99% (3·56–18·25)	6·19% (1·38–13·07)	0·95% (0·16–2·03)	1·62% (0·16–3·83)	0	44·58% (22·85–64·57)
Southern Latin America	13·00% (11·27–14·71)	21·68% (13·89–30·16)	13·61% (4·67–25·00)	14·34% (3·98–28·60)	3·51% (0·51–8·08)	2·41% (0·19–5·85)	0	31·45% (13·62–52·38)
Tropical Latin America	12·90% (11·14–14·62)	21·88% (15·57–28·47)	10·45% (3·72–19·07)	7·39% (1·68–15·61)	1·33% (0·24–2·87)	1·54% (0·15–3·60)	0	44·50% (22·78–64·56)
North Africa and Middle East	12·34% (10·50–14·16)	28·11% (20·11–36·57)	6·89% (2·20–13·16)	3·16% (0·35–7·38)	1·39% (0·27–2·94)	4·47% (0·72–10·13)	2·62% (2·40–2·85)	41·01% (17·39–66·13)
High-income North America	13·08% (11·33–14·77)	20·13% (12·79–28·14)	13·45% (4·58–24·72)	15·85% (4·51–31·29)	4·33% (0·65–9·99)	2·39% (0·18–5·85)	0	30·76% (13·33–51·20)
Oceania	12·61% (10·79–14·39)	47·29% (36·49–57·70)	6·72% (2·60–12·07)	3·08% (0·70–6·35)	0·32% (0·05–0·67)	4·24% (0·77–9·13)	0	25·75% (8·95–46·71)
Central sub-Saharan Africa	12·72% (10·93–14·50)	43·62% (33·32–54·01)	14·14% (5·34–25·10)	5·18% (1·26–10·67)	0·47% (0·09–0·97)	4·01% (0·71–8·83)	0·27% (0·25–0·29)	19·60% (6·23–37·59)
East sub-Saharan Africa	12·16% (10·31–14·00)	44·67% (34·66–54·55)	11·70% (4·16–21·30)	3·16% (0·70–6·63)	0·23% (0·04–0·48)	3·76% (0·63–8·48)	7·02% (6·13–7·95)	17·29% (5·49–33·18)
Southern sub-Saharan Africa	12·38% (10·53–14·23)	35·18% (25·65–45·26)	15·47% (5·55–27·92)	11·75% (2·97–23·72)	1·56% (0·29–3·27)	4·05% (0·63–9·15)	0·51% (0·44–0·58)	19·09% (6·05–36·61)
West sub-Saharan Africa	12·36% (10·53–14·16)	43·56% (33·51–53·63)	13·27% (4·93–23·74)	3·98% (0·92–8·30)	0·39% (0·07–0·80)	3·85% (0·70–8·44)	3·43% (2·91–4·01)	19·15% (6·11–36·70)
World	20·28% (18·23–22·24)	35·15% (26·40–44·03)	8·49% (2·99–15·66)	5·93% (1·46–12·18)	1·06% (0·15–2·38)	3·21% (0·50–7·19)	0·97% (0·80–1·15)	24·92% (9·58–43·36)

Data are mean (80% uncertainty interval).

Table 1: **Contribution of each cause to blindness among adults aged 50 years and older in 1990 and 2015**

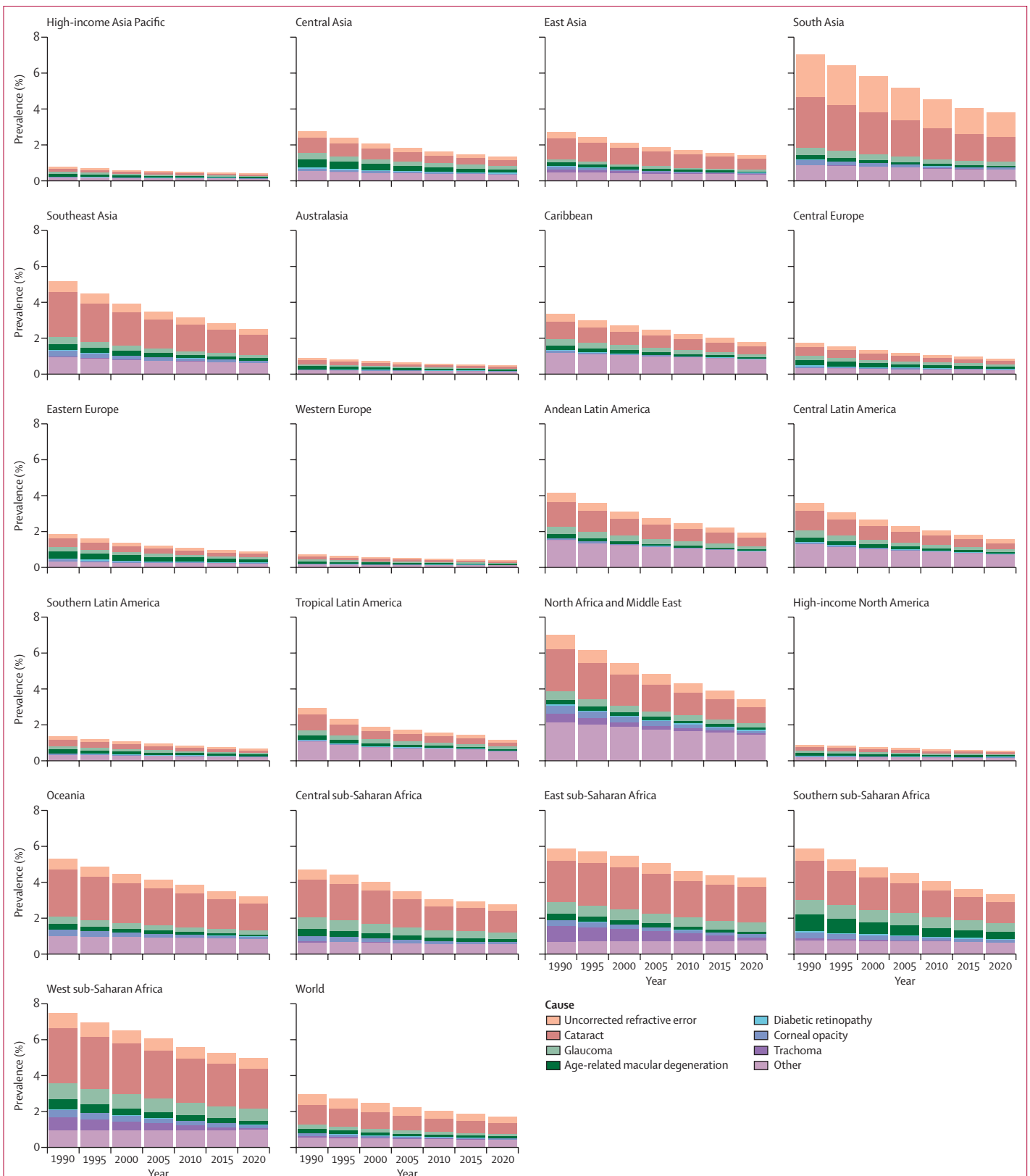

Figure 1: **Age-standardised prevalence of blindness in adults aged 50 years and older from 1990 to 2015**

Results

Since the previous analysis of the Global Vision Database,[2] 61 new studies were added from 35 different countries (of which 44 contributed disaggregated vision impairment prevalence data by cause and 28 involved rapid assessment of avoidable blindness survey methods), giving a total of 288 studies of 3 983 541 participants contributing data from 98 countries (appendix). Among the global population who were blind in 2015 (36·0 million [80% UI 12·9 million to 65·4 million), the leading causes of blindness (crude prevalence) among all ages were cataract, followed by uncorrected refractive error, glaucoma, age-related macular degeneration, corneal opacity, trachoma, and diabetic retinopathy (appendix). Among the global population with moderate or severe vision impairment in 2015 (216·6 million [98·5 million to 359·1 million]), the ranking was as follows: uncorrected refractive error, cataract, age-related macular degeneration, glaucoma, corneal opacity, diabetic retinopathy, and trachoma (appendix).

The leading causes of blindness in those aged 50 years and older in 2015 were cataract followed by uncorrected refractive error and glaucoma (table 1, figure 1). Cataract and uncorrected refractive error combined contributed to 55% of blindness and 77% of vision impairment in adults aged 50 years and older in 2015. Deconstructing these global averages, we observed large differences in the causes of blindness by region in this age group. In 2015, the proportion of blindness in those aged 50 years and older attributable to cataract ranged from <22% in high-income subregions to more than 44% in southeast Asia and Oceania (table 1). The proportion of blindness attributable to glaucoma varied considerably from the lowest values in south Asia to a much higher proportion in southern sub-Saharan Africa. The proportion of blindness attributable to age-related macular degeneration was higher in regions with older populations, namely the high-income subregions where more than 14% of blindness was attributed to age-related macular degeneration. By contrast, we observed the lowest proportion in the south Asia region. We observed no trachoma-related blindness in 13 of the 21 world regions in 2015. Diabetic retinopathy contributed to only a small proportion of global blindness, with a profound inter-regional range. Although the data for contribution of corneal opacity to blindness should be interpreted with caution, our model estimated that 3·2% (80% UI 0·5–7·2) of global blindness could be attributed to this cause (all ages 3·5% [0·5–7·8; appendix).

Globally in 2015, the leading causes of moderate or severe vision impairment in those aged 50 years and older were uncorrected refractive error followed by cataract and age-related macular degeneration (table 2, figure 2). Uncorrected refractive error contributed to a larger proportion of vision impairment in south Asia than in other regions. As with blindness, the proportion of vision impairment attributed to cataract in those aged 50 years and older was smallest in high-income subregions (ranging from 14% to 16%) and greater than 30% in the central, eastern, and western regions of sub-Saharan Africa (ranging from 32% to 34%), Oceania, southeast Asia, and east Asia. The proportion of vision impairment attributable to age-related macular degeneration was small in comparison, yet considerable regional variation existed, with low proportions in south Asia, but proportions exceeding 9% in the high-income subregions, central and eastern Europe, and central Asia, which have predominantly white populations. Glaucoma, diabetic retinopathy, corneal opacity, and trachoma each accounted for <3% of vision impairment worldwide. A regional breakdown of the proportion of blindness and vision impairment by cause in 2015 for all ages is given in the appendix. In 2010, 2·5% (80% UI 1·0–4·6) of the world's population was estimated to be blind or vision impaired due to uncorrected refractive error and cataract. By 2020, we estimate that this proportion will be 2·7% (1·0–5·1).

We observed sex differences by cause in the attributable fraction for both blindness and vision impairment when considering all ages in 2015. As our statistical model contains a term for sex, we were able to derive posterior estimates of the relative odds ratio for women versus men. Cataract, uncorrected refractive error, and diabetic retinopathy were more common causes of blindness and vision impairment in women than in men, with relative odds ratio of women versus men of 1·21 (80% UI 1·17–1·25) for cataract, 1·07 (1·03–1·11) for uncorrected refractive error, and 2·52 (1·48–3·73) for diabetic retinopathy. Whereas men were more likely to be blind or have vision impairment due to glaucoma (0·71 [0·57–0·86]) or corneal opacity (0·54 [0·43–0·66]) than were women, for age-related macular degeneration, we observed no clear sex difference (0·91 [0·70–1·14]).

Globally, although the age-specific prevalence has declined over time, the proportion of prevalent blindness in adults aged 50 years and older attributable to cataract has remained almost unchanged, showing a slight reduction from 36·7% (80% UI 30·1–43·2) in 1990 to 35·1% (26·4–44·0) in 2015 (table 1; 91% posterior probability of decline over time based on our model), with a further decline to 34·7% (25·0–44·6) anticipated by 2020 (appendix). The contribution of glaucoma (posterior probability of decline over time of 83%), age-related macular degeneration (posterior probability of decline of 99%), diabetic retinopathy (posterior probability of decline of 95%), and corneal opacity (posterior probability of decline of 85%) to blindness also declined between 1990 and 2015 according to the posterior probability of the model. The contribution of uncorrected refractive error to blindness marginally increased (for all ages, the proportion in 1990 was 20·2% [80% UI 18·1–22·3] and in 2015 was 20·6% [18·6–22·6]; appendix), and the other cause also increased.

Globally, the crude prevalence (all ages) of blindness due to all causes except for diabetic retinopathy reduced between 1990 and 2015 (expressed as the difference in

	Uncorrected refractive error	Cataract	Glaucoma	Age-related macular degeneration	Diabetic retinopathy	Corneal opacity	Trachoma	Other
1990								
High-income Asia Pacific	49·41% (47·51–51·08)	17·63% (12·98–22·65)	3·63% (1·30–6·82)	12·70% (4·50–23·33)	3·02% (0·74–6·17)	1·10% (0·11–2·51)	0	12·51% (4·42–22·22)
Central Asia	46·51% (41·54–50·29)	22·02% (16·11–28·52)	3·94% (0·87–8·43)	11·63% (2·58–24·12)	2·44% (0·35–5·67)	2·20% (0·16–4·79)	0	11·26% (1·87–25·14)
East Asia	45·83% (40·95–49·77)	32·00% (26·49–37·46)	1·49% (0·55–2·68)	4·53% (1·04–9·57)	0·41% (0·09–0·84)	2·16% (0·36–4·65)	5·29% (4·97–5·62)	8·29% (2·46–16·35)
South Asia	64·59% (58·92–69·42)	25·80% (21·67–29·77)	1·12% (0·37–2·09)	1·76% (0·41–3·70)	0·10% (0·02–0·20)	1·28% (0·21–2·75)	0·14% (0·12–0·16)	5·21% (1·57–10·32)
Southeast Asia	44·14% (38·96–48·67)	37·59% (31·31–43·79)	1·58% (0·58–2·87)	4·08% (0·89–8·70)	0·33% (0·06–0·68)	2·52% (0·41–5·48)	0·34% (0·33–0·35)	9·41% (2·80–18·53)
Australasia	48·79% (46·14–50·91)	17·78% (13·08–22·84)	3·65% (1·31–6·85)	13·28% (4·77–24·21)	2·99% (0·73–6·10)	1·10% (0·11–2·53)	0	12·41% (4·38–22·06)
Caribbean	46·74% (42·23–50·32)	21·47% (16·96–26·14)	2·55% (0·84–4·89)	5·75% (1·35–12·07)	0·77% (0·15–1·60)	0·88% (0·08–2·03)	0·02% (0·02–0·02)	21·81% (8·56–35·80)
Central Europe	48·61% (45·00–51·35)	20·44% (14·85–26·55)	3·87% (0·86–8·27)	12·60% (2·96–25·57)	2·36% (0·33–5·51)	2·00% (0·14–4·33)	0	10·12% (1·66–22·71)
Eastern Europe	47·12% (42·97–50·53)	17·96% (12·64–23·74)	4·05% (0·88–8·74)	15·07% (3·84–29·38)	3·87% (0·58–9·05)	1·98% (0·13–4·37)	0	9·95% (1·64–22·30)
Western Europe	49·34% (47·59–50·92)	18·14% (13·35–23·27)	3·59% (1·29–6·74)	13·23% (4·82–24·01)	2·45% (0·58–5·03)	1·11% (0·11–2·55)	0	12·15% (4·27–21·63)
Latin America, Andean	44·63% (38·93–49·12)	24·91% (19·98–29·97)	2·45% (0·81–4·76)	3·24% (0·59–7·17)	0·32% (0·05–0·66)	0·94% (0·09–2·16)	0	23·51% (9·29–38·45)
Central Latin America	46·39% (42·01–50·06)	22·34% (17·72–27·05)	2·51% (0·85–4·81)	4·70% (0·99–10·08)	0·58% (0·11–1·19)	0·90% (0·09–2·07)	0	22·59% (8·90–36·99)
Southern Latin America	47·75% (44·69–50·33)	20·63% (15·36–26·27)	3·74% (1·35–7·01)	10·98% (3·56–21·00)	2·16% (0·51–4·46)	1·19% (0·13–2·71)	0	13·55% (4·79–24·07)
Tropical Latin America	48·34% (44·91–51·06)	20·42% (16·14–24·87)	2·53% (0·86–4·82)	4·95% (1·07–10·59)	0·77% (0·15–1·58)	0·84% (0·09–1·92)	0	22·16% (8·76–36·23)
North Africa and Middle East	42·67% (36·63–48·00)	25·84% (20·35–31·67)	1·57% (0·47–3·00)	2·44% (0·25–5·90)	0·85% (0·15–1·79)	2·65% (0·41–5·78)	4·86% (4·73–5·00)	19·13% (6·90–34·17)
High-income North America	49·06% (46·80–51·00)	16·96% (12·39–21·87)	3·57% (1·26–6·72)	14·24% (5·34–25·45)	3·17% (0·77–6·48)	1·10% (0·11–2·53)	0	11·90% (4·19–21·18)
Oceania	46·62% (42·35–50·11)	36·25% (30·17–42·25)	1·52% (0·56–2·74)	3·53% (0·73–7·58)	0·29% (0·06–0·60)	2·47% (0·41–5·35)	0	9·33% (2·79–18·34)
Central sub-Saharan Africa	45·16% (39·41–49·70)	35·46% (28·98–42·15)	3·47% (1·31–6·35)	5·15% (1·16–10·91)	0·45% (0·08–0·92)	2·37% (0·40–5·09)	0·83% (0·82–0·85)	7·10% (1·95–14·34)
East sub-Saharan Africa	46·25% (41·63–49·94)	27·43% (22·39–32·58)	2·65% (0·96–4·90)	4·32% (1·01–9·07)	0·46% (0·08–0·94)	1·83% (0·29–3·98)	11·73% (11·26–12·20)	5·33% (1·46–10·78)
Southern sub-Saharan Africa	47·32% (43·45–50·48)	27·69% (21·77–33·77)	3·78% (1·33–7·09)	9·92% (2·58–20·11)	1·48% (0·27–3·07)	2·15% (0·35–4·67)	1·16% (1·12–1·19)	6·51% (1·78–13·16)
West sub-Saharan Africa	45·19% (40·25–49·29)	31·43% (25·71–37·34)	3·02% (1·13–5·52)	4·19% (0·91–8·91)	0·39% (0·07–0·78)	2·08% (0·35–4·47)	7·43% (7·10–7·76)	6·27% (1·72–12·68)
World	50·80% (46·12–54·74)	26·62% (21·53–31·78)	2·14% (0·69–4·11)	5·97% (1·63–11·87)	1·03% (0·20–2·22)	1·75% (0·25–3·81)	1·99% (1·88–2·09)	9·71% (3·03–18·50)
2015								
High-income Asia Pacific	49·36% (47·46–51·02)	14·66% (9·46–20·49)	3·60% (1·05–7·15)	11·60% (3·30–22·82)	4·07% (0·62–9·30)	0·79% (0·07–1·89)	0	15·92% (5·58–28·36)
Central Asia	48·26% (44·85–50·98)	18·11% (11·70–25·35)	4·05% (0·73–9·28)	10·05% (1·74–22·69)	4·06% (0·45–9·75)	1·41% (0·09–2·98)	0	14·06% (2·34–31·39)
East Asia	47·08% (43·32–50·19)	32·54% (24·96–40·48)	1·56% (0·57–2·90)	3·39% (0·81–7·11)	0·57% (0·10–1·18)	1·54% (0·25–3·34)	1·33% (0·87–1·80)	11·99% (3·55–23·66)
South Asia	66·39% (62·16–69·95)	23·62% (18·43–28·79)	1·09% (0·37–2·03)	1·31% (0·37–2·62)	0·15% (0·03–0·32)	0·74% (0·14–1·56)	0·03% (0·00–0·05)	6·67% (2·00–13·24)
Southeast Asia	46·14% (42·19–49·51)	33·95% (26·09–42·07)	1·57% (0·56–2·94)	3·46% (0·79–7·33)	0·71% (0·12–1·49)	1·63% (0·26–3·53)	0·07% (0·05–0·08)	12·48% (3·71–24·59)
Australasia	49·26% (46·91–51·17)	14·10% (9·09–19·75)	3·59% (1·04–7·14)	11·36% (3·17–22·44)	4·72% (0·73–10·81)	0·78% (0·07–1·88)	0	16·18% (5·69–28·77)
Caribbean	47·85% (44·44–50·66)	18·09% (13·08–23·36)	2·25% (0·68–4·30)	3·76% (0·78–8·16)	0·89% (0·16–1·90)	0·52% (0·05–1·23)	0	26·64% (10·50–43·58)
Central Europe	49·40% (46·71–51·60)	18·16% (11·65–25·53)	3·95% (0·73–9·07)	10·85% (1·95–24·55)	3·12% (0·32–7·43)	1·38% (0·09–2·95)	0	13·14% (2·14–29·55)
Eastern Europe	48·53% (45·35–51·05)	14·84% (9·18–21·40)	4·13% (0·73–9·56)	13·39% (2·49–29·77)	5·06% (0·56–12·33)	1·32% (0·07–2·85)	0	12·72% (2·09–28·52)
Western Europe	49·61% (47·74–51·21)	15·49% (10·05–21·56)	3·58% (1·05–7·09)	10·68% (3·02–21·13)	3·48% (0·52–7·95)	0·81% (0·07–1·93)	0	16·35% (5·74–29·11)
Andean Latin America	46·07% (41·71–49·60)	20·23% (14·87–25·82)	2·22% (0·70–4·16)	2·44% (0·47–5·27)	0·42% (0·07–0·89)	0·53% (0·06–1·22)	0	28·09% (11·05–46·03)
Central Latin America	47·90% (44·70–50·60)	17·03% (12·25–22·14)	2·34% (0·72–4·46)	3·96% (0·82–8·60)	1·02% (0·19–2·14)	0·52% (0·05–1·21)	0	27·23% (10·72–44·58)

(Table 2 continues on next page)

prevalence between 2015 and 1990 divided by the 1990 prevalence multiplied by 100; percentage changes by cause were –16·6% for cataract, –13·3% for uncorrected refractive error, –37·0% for age-related macular degeneration, –15·7% for glaucoma, 7·7% for diabetic retinopathy, –43·2% for corneal opacity, and –68·9% for trachoma [appendix]). For vision impairment, these percentage changes by cause were –4·0% for cataract, –0·9% for uncorrected refractive error, –28·6% for age-related macular degeneration, –3·8% for glaucoma, 28·8% for diabetic retinopathy, –36·7% for corneal opacity, and –66·6% for trachoma (appendix). The crude prevalence of blindness and vision impairment by cause in 1990 and 2015 for those aged 50 years and older is given in appendix. The percentage changes in age-standardised prevalence by cause for the same causes of blindness and vision impairment were as follows: cataract (blindness –42·0%; vision impairment –32·7%), uncorrected refractive error (–38·8%; –26·7%), age-related macular degeneration (56·6%; –46·7%), glaucoma (–38·7%; –27·6%), diabetic retinopathy (–13·7%; 9·6%), corneal opacity (–59·2%; –52·9%), and trachoma (–74·8%; –71·0%; appendix). Age-standardised prevalence of blindness and vision impairment by cause in 1990 and 2015 for those aged 50 years and older is given in the appendix.

Avoidable vision loss due to a preventable or treatable cause can be defined as any vision loss due to cataract, uncorrected refractive error, trachoma, glaucoma, diabetic retinopathy, or corneal opacity. With use of this definition, of the 190·4 million blind or vision impaired in 1990, 158·0 million (80% UI 54·3 million to 321 million [83·0% (69·4–98·1)]) had a preventable or treatable cause. Of the 233·3 million blind or vision impaired in 2010, the number avoidable was 190·6 million (73·6 million to 372·3 million [81·7% (68·9–96·2)]), by 2015, of 252·6 million, it was 205·1 million (75·4 million to 409·8 million [81·2% (67·7–96·5)]), and by 2020, of the projected 275.6 million, it is projected to be 222·6 million (76·1 million to 457·5 million [80·8% (66·4–97·3)]). The number of people within the other cause category increased from 22 million (80% UI 3 million to 70 million) in 1990 to 32 million (5 million to 101 million) by 2010 and to 37 million (5 million to 117 million) by 2015 and is projected to increase to 42 million (6 million to 136 million) by 2020.

Despite the observed reduction in crude or age-standardised prevalence of cataract between 1990 and 2015, the effect of growing and ageing populations means that the number of people affected by cause-specific blindness is actually increasing. The number of people affected by blindness due to cataract increased between 1990 and 2015 from 10·9 million (80% UI 2·9 million to 24·3 million) to 12·6 million (3·4 million to 28·7 million) and by vision impairment due to cataract from 39·6 million (13·9 million to 80·0 million) to 52·6 million (18·2 million to 109·6 million; appendix). The decline in adult (aged 50 years and older) age-standardised

	Uncorrected refractive error	Cataract	Glaucoma	Age-related macular degeneration	Diabetic retinopathy	Corneal opacity	Trachoma	Other
(Continued from previous page)								
Southern Latin America	48·20% (45·38–50·51)	15·95% (10·40–22·13)	3·71% (1·09–7·35)	10·11% (2·78–20·18)	3·93% (0·60–8·97)	0·82% (0·07–1·96)	0	17·28% (6·09–30·72)
Tropical Latin America	49·26% (46·68–51·36)	15·27% (10·84–20·04)	2·41% (0·73–4·62)	4·68% (0·98–10·20)	1·38% (0·26–2·90)	0·49% (0·05–1·14)	0	26·52% (10·43–43·45)
North Africa and Middle East	44·58% (39·90–48·71)	21·37% (14·90–28·08)	1·62% (0·45–3·27)	2·16% (0·22–5·25)	1·61% (0·33–3·39)	1·67% (0·26–3·63)	1·90% (1·73–2·08)	25·10% (9·03–44·90)
High-income North America	49·53% (47·47–51·32)	14·39% (9·30–20·10)	3·56% (1·03–7·08)	10·86% (3·01–21·54)	4·55% (0·70–10·40)	0·79% (0·07–1·90)	0	16·32% (5·74–29·01)
Oceania	47·76% (44·48–50·49)	34·60% (26·95–42·45)	1·43% (0·52–2·64)	2·07% (0·47–4·37)	0·34% (0·06–0·70)	1·55% (0·26–3·34)	0	12·25% (3·65–24·12)
Central sub-Saharan Africa	46·50% (42·03–50·09)	34·41% (26·23–43·07)	3·63% (1·24–6·86)	3·42% (0·85–6·98)	0·51% (0·10–1·08)	1·55% (0·26–3·37)	0·21% (0·20–0·23)	9·77% (2·67–19·76)
East sub-Saharan Africa	46·79% (43·03–49·98)	32·35% (24·90–40·13)	2·90% (0·97–5·55)	2·37% (0·57–4·86)	0·31% (0·06–0·64)	1·36% (0·22–2·95)	5·78% (5·08–6·52)	8·15% (2·22–16·48)
Southern sub-Saharan Africa	48·05% (44·96–50·67)	26·94% (19·62–34·83)	4·12% (1·28–8·13)	8·01% (2·03–16·40)	1·77% (0·34–3·83)	1·53% (0·23–3·38)	0·31% (0·27–0·36)	9·26% (2·51–18·73)
West sub-Saharan Africa	46·35% (42·44–49·69)	34·14% (26·22–42·50)	3·29% (1·12–6·24)	2·54% (0·60–5·21)	0·38% (0·07–0·80)	1·49% (0·25–3·20)	2·46% (2·00–2·95)	9·36% (2·56–18·92)
World	52·34% (48·66–55·45)	25·15% (18·83–31·76)	2·05% (0·62–4·03)	4·38% (1·05–9·15)	1·30% (0·20–2·93)	1·14% (0·17–2·48)	0·64% (0·50–0·79)	13·00% (4·14–24·57)

Data are mean (80% uncertainty interval).

Table 2: **Contribution of each cause to moderate or severe vision impairment among adults aged 50 years and older in 1990 and 2015**

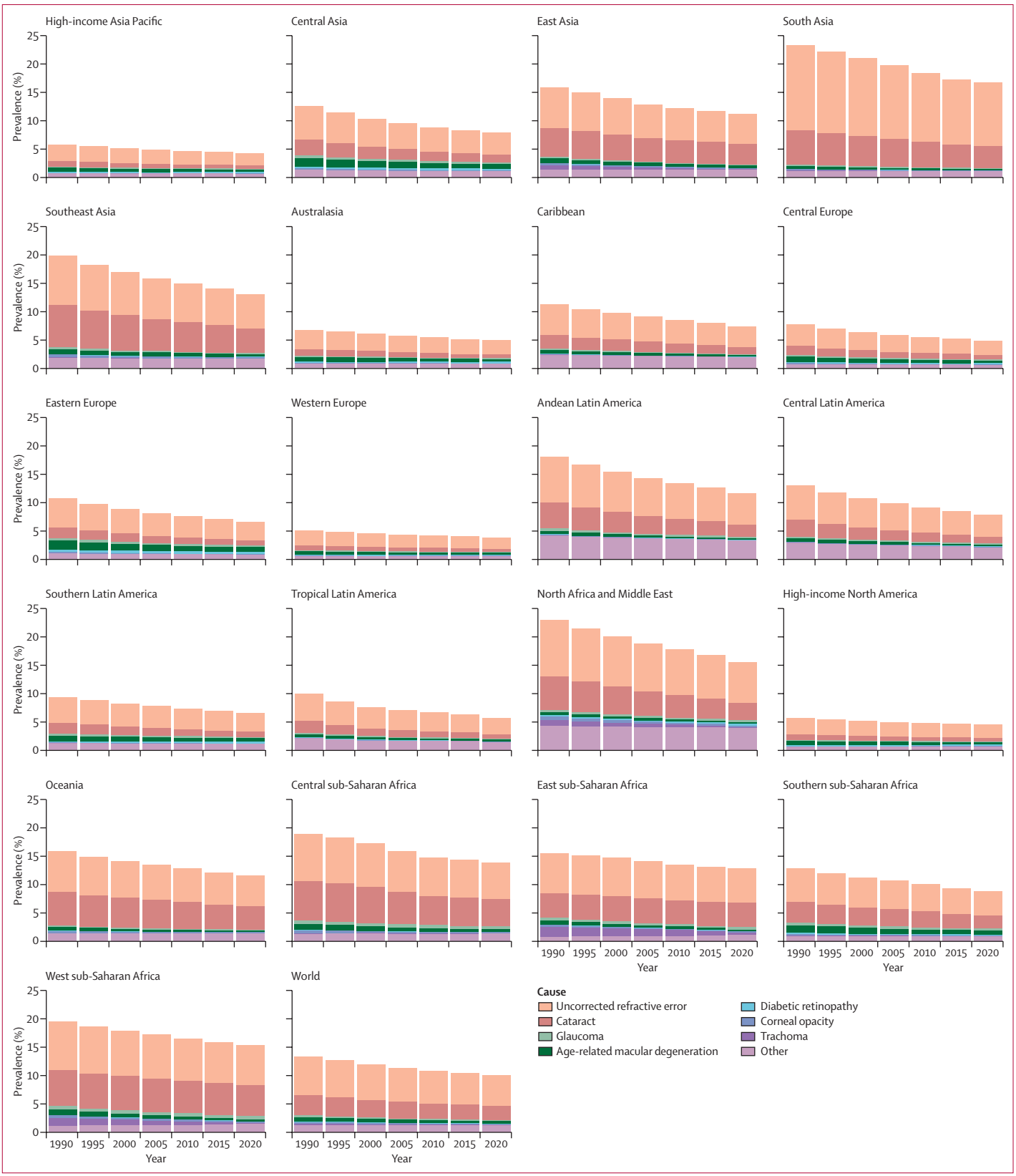

Figure 2: **Age-standardised prevalence of moderate or severe vision impairment in adults aged 50 years and older from 1990 to 2015**

prevalence of cataract blindness and vision impairment combined was most marked in eastern Europe and Latin American regions (with the age-standardised prevalence falling by more than 47% in these regions); the region with the smallest decline was east sub-Saharan Africa (appendix).

The number of people affected by blindness due to diabetic retinopathy increased between 1990 and 2015 from 0·2 million (80% UI none to 1·0 million) to 0·4 million (none to 1·5 million) and by vision impairment due to diabetic retinopathy increased from 1·4 million (0·1 million to 5·4 million) to 2·6 million (0·2 million to 9·9 million; appendix). We observed a decrease in adult age-standardised prevalence of blindness and vision impairment due to diabetic retinopathy in all regions of sub-Saharan Africa, Oceania, Andean Latin America, central and eastern Europe, and the Caribbean, yet observed an increase in the high-income subregions, Asian regions, and north Africa and the Middle East (appendix).

The number of people affected by blindness due to age-related macular degeneration reduced between 1990 and 2015 from 2·2 million (80% UI 0·2 million to 8·3 million) to 2·0 million (0·2 million to 7·3 million) and by vision impairment due to age-related macular degeneration reduced from 8·5 million (1·0 million to 29·4 million) to 8·4 million (0·9 million to 29·5 million; appendix). We noted a decline in adult age-standardised prevalence of age-related macular degeneration blindness and vision impairment combined in all regions (appendix).

The number of people affected by blindness due to glaucoma increased between 1990 and 2015 from 2·5 million (80% UI 0·3 million to 8·6 million) to 3·0 million (0·4 million to 9·9 million) and by vision impairment due to glaucoma increased from 3·0 million (0·4 million to 9·9 million) to 4·0 million (0·6 million to 13·3 million; appendix). We noted a decline in adult age-standardised prevalence of glaucoma blindness and vision impairment combined in all regions, with a less marked reduction noted in sub-Saharan Africa regions and the high-income regions than in other regions (appendix).

The number of people affected by blindness due to uncorrected refractive error increased between 1990 and 2015 from 6·2 million (80% UI 1·7 million to 12·9 million) to 7·4 million (2·4 million to 14·8 million) and by vision impairment increased from 84·8 million (33·1 million to 151·5 million) to 116·3 million (49·4 million to 202·1 million; appendix). We noted declining adult age-standardised prevalence of uncorrected refractive error blindness and vision impairment combined in all regions (appendix). We also observed this decline when considering all ages (appendix).

The number of people affected by blindness due to corneal opacity (not related to trachoma) declined between 1990 and 2015 from 1·6 million (80% UI 0·1 million to 6·8 million) to 1·3 million (0·1 million to 5·2 million) and by visual impairment due to corneal opacity from 3·3 million (0·2 million to 12·6 million) to 2·9 million (0·2 million to 10·5 million; appendix). We noted a decline in adult and all-age age-standardised and crude prevalence of corneal opacity blindness and vision impairment combined in all regions, with a less marked reduction noted in sub-Saharan Africa regions, east Asia, and high-income regions than in the other world regions (appendix).

Of the 216·6 milllion people of all ages with moderate or severe vision impairment in 2015, 78% were vision impaired due to cataract or uncorrected refractive error, whereas these causes were responsible for 56% of the 36·0 million people blind.

The number of people affected by blindness due to trachoma sharply reduced between 1990 and 2015 from 0·9 million (80% UI 0·3 million to 1·8 million) to 0·4 million (0·1 million to 0·9 million) and by vision impairment due to trachoma reduced from 3·5 million (1·4 million to 6·3 million) to 1·6 million (0·5 million to 3·3 million; appendix).

By 2020, among the global population with moderate or severe vision impairment (237·1 million [80% UI 101·5 million to 399·0 million]), uncorrected refractive error is estimated to affect 127·7 million (51·0 million to 225·3 million) people, with the next commonest cause of vision impairment being cataract, affecting 57·1 million (17·9 million to 124·1 million), then age-related macular degeneration, affecting 8·8 million (0·8 million to 32·1 million), then glaucoma, affecting 4·5 million (0·5 million to 15·4 million), and then diabetic retinopathy, affecting 3·2 million (0·2 million to 12·9 million; appendix). Among a global blind population of 38·5 million (13·2 million to 70·9 million) people in 2020, the greatest number of people blind by cause is estimated to be due to cataract (13·4 million [3·3 million to 31·6 million]) followed by uncorrected refractive error (8·0 million [2·5 million to 16·3 million]), glaucoma (3·2 million [0·4 million to 11·0 million]), and age-related macular degeneration (2·0 million [0·2 million to 7·6 million]; appendix). From 1990 to 2015 and in 2020 projections, the low-prevalence causes of blindness and vision impairment (unspecified in this analysis and most vision impairment surveys) in aggregate make up an increasingly large proportion of the burden of disease (appendix).

Discussion

This study is a continuation of a series of systematic analyses, most recently for 2010 estimations.[2] Refreshment of the Global Vision Database added a further 61 population-based studies, of which 44 contributed disaggregated vision impairment prevalence data by cause. 28 new studies involved rapid assessment of avoidable blindness survey methods, from which at least cataract-specific prevalence could be extracted. In preparing the new estimates for 2015, we revisited all the studies within the Global Vision Database as a whole, with an interest in exploring the contribution of causes that are

not considered separate causes by the Global Burden of Disease Study—eg, myopic macular degeneration and amblyopia—causes that are known to be of great importance in some populations.[3] Data sparsity meant that meaningful global estimates for these low-prevalence conditions could not be made. These causes will therefore be contributors to the other cause category, which remains large. However, we did have sufficient data sources to disaggregate non-trachomatous corneal opacity as a cause of vision impairment. Studies have substantiated corneal opacity as a common cause of childhood[8] and adult[3,4] blindness. A WHO report[9] in 2002 stated that 5·1% of blindness was estimated to be a result of corneal opacification. This figure falls within the interval of uncertainty for our estimates in both 1990 and 2015. The challenge with reporting of corneal opacity as a cause of bilateral vision impairment is that, historically, the specific cause of the opacity was not reported in population-based surveys. The various known causes of corneal opacification include corneal injury; infection; dystrophy; keratoconus; iridocorneal endothelial syndrome; and other specific causes, such as onchocerciasis, trachoma, and iatrogenic causes.[10] In the past, smallpox was a potent cause of bilateral corneal blindness. In the case of corneal opacity, considerable imprecision exists at the regional level for reasons of data sparsity and one has to be cautious about these regional results.

Several limitations apply to a causal analysis of this type. Many country-years remained without data or only had subnational data, and only 12 national studies reporting vision impairment for all ages and all causes were available. Case definitions varied between studies, and other causes contributed to 25% of the blindness burden of 2015 and 13% of that of vision impairment. We used a similar approach for trachoma as for the previous meta-analysis,[2] which derived estimates for the prevalence of trachoma from nationally representative surveys of vision impairment and a Bayesian predictive model that used data for the prevalence of trichiasis,[5] a complication of trachoma that is a direct cause of vision impairment. The analysis was limited in that no data for prevalence of trachoma or trichiasis existed in 24 countries considered by WHO to have trachoma endemic areas. We therefore conservatively assumed a trachoma cause proportion of zero for these countries, which could have led to an underestimation of the prevalence of trachoma as a cause of blindness and vision impairment. Substantial improvements in reduction of trachoma prevalence and increases in the number of surgical operations for trichiasis would account for the observed reduction in vision impairment.[11] Protocols often dictate that population-based studies report one cause as the principal cause for an individual examined in that particular study to arrive at the causal prevalence. When coexisting disorders contributed equally to blindness or vision impairment, only the "most readily curable" or "most easily preventable" was recorded.[12] This approach had the potential to underestimate the effect of diabetic retinopathy, glaucoma, or other diseases when the survey participant presented with cataract, while underestimating the burden of cataract when participants also have an uncorrected refractive error.[13] Some studies had a small sample size, therefore the CIs of the cause-specific prevalence estimate were large. Our methods took into account sample size, so studies with small sample sizes influenced the estimates less than studies with large sample sizes did, and estimated uncertainty was large when only small studies were available. Most sample sizes for vision impairment surveys are powered to achieve precision of the all-cause blindness estimate, with inadequate sample size for precision of a cause-specific prevalence of blindness. Risk factors such as race or ethnicity are associated with specific causes such as glaucoma and age-related macular degeneration. Our modelling exercise did not characterise these risk factors, yet in future analyses, these factors would be important covariates to consider in the model. Our model does not include a varying refractive error term by region, which accounts for the proportion of vision impairment due to refractive error remaining constant across all regions except for south Asia. More regional specificity than in this study for uncorrected refractive error will be a feature of future updates. Greater imprecision in the definition of macular degeneration in older studies might have contributed to the unexpectedly large declines in age-specific blindness and vision impairment due to age-related macular degeneration that our model indicates. Older time periods might have been more influenced by misclassification of any kind of maculopathy as being age-related macular degeneration and information about age-related macular degeneration trends might be weaker than for the other specified diseases. Relative differences in prevalence of vision impairment or blindness by cause over time should not be overinterpreted as they correspond to very small absolute differences. Instead, we have drawn attention to our estimates of substantial change over time on the basis of the model, which demonstrates temporal differences in terms of the relative attributable fractions, rather than the crude overall prevalences. Caution should be exercised in interpretation of projections to 2020 by cause. These projections assumed that the UN population projections for the future were correct and the covariates that we used in our model for access to health care[14] and literacy,[15] which have not been modelled into the future, will remain unchanged after 2015.

The strengths of our study included addition of 61 new studies in this refreshment of the Global Vision Database and also some additional cause-specific data to existing studies in the database; analysis of trends in the causes of vision impairment, with projections to 2020; increasing differentiation of age-related macular degeneration from other maculopathies; incorporation of non-linear age trends and accounting for data that were not reported by age; and systematic quantitative analysis and reporting of uncertainty.

The top three causes of blindness in 2015 were cataract, uncorrected refractive error, and glaucoma and for vision impairment were uncorrected refractive error, cataract, and age-related macular degeneration. We noted large differences in the distribution of causes of blindness by region. Although the prevalence of cataract blindness exceeded that caused by age-related macular degeneration in high-income subregions, these regions had a lower prevalence of cataract and higher prevalence of age-related macular degeneration as causes of blindness and vision impairment than did other regions. Although we have not modelled age effects within those aged 50 years and older, the prevalence of cause-specific blindness is anticipated to increase in the much older age groups, in keeping with the precipitous increase in global blindness prevalence of all causes observed in our previous analysis (50–54 years 0·4%; 75–79 years 4%; >90 years 11%).[1]

In our report[1] of all-cause prevalence, more women than men were vision impaired, with a world female-to-male age-standardised prevalence ratio among adults of 1·05 for blindness and 1·07 for moderate or severe vision impairment. In this further analysis by cause, we noted no clear sex difference in the prevalence of blindness or vision impairment caused by age-related macular degeneration; this finding concurs with a meta-analysis[16] of 39 population-based studies, which did not find evidence of sex difference in the prevalence of both early and late age-related macular degeneration prevalence. Likewise, our finding of a male preponderance in those vision impaired because of glaucoma concurs with a meta-analysis of 50 studies by Tham and colleagues,[17] which reported a higher prevalence of primary open angle glaucoma among men than among women. A meta-analysis[18] of diabetic retinopathy prevalence showed a similar prevalence for men and women when considering any diabetic retinopathy or vision-threatening diabetic retinopathy, whereas our analysis suggested a female preponderance for vision-impairing diabetic retinopathy. Our finding was surprising and the new data added to the Global Vision Database for diabetic retinopathy were actually aggregated data, with men and women combined. This discrepancy highlights the need for future research into this sex difference and the need to disaggregate between men and women in reporting of research. Like our previous report[2] that presented an increase in causal contribution of diabetic retinopathy to blindness between 1990 and 2010, we report in this study that between 1990 and 2015, the proportion due to this cause has increased, as has the crude and age-standardised prevalence of blindness due to diabetic retinopathy. However, the statistical test of posterior probability suggested a decline over this time period. Wide prevalence uncertainty intervals make it difficult to reach a conclusion as to the nature of this temporal change. Since our previous report, several rapid assessment studies involving a diabetic retinopathy module have been added to the Global Vision Database. Additionally, considerable regional differences exist in vision impairment or blindness due to diabetic retinopathy. Since the life expectancy of individuals with diabetes, in particular in south Asia, is reduced,[19] they often do not have the chance to develop diabetic retinopathy as a sequela of diabetes. This factor could explain the finding that, despite a high proportion of diabetes in the population,[20] the prevalence of diabetic retinopathy as a cause of vision impairment and blindness is low in that world region. With further improvement in the medical infrastructure in south Asia and an increase of life expectancy for patients with diabetes, an increase in the prevalence of diabetic retinopathy might be expected.

82·9% of people blind or vision impaired in 1990 had a preventable or treatable cause, decreasing to 81·7% by 2010 and to 81·2% by 2015 and it is projected to be 80·8% in 2020. A further proportion of people blind or vision impaired due to other causes will have a preventable or treatable cause, such as onchocerciasis. The number of people within the other cause category increased from 22 million in 1990 to 32 million by 2010 and to 37 million by 2015 and is projected to increase to 42 million by 2020, therefore the increase in cases ascribed to other causes could have masked what would otherwise have been a more profound reduction in the proportion of cases with avoidable or preventable causes than shown in this study. Member States of WHO have agreed to work towards a reduction of prevalence of avoidable vision impairment of 25% by 2019 from the baseline established in 2010. This Global Action Plan[21] includes only uncorrected refractive error and cataract as the avoidable causes. In 2010, 2·5% of the world's population was estimated to be blind or vision impaired due to these two causes. By 2020, we estimate that this proportion will be 2·7% (largely because of population ageing) unless specific activities to address these needs are increased. The 2010 baseline estimate for avoidable blindness and vision impairment used by the Global Action Plan was 3·18%, calculated from data from a less sophisticated statistical model[22] than in our study as follows: (crude prevalence of vision impairment × proportion due to cataract) + (crude prevalence of vision impairment × proportion due to uncorrected refractive error), whereas our 2010 estimate using the same formula was 2·49%. For this reason and also the fact that the statistical models and data sources used for these two sets of estimates are different, one should be cautious in making this comparison, yet we are reporting a rise of 5·6% compared with the planned 25% reduction set by WHO.

On the basis of our findings and those of the previous report,[2] some clear recommendations emerge for future research in this area. Improvements in modelling of causal data can be obtained by giving consideration to potential upstream health system factors that influence cause attribution in different studies at different times. These indicators and other health system indicators for the country or region at the time of the eye survey, such

For the **international project** see http://www.globalvisiondata.org/news/development-of-consensus-guidelines-for-population-based-eye-and-vision-surveys

as existence of universal access to basic eye care, availability of free access to essential ocular medicines, whether or not a diabetic retinopathy screening programme exists, the cataract surgical coverage rate, eye care staff to population ratios, and proportion of gross domestic product spent on health care, are under consideration as part of an international project to assess the quality and risk of bias of national population-based surveys of vision impairment. This line of analysis was initiated at the World Ophthalmology Congress of 2016 by the Vision Loss Expert Group. Greater standardisation of measurement protocols and case definitions than at present in surveys is recommended, with greater sophistication in the definition of potentially avoidable conditions in both surveys and meta-analyses to reflect changing treatments and enhanced understanding over time. As population-based surveys become more precise at identifying specific causes than at present, disaggregation by cause when reporting on causes of vision impairment becomes increasingly important.

Of the 216·6 milllion people of all ages with moderate or severe vision impairment in 2015, 78% were vision impaired because of cataract or uncorrected refractive error, which are completely treatable causes, with these causes responsible for 56% of the 36·0 million people blind. Glaucoma, age-related macular degeneration, corneal opacity, diabetic retinopathy, and trachoma were less frequent causes of blindness and vision impairment than were cataract or uncorrected refractive error, some of which are preventable and treatable as well. Globally, the overall crude prevalence of blindness and vision impairment that incorporates all of these causes reduced between 1990 and 2015.[1] However, with growing and ageing populations, the number of people affected by cause-specific blindness is generally increasing. Projections to 2020, an important milestone for the WHO's Global Action Plan,[21] lead us to conclude that the prevalence of avoidable vision impairment is not reducing fast enough to keep pace with this demographic change in the world's population, so more attention to this problem is needed than has been given to it so far.

Contributors

RRAB, MVC, AD, AS, NT, and TB prepared the vision impairment survey data. SRF, GAS, and RRAB analysed the data. RRAB and SRF wrote the first draft of the report. All authors designed the study, analysed data, and wrote the report. RRAB oversaw the research.

Declaration of interests

SR, KN, and NT are part-employed by the Brien Holden Vision Institute. SR, KN, and NT were funded by the Brien Holden Vision Institute for the purpose of this project. All other authors declare no competing interests.

Acknowledgments

The Brien Holden Vision Institute provided unrestricted funds to support the commissioning of the systematic review and the statistical analysis involved in this work.

References

1 Bourne RR, Flaxman SR, Braithwaite T, et al. Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis. *Lancet Glob Health* 2017; **5:** e888–97.

2 Bourne RR, Stevens GA, White RA, et al. Causes of vision loss worldwide, 1990–2010: a systematic analysis. *Lancet Glob Health* 2013; **1:** e339–49.

3 Xu L, Wang Y, Li Y, et al. Causes of blindness and visual impairment in urban and rural areas in Beijing: the Beijing Eye Study. *Ophthalmology* 2006; **113:** 1134.e1–11.

4 Liang YB, Friedman DS, Wong TY, et al. Prevalence and causes of low vision and blindness in a rural Chinese adult population: the Handan Eye Study. *Ophthalmology* 2008; **115:** 1965–72.

5 Global Atlas of Trachoma. www.trachomaatlas.org/global-trachoma-atlas (accessed Aug 14, 2017).

6 Ahmad OB, Boschi-Pinto C, Lopez AD, Murray CJ, Lozano R, Inoue M. Age standardization of rates: a new WHO standard. http://www.who.int/healthinfo/paper31.pdf (accessed Aug 4, 2017).

7 UN. World population prospects: the 2015 revision. New York: United Nations, 2015.

8 Gilbert CE, Anderton L, Dandona L, Foster A. Prevalence of visual impairment in children: a review of available data. *Ophthalmic Epidemiol* 1999; **6:** 73–82.

9 Resnikoff S, Pascolini D, Etya'ale D, et al. Global data on visual impairment in the year 2002. *Bull World Health Organ* 2004; **82:** 844–51.

10 Burton MJ. Corneal blindness: prevention, treatment and rehabilitation. *Comm Eye Health* 2009; **22:** 33–35.

11 WHO Alliance for the Global Elimination of Trachoma by 2020: progress report on elimination of trachoma, 2014–2016. *Wkly Epidemiol Rec* 2017; **92:** 359–68.

12 WHO. Coding instructions for the WHO/PBL eye examination record (version III). http://apps.who.int/iris/bitstream/10665/67896/1/PBL_88.1.pdf (accessed Aug 14, 2017).

13 Kempen JH. The need for a revised approach to epidemiological monitoring of the prevalence of visual impairment. *Ophthalmic Epidemiol* 2011; **18:** 99–102.

14 GHME Conference Organizing Committee. Shared innovations in measurement and evaluation. *Lancet* 2011; **377:** 969–70.

15 Gakidou E, Cowling K, Lozano R, Murray CJ. Increased educational attainment and its effect on child mortality in 175 countries between 1970 and 2009: a systematic analysis. *Lancet* 2010; **376:** 959–74.

16 Wong WL, Su X, Li X, et al. Global prevalence of age-related macular degeneration and disease burden projection for 2020 and 2040: a systematic review and meta-analysis. *Lancet Glob Health* 2014; **2:** e106–16.

17 Tham YC, Li X, Wong TY, Quigley HA, Aung T, Cheng CY. Global prevalence of glaucoma and projections of glaucoma burden through 2040: a systematic review and meta-analysis. *Ophthalmology* 2014; **121:** 2081–90.

18 Yau JW, Rogers SL, Kawasaki R, et al. Global prevalence and major risk factors of diabetic retinopathy. *Diabetes Care* 2012; **35:** 556–64.

19 GBD 2016 Causes of Death Collaborators. Global, regional, and national age-sex specific mortality for 264 causes of death, 1980–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet* 2017; **390:** 1151–210.

20 GBD 2016 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet* 2017; **390:** 1211–59.

21 WHO. Universal eye health: a global action plan 2014–2019. Geneva: World Health Organization, 2013.

22 Pascolini D, Mariotti SP. Global estimates of visual impairment: 2010. *Br J Ophthalmol* 2012; **96:** 614–18.