Causes of vision loss worldwide, 1990–2010: a systematic analysis

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Summary

Background Data on causes of vision impairment and blindness are important for development of public health policies, but comprehensive analysis of change in prevalence over time is lacking.

Methods We did a systematic analysis of published and unpublished data on the causes of blindness (visual acuity in the better eye less than 3/60) and moderate and severe vision impairment ([MSVI] visual acuity in the better eye less than 6/18 but at least 3/60) from 1980 to 2012. We estimated the proportions of overall vision impairment attributable to cataract, glaucoma, macular degeneration, diabetic retinopathy, trachoma, and uncorrected refractive error in 1990–2010 by age, geographical region, and year.

Findings In 2010, 65% (95% uncertainty interval [UI] 61–68) of 32·4 million blind people and 76% (73–79) of 191 million people with MSVI worldwide had a preventable or treatable cause, compared with 68% (95% UI 65–70) of 31·8 million and 80% (78–83) of 172 million in 1990. Leading causes worldwide in 1990 and 2010 for blindness were cataract (39% and 33%, respectively), uncorrected refractive error (20% and 21%), and macular degeneration (5% and 7%), and for MSVI were uncorrected refractive error (51% and 53%), cataract (26% and 18%), and macular degeneration (2% and 3%). Causes of blindness varied substantially by region. Worldwide and in all regions more women than men were blind or had MSVI due to cataract and macular degeneration.

Interpretation The differences and temporal changes we found in causes of blindness and MSVI have implications for planning and resource allocation in eye care.

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Introduction

Data on the causes of vision impairment and blindness form an important basis for recommendations in public health policies, such as planning of national budgets and health services, and are important for scientific research. Population-based studies done in the past 20 years have revealed that cataract, glaucoma, macular degeneration, diabetic retinopathy, trachoma, and uncorrected refractive error are the most common causes of blindness and vision impairment worldwide.[1–4] Most studies have focused on one population within a circumscribed region and frequently within one ethnic group. Important differences between ethnic groups, regions of habitation, demographic parameters, lifestyle, exposure to environmental factors, and other factors, however, can affect the causes and prevalence of vision loss. The information about vision loss, therefore, might not be relevant at the worldwide level. Assessment of causes of vision impairment, their trends, and the effects of interventions is most accurate when repeated surveys are done within the same population, but such data are rarely collected. In their absence, estimates of patterns and trends in vision impairment derived from available data might be useful to set policy priorities.

Estimates of the leading causes of vision impairment worldwide have been generated by meta-analyses.[5–8] The first of these, done by Thylefors and colleagues in 1995,[5] estimated that 38 million people were blind, mainly due to cataract, trachoma, and glaucoma. A lack of prevalence data for diabetic retinopathy and macular degeneration precluded an estimate of their burden at that time. The Global Burden of Disease, Risk Factors and Injury Study 2010 (GBD), which started in 2007, aimed to calculate comparable estimates of burden of disease, injuries, and risk factors from 1990 and 2010.[9,10] The Vision Loss Expert Group (VLEG) of the GBD published its methods for a systematic review of published and unpublished data from population-based studies that reported the prevalence of blindness and vision impairment in 1980–2012.[11] We have found an decrease in age-standardised prevalence of blindness and MSVI over the past 20 years. Nevertheless, because of population growth and the increase in the number of elderly adults, the blind population has remained stable and the vision-impaired population might have increased.[12]

Here we report a systematic analysis of the VLEG GBD dataset. We aimed to estimate the main causes of blindness and vision impairment worldwide and by geographical region, including analysis of trends over time.

Methods

Study design

We estimated trends in causes of vision impairment, including analysis of uncertainties, by age, sex, and

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See Online for appendix

geographical region (we used the 21 regions defined in the GBD; appendix pp 1–2). We estimated what proportions of overall vision impairment were from six common causes of blindness and vision impairment: cataract, glaucoma, macular degeneration, diabetic retinopathy, trachoma, and uncorrected refractive error (table 1). We also estimated the proportions of blindness and vision impairment related to other causes. We calculated the causes of moderate and severe vision impairment (MSVI), defined as visual acuity in the better eye lower than 6/18 but at least 3/60 at presentation, and blindness, defined as visual acuity in the better eye lower than 3/60 at presentation. We did our analysis in three steps: data identification and access, as described previously;[11] estimation of fractions for each cause, by severity of vision impairment, sex, age, and region, as described in this report; and application of cause fractions to the prevalence of all-cause presenting vision impairment, which was estimated previously.[12]

	Description
Cataract	Age-related cataract leading to progressive visual impairment
Glaucoma	All types of glaucoma combined
Macular degeneration	Degeneration of macula and posterior pole, including age-related macular degeneration, myopic maculopathy, macular hole, and any other macular disorder
Diabetic retinopathy	Diabetic retinopathy and sequelae
Trachoma	Trachoma-related corneal scarring
Uncorrected refractive error	Estimated as the difference between vision impairment at presentation and best-corrected sight (includes aphakia)
Other	All other causes, including unidentified causes

***Table 1*: Definitions of causes of blindness and vision impairment used in this study**

Panel: Research in context

Systematic review

We did a systematic review of articles published from January, 1980, to January, 2012, in the following sources: Medline, Embase, and the WHO library information system. Search terms included concepts to describe "blindness", "VI", "population", "eye", "survey", and a list of disorders that affect the eyes. We identified additional unpublished data sources through personal communication with researchers identified in the literature search.[11] Literature reviews published by WHO and the WHO Prevention of Blindness and Deafness programme have been used to make worldwide estimates of numbers of people blind or with vision impairment. The latest of studies included literature published in 2000–10, and the analysis was limited to three age groups, with no breakdown by sex, provision of a point estimate for 2010, or estimates for the six WHO epidemiological subregions within a more limited timeframe.[8]

Interpretation

We have previously reported prevalence of vision impairment and blindness worldwide and shown that the age-standardised prevalence of both has decreased between 1990 and 2010.[12] This study added to those findings by investigating the contribution of various causes to the burden of vision loss, and by analysing temporal trends in contribution. 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. By contrast with the WHO data, we undertook a granular analysis, and present data in 5-year age groups and by sex, provide time-series estimates for the period 1990–2010, and break them down geographically for 21 regions. Thus, our estimates of prevalence are more detailed and show temporal change. This analysis, therefore, provides useful information for the setting of priorities, development of policies, and planning. Additionally, the data might provide a resource for advocacy efforts to help mobilise resources for eye-care services from governments, donors, and civil society.

Data sources

The methods for the data search have been published previously.[11] Briefly, we searched for articles published from Jan 1, 1980, to Jan 31, 2012 (panel). Our initial search identified 14908 relevant manuscripts, which were distilled by application of rigorous selection criteria and review by an expert panel to 243 high-quality, population-based studies (appendix pp 3–18). Data from epidemiological studies that reported prevalence disaggregated by cause (128 studies) were used to calculate the proportions of blindness and MSVI that were due to cataract, glaucoma, macular degeneration, diabetic retinopathy, trachoma, and undercorrection of refractive error or other causes. Many countries with endemic trachoma lack epidemiological data on trachomatous blindness and, therefore, we also obtained data from the authors of an unpublished working paper, which uses trichiasis data extracted from the Global Atlas of Trachoma[13] to model the prevalence of trachoma-related vision impairment in specific countries (Smith JL, Solomon A, Haddad D, Brooker S, personal communication).

Statistical analysis

We used the DisMod-MR model from GBD to calculate the fraction of vision impairment due to cataract, glaucoma, macular degeneration, and diabetic retinopathy. This model is a Bayesian multi-level regression tool that incorporates age.[10,14] Briefly, DisMod-MR includes the following elements: covariates that predict variation in the true proportion of vision impairment from each disease (eg, year); fixed effects that adjust for differences in definitions (eg, whether causes were reported on the basis of vision at presentation *vs* best-corrected vision); a hierarchical model structure that fits random intercepts in individual countries derived from the data observed in a country, its region, and in other regions, on the basis of the availability and consistency of country-specific and region-specific data; a piecewise linear spline model of the age pattern; and a fixed effect for data on men and boys. We used a specific set of parameters for each cause of vision impairment (appendix p 19). We assessed all model fits visually.

For causes of cataract we fitted two DisMod-MR models, one with data on the proportion of blindness caused by cataract and one for MSVI caused by cataract (appendix p 19). We fitted each model with three covariates: an indicator variable that described whether the data were based on visual acuity at presentation or best-corrected visual acuity, a year covariate that allowed for analysis of time trends, and a country covariate that

reflected access to health systems.[15] We have shown previously that the latter variable, which was developed for the GBD, can predict the prevalence of all-cause vision impairment.[12] We predicted the proportion of best-corrected vision impairment that was caused by cataract.

We fitted one DisMod-MR model for each of glaucoma, macular degeneration, and diabetic retinopathy (appendix p 19). In the models for glaucoma and macular degeneration we used three covariates: an indicator variable that described whether the data were for blindness or for MSVI, another that described whether the data were based on visual acuity at presentation or best-corrected visual acuity, and a country covariate that reflected access to health systems. We made two sets of predictions for glaucoma and macular degeneration, one for best-corrected blindness and one for best-corrected MSVI. For diabetic retinopathy, we used three covariates: an indicator variable that described whether the data were based on visual acuity at presentation or best-corrected visual acuity, a year covariate to allow for time trends, and a country covariate that reflected access to health systems. We predicted the proportion best-corrected visual acuity caused by diabetic retinopathy, and used the same proportions for blindness and MSVI.

Estimates for the prevalence of trachoma were derived from nationally representative surveys of vision impairment and from a Bayesian predictive model that used data on the prevalence of trichiasis, a clinical stage of trachoma that is a direct cause of visual impairment, as described above. In 16 countries we obtained data on the proportion of vision impairment caused by trachoma from national surveys, in 25 countries we based estimates on trichiasis prevalence, and in two countries we used both sources of data. On the basis of national survey data, we made estimates for five countries that WHO does not currently classify as having endemic disease: Dominican Republic, Ecuador, Paraguay, Saudi Arabia, and Thailand.[16] For another 20 countries that are deemed by WHO to be endemic for trachoma[16] we could obtain no data and conservatively assigned each as having no trachoma-related vision impairment. These countries were predominantly small countries that would not affect regional or worldwide estimates (eg, the Solomon Islands) or those that had no data because the prevalence of trachomatous blindness is low (eg, Pakistan). For all countries classified as not having endemic trachoma, we estimated no trachoma-related vision impairment.

With these data, we fitted the following regression (equation, appendix p 19):

$$\text{logit}(P_T) = \beta_0 + \beta_1 \text{sex} + \beta_2 \text{year} + \beta_3 \text{vision level} + \beta_4 \text{country}$$

Vision level was an indicator variable used to indicate whether data related to blindness or MSVI. Country was a fixed effect, sex was an indicator variable, and year was a linear covariate. We used the fitted coefficients from this regression model to predict the proportion of blindness and MSVI caused by trachoma in men and women in each endemic country, for 1990 and 2010.

As described previously,[12] the total prevalence of vision impairment and its uncertainty were estimated from data on presenting visual acuity and best-corrected visual acuity. This model implicitly estimated the difference between the prevalence of blindness (and of MSVI) on the basis of visual acuity and on best-corrected visual acuity. We interpreted this difference as the prevalence of vision impairment caused by uncorrected refractive error.

The proportions of best-corrected vision attributable to causes other than cataract, macular degeneration, glaucoma, or trachoma were calculated with data from surveys that included at least cataract and macular degeneration (only 3% of survey data did not report glaucoma). We modelled these data with DisMod-MR (appendix p 19). The covariates were year and an indicator variable for MSVI. We made two sets of predictions, one for blindness and one for MSVI. We deducted the estimated proportions of blindness and MSVI caused by diabetic retinopathy to find the proportion of best-corrected vision caused by other vision impairment. This category comprises avoidable, unavoidable, and unidentified causes.

DisMod-MR produced 1000 draws for each country, sex, age, and year (1990 and 2010). We used the mean of the draws as the central estimate. For computational efficiency, we selected every second draw (total 500) to propagate uncertainty. We also extracted the central estimate and 500 draws for uncorrected refractive error.[12] For the central estimate and each draw, we normalised the proportions attributable to all causes of best-corrected vision loss (cataracts, glaucoma, macular degeneration, diabetic retinopathy, trachoma, and other) to sum to the remaining vision impairment not due to refractive error. We applied the results to previously estimated prevalence of blindness and MSVI by country, age, sex, and draw.[12] We calculated uncertainty intervals (UIs) as the 2·5th–97·5th percentiles of the distribution of draws.

For presentation, we age-standardised prevalence with the WHO reference population.[17] We also calculated numbers of people with blindness and MSVI by cause in each region to reflect that region's population size and age distribution.

Role of the funding sources

The sponsors had no involvement 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 the paper for publication.

Results

At least two studies were identified for 18 of 21 GBD study regions. No studies with cause-specific data were

identified for central Africa or eastern Europe and one study was identified for central Europe. No studies were identified for 126 (66%) of 191 countries.

In 1990 and in 2010, the leading causes of blindness worldwide, based on presenting visual acuity measurements, were cataract, uncorrected refractive

	Cataract	Uncorrected refractive error	Macular degeneration	Glaucoma	Diabetic retinopathy	Trachoma	Other causes/ unidentified
1990							
Asia Pacific, high income	18·8% (13·3–25·6)	14·0% (8·4–18·2)	14·9% (10·3–21·3)	9·0% (6·0–12·8)	4·8% (3·3–7·2)	0	38·5% (30·4–46·4)
Asia, central	29·0% (24·3–33·6)	13·7% (8·2–17·6)	11·6% (8·8–15·3)	9·5% (7·3–12·6)	3·4% (2·7–4·6)	0	33·0% (28·7–37·5)
Asia, east	37·2% (29·7–45·4)	13·5% (8·0–17·5)	5·0% (3·2–7·9)	3·9% (2·6–5·8)	1·0% (0·65–1·6)	5·4% (4·4–6·6)	34·1% (26·5–42·6)
Asia, south	47·7% (39·5–59·4)	35·4% (20·3–45·9)	1·4% (1·0–1·9)	2·4% (1·7–3·3)	1·9% (1·3–2·9)	0·25% (0·20–0·35)	10·9% (8·6–13·9)
Asia, southeast	47·2% (42·0–51·7)	13·0% (7·8–17·1)	3·7% (2·9–5·0)	3·3% (2·6–4·4)	1·1% (0·88–1·4)	0·33% (0·25–0·45)	31·4% (27·2–36·1)
Australasia	19·7% (15·2–26·0)	14·0% (8·4–18·0)	16·8% (12·9–22·2)	9·6% (7·4–13·1)	4·5% (3·4–6·2)	0	35·5% (29·2–41·6)
Caribbean	32·9% (28·3–38·0)	13·3% (8·0–17·4)	4·5% (3·4–6·0)	9·1% (7·3–11·8)	2·1% (1·7–2·8)	0·03% (0·02–0·04)	38·0% (33·4–42·7)
Europe, central	26·9% (23·1–31·5)	13·8% (8·2–17·9)	12·2% (9·3–15·6)	10·2% (7·9–13·3)	3·5% (2·8–4·5)	0	33·4% (28·6–38·3)
Europe, eastern	25·3% (18·7–32·5)	13·8% (8·3–17·7)	13·1% (9·1–19·2)	10·8% (7·7–15·4)	3·5% (2·4–5·4)	0	33·7% (25·5–42·0)
Europe, western	19·2% (16·2–22·7)	13·9% (8·3–18·0)	16·1% (13·4–19·6)	9·0% (7·4–11·3)	4·4% (3·8–5·6)	0	37·4% (32·4–43·0)
Latin America, Andean	37·5% (30·5–44·2)	13·3% (8·0–17·4)	3·7% (2·6–5·5)	6·8% (5·0–9·6)	2·1% (1·5–3·1)	0	36·6% (30·4–43·0)
Latin America, central	32·9% (27·6–38·6)	13·2% (8·0–17·2)	4·6% (3·5–6·2)	8·6% (6·7–11·7)	2·2% (1·7–2·9)	0	38·6% (32·6–43·8)
Latin America, southern	24·3% (18·5–31·2)	13·6% (8·1–17·6)	14·6% (10·6–19·6)	9·3% (6·6–12·6)	5·4% (3·9–8·0)	0	32·9% (25·0–40·1)
Latin America, tropical	32·7% (23·9–42·5)	13·4% (8·0–17·3)	5·0% (3·1–8·0)	9·2% (5·9–14·0)	2·5% (1·6–4·1)	0	37·2% (29·0–46·1)
North Africa/Middle East	29·2% (25·5–33·4)	12·7% (7·6–16·6)	6·4% (5·2–8·0)	5·6% (4·4–7·6)	2·7% (2·3–3·5)	5·1% (3·4–6·2)	38·3% (34·2–42·8)
North America, high income	17·4% (12·5–22·8)	14·0% (8·4–18·1)	16·4% (12·2–21·4)	9·2% (6·7–11·9)	4·1% (3·0–5·8)	0	39·0% (32·0–46·9)
Oceania	43·3% (35·2–49·9)	13·4% (8·0–17·5)	3·3% (2·3–4·7)	2·8% (2·0–4·1)	1·2% (0·85–1·8)	0	36·0% (29·7–43·7)
Sub-Saharan Africa, central	41·0% (33·3–47·5)	13·3% (7·8–17·2)	4·8% (3·5–7·1)	3·3% (2·4–4·6)	2·5% (1·8–3·6)	0·94% (0·52–1·6)	34·2% (28·4–41·2)
Sub-Saharan Africa, east	35·4% (31·7–39·8)	12·9% (7·7–17·1)	4·1% (3·4–5·1)	2·9% (2·4–3·6)	2·0% (1·6–2·5)	13·5% (11·7–15·1)	29·2% (26·4–32·5)
Sub-Saharan Africa, southern	34·0% (29·0–39·8)	13·2% (7·8–17·3)	6·9% (5·5–8·9)	5·4% (4·2–7·3)	2·9% (2·0–4·1)	1·6% (1·1–2·6)	36·1% (30·1–42·4)
Sub-Saharan Africa, west	37·1% (32·1–41·9)	12·9% (7·6–17·0)	4·1% (3·4–5·4)	2·9% (2·4–3·8)	2·4% (1·9–3·1)	7·3% (6·6–8·6)	33·4% (28·9–38·4)
Worldwide	38·6% (35·2–42·0)	19·9% (14·9–24·9)	4·9% (4·4–5·8)	4·4% (4·0–5·1)	2·1% (1·9–2·5)	2·8% (2·3–3·1)	27·4% (24·9–30·0)
2010							
Asia Pacific, high income	13·1% (8·3–20·8)	14·1% (8·4–18·2)	19·5% (12·3–28·8)	11·7% (7·1–18·8)	4·3% (2·6–7·1)	0	37·3% (25·9–46·7)
Asia, central	24·2% (18·6–29·7)	13·9% (8·3–18·0)	13·3% (9·4–18·1)	12·0% (8·7–17·2)	4·0% (2·9–6·0)	0	32·6% (26·4–38·9)
Asia, east	28·2% (19·3–37·3)	13·8% (8·2–17·8)	6·9% (4·5–11·0)	5·4% (3·5–8·5)	1·1% (0·61–2·0)	2·0% (1·6–2·5)	42·7% (33·4–51·3)
Asia, south	41·7% (33·0–51·6)	36·0% (20·7–46·6)	2·6% (1·7–4·2)	4·7% (3·3–7·5)	2·8% (1·7–4·8)	0·15% (0·11–0·24)	12·1% (9·1–17·3)
Asia, southeast	42·0% (34·8–47·9)	13·4% (8·0–17·4)	5·9% (4·7–8·3)	5·6% (4·3–8·2)	1·4% (1·1–2·1)	0·15% (0·11–0·23)	31·5% (25·8–37·3)
Australasia	14·5% (8·5–22·4)	14·1% (8·4–18·1)	17·7% (11·1–26·3)	11·3% (6·8–18·8)	4·3% (2·5–7·7)	0	38·2% (25·9–48·1)
Caribbean	30·2% (23·8–37·1)	13·5% (8·1–17·8)	6·1% (4·3–8·9)	11·2% (8·0–15·1)	2·3% (1·7–3·4)	0·01% (0·01–0·02)	36·8% (30·7–42·7)
Europe, central	21·6% (17·0–26·7)	14·0% (8·3–18·0)	15·4% (10·9–20·8)	12·5% (9·1–17·0)	3·7% (2·8–5·5)	0	32·9% (26·7–38·3)
Europe, eastern	20·6% (13·1–30·5)	14·0% (8·4–18·0)	16·6% (10·1–25·1)	13·5% (8·6–20·6)	4·0% (2·5–6·9)	0	31·3% (21·0–40·9)
Europe, western	13·8% (11·2–17·9)	14·0% (8·4–18·1)	16·1% (12·5–20·1)	10·6% (8·2–14·0)	4·2% (3·4–5·9)	0	41·4% (35·4–46·5)
Latin America, Andean	31·0% (23·3–38·7)	13·6% (8·2–17·7)	6·2% (4·1–9·2)	11·7% (7·9–17·1)	2·5% (1·6–4·2)	0	35·1% (26·7–43·0)
Latin America, central	26·4% (20·9–32·3)	13·5% (8·1–17·5)	6·8% (4·9–9·9)	13·0% (9·6–18·2)	2·5% (1·9–3·7)	0	37·8% (30·4–44·6)
Latin America, southern	18·0% (12·0–25·8)	13·7% (8·2–17·7)	19·5% (13·2–26·8)	12·6% (7·9–19·3)	5·5% (3·6–9·1)	0	30·8% (21·8–39·3)
Latin America, tropical	23·9% (16·2–32·5)	13·6% (8·1–17·5)	9·1% (5·7–13·3)	15·5% (9·6–21·9)	2·9% (1·9–4·6)	0	35·1% (26·3–43·7)
North Africa/Middle East	23·4% (18·7–28·6)	13·1% (7·8–17·1)	10·3% (7·8–13·6)	9·6% (7·5–13·2)	3·5% (2·8–5·0)	2·6% (1·6–3·3)	37·6% (31·6–43·3)
North America, high income	12·7% (8·3–18·7)	14·1% (8·4–18·2)	16·4% (10·8–23·4)	10·7% (7·0–15·7)	3·9% (2·7–6·4)	0	42·2% (32·6–50·1)
Oceania	40·6% (31·5–48·6)	13·6% (8·1–17·7)	4·6% (3·1–7·6)	4·2% (2·5–7·2)	1·4% (0·91–2·4)	0	35·6% (27·4–45·0)
Sub-Saharan Africa, central	34·8% (25·3–42·5)	13·6% (8·0–17·5)	6·9% (4·7–11·0)	5·2% (3·4–8·8)	3·0% (2·0–5·2)	0·44% (0·24–0·82)	36·0% (28·4–44·0)
Sub-Saharan Africa, east	36·7% (31·9–41·5)	13·1% (7·8–17·2)	5·8% (4·6–7·7)	4·0% (3·1–5·4)	2·4% (1·9–3·4)	8·1% (6·8–9·5)	29·9% (25·6–34·5)
Sub-Saharan Africa, southern	31·2% (24·6–39·0)	13·5% (8·0–17·7)	9·7% (6·7–14·1)	7·3% (5·2–10·4)	3·4% (2·1–5·8)	0·69% (0·45–1·1)	34·0% (27·1–42·2)
Sub-Saharan Africa, west	33·8% (28·1–39·3)	13·2% (7·8–17·3)	6·2% (4·8–8·4)	4·4% (3·4–5·9)	3·1% (2·4–4·9)	3·6% (3·2–4·6)	35·6% (30·1–41·6)
Worldwide	33·4% (29·6–36·4)	20·9% (15·2–25·9)	6·6% (6·0–7·9)	6·6% (5·9–7·9)	2·6% (2·2–3·4)	1·4% (1·2–1·7)	28·6% (26·1–31·5)

Data are proportions (95% uncertainty intervals).

***Table 2*: Causes of blindness in 21 regions and worldwide in 1990 and 2010**

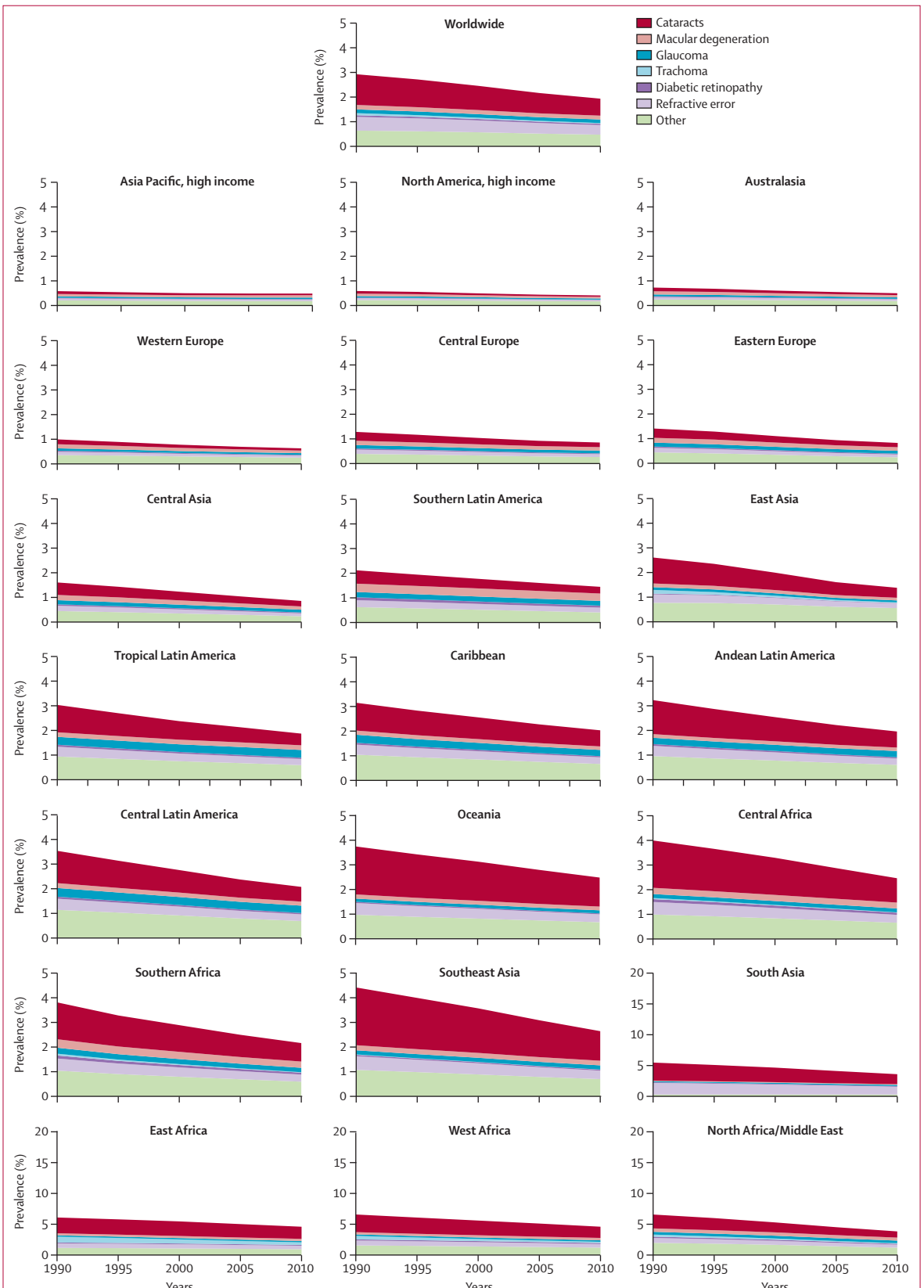

Figure 1: **Prevalence of blindness in adults aged 50 years and older, by cause, in 21 regions and worldwide, from 1990 to 2010**

error, and macular degeneration (table 2, figure 1). Avoidable vision loss due to preventable or treatable causes can be defined as vision loss due to cataract, uncorrected refractive error, trachoma, glaucoma, and diabetic retinopathy. Avoidable vision loss due to preventable or treatable causes affected 68% (95% UI 65–70) of 31·8 million blind people in 1990, but by 2010, the proportion had decreased significantly to 65% (61–68) of 32·4 million blind. Additionally, the rate of preventable or treatable MSVI decreased from 1990 (80%, 78–83) to 2010 (76%, 73–79).

Breakdown of the worldwide averages showed large differences in the causes of blindness between regions (figure 1). In 2010, the proportion of blindness caused by cataracts ranged from less than 15%, with the lowest values seen in high-income regions, to more than 40% in south and southeast Asia and Oceania. The proportion of blindness caused by macular degeneration was higher in regions with older populations, such as high-income regions and southern Latin America, and central and eastern Europe, where more than 15% of blindness was caused by macular degeneration, whereas the proportion was much lower in regions such as south Asia (2·6%, 95% UI 1·7–4·2; table 2). The proportion of blindness caused by glaucoma varied notably, with the lowest values being seen in south Asia (4·7%, 3·3–7·5), east and west sub-Saharan Africa (4·0%, 3·1–5·4 and 4·4%, 3·4–5·9, respectively), and Oceania (4·2%, 2·5–7·2), and the highest value being seen in tropical Latin America (15·5%, 9·6–21·9). We estimated that there was no trachoma-related blindness in 13 of 21 world regions, but that 3·6% (3·2–4·6) of blindness in west sub-Saharan Africa and 8·1% (6·8–9·5) in east sub-Saharan Africa was caused by trachoma-related corneal scars in 2010.

Worldwide, the leading causes of MSVI were uncorrected refractive error, cataract, and macular degeneration (table 3, figure 2). In 2010, uncorrected refractive error caused a larger proportion of MSVI in south Asia (65·4%, 95% UI 62·0–72·0) than in other regions (range 43·2–48·1%). As with blindness, the proportion of MSVI caused by cataract was smallest in the highest-income regions (range 13·0–13·8%) and largest in south Asia (21·4%, 95% UI 16·1–24·2) and southeast Asia (22·7%, 17·9–27·4). The proportion of MSVI caused by macular degeneration was small in comparison (range 1·0–8·0%). Glaucoma, diabetic retinopathy, and trachoma caused less than 5·5% of MSVI in all regions.

In all regions and worldwide, higher proportions of blindness and MSVI were caused by cataract and macular degeneration in women than in men. Worldwide, cataract caused 35·5% (95% UI 31·0–39·1) of blindness in women, compared with 30·1% (25·2–33·7) in men, and for MSVI the values were 20·2% (17·2–23·0) and 15·9% (12·8–18·6), respectively. Likewise, macular degeneration caused 7·3% (6·4–8·9) of blindness in women worldwide, compared with 5·5% (4·8–6·8) in men. The disparities between sexes were less for all other causes of vision impairment.

The age-standardised prevalence of trachoma, cataract, and uncorrected refractive error worldwide between 1990 and 2010 showed the greatest declines (appendix pp 20–23). For glaucoma, macular degeneration, and diabetic retinopathy, prevalence had declined less (for blindness) or increased slightly (for MSVI).

The number of people affected by blindness due to cataract decreased between 1990 and 2010 from 12·3 million (95% UI 10·7 million to 14·2 million) to 10·8 million (9·3 million to 12·3 million), and for MSVI fell from 44·0 million (35·6 million to 52·4 million) to 35·2 million (29·6 million to 43·5 million; appendix pp 20–23). In 2010, the age-standardised prevalence of blindness and MSVI caused by cataract in people aged 50 years or older was 0·7% (95% UI 0·6–0·8) and 2·2% (1·9–2·7), respectively. These values represent declines from 1990 (1·3%, 1·1–1·5 for blindness and 4·4%, 3·6–5·2 for MSVI; appendix pp 20–23). The decline in blindness or MVSI due to cataract was greatest in east Asia, tropical Latin America, and western Europe, in all of which prevalence fell by more than half. The region with the least decline was east sub-Saharan Africa (appendix pp 24–27).

The number of people with blindness or MSVI caused by trachoma decreased from 0·87 million (95% CI 0·70 million to 1·0 million) and 2·2 million (1·5 million to 2·8 million) in 1990 to 0·45 million (0·38 million to 0·54 million) and 1·4 million (1·1 million to 1·8 million) in 2010, respectively. The age-standardised prevalence of trachoma as a cause of blindness and MSVI combined was 0·29% (0·22–0·34) in 1990 and 0·11% (0·09–0·13) in 2010. The proportion of global blindness caused by trachoma decreased from 2·8% in 1990 (2·3–3·1) to 1·4% (1·2–1·7) in 2010; for MSVI the values are 1·3% (1·0–1·5) and 0·7% (0·6–0·9), respectively. The greatest decreases were seen in east and west sub-Saharan Africa (appendix pp 24–27).

The number of people worldwide affected by blindness or MSVI caused by uncorrected refractive error increased from 6·3 million (4·4 million to 8·1 million) and 88·0 million (69·9 million to 103·3 million) in 1990 to 6·8 million (4·7 million to 8·8 million) and 101·2 million (87·88 million to 125·5 million) in 2010, respectively. The age-standardised prevalence of uncorrected refractive error as a cause for adult blindness and MSVI combined, however, was 7·5% (6·1–8·5%) in 1990 and 5·7% (5·0–6·9%) in 2010. Between 1990 and 2010, the percentage reductions in age-standardised prevalence of uncorrected refractive error as a cause for adult blindness and MSVI combined were greatest in tropical Latin America (36%), central Asia (36%), and high-income Asia Pacific (35%), and smallest in eastern sub-Saharan Africa (17%), Oceania (20%), and western sub-Saharan Africa (21%).

The worldwide age-standardised prevalence for blindness and for MSVI declined substantially from 1990

to 2010. Of this overall decline in vision impairment, around half was a result of decline in vision impairment caused by cataracts. A further 20% and 45% of the reductions in the prevalence of blindness and MSVI, respectively, resulted from declines in uncorrected refractive error. Despite the large decline in the

	Cataract	Uncorrected refractive error	Macular degeneration	Glaucoma	Diabetic retinopathy	Trachoma	Other causes/ unidentified
1990							
Asia Pacific, high income	22·8% (18·1–29·4)	47·9% (38·4–54·1)	3·5% (2·4–5·1)	2·3% (1·5–3·5)	2·8% (1·9–4·1)	0	20·8% (15·8–27·3)
Asia, central	26·6% (22·1–31·2)	45·1% (36·8–51·6)	3·3% (2·4–4·6)	2·3% (1·8–3·3)	2·0% (1·6–3·0)	0	20·6% (17·3–25·1)
Asia, east	24·1% (18·9–29·4)	44·8% (36·4–51·7)	3·1% (1·9–5·2)	0·92% (0·57–1·5)	0·68% (0·43–1·1)	2·9% (2·3–3·8)	23·6% (17·8–29·3)
Asia, south	26·7% (21·4–29·5)	63·9% (60·0–70·8)	0·45% (0·32–0·61)	0·66% (0·47–0·90)	1·2% (0·76–1·8)	0·13% (0·10–0·17)	7·0% (5·4–8·6)
Asia, southeast	30·1% (25·4–35·2)	42·8% (34·2–49·7)	0·93% (0·72–1·3)	0·83% (0·65–1·1)	0·76% (0·59–1·0)	0·20% (0·15–0·28)	24·4% (20·4–29·4)
Australasia	21·9% (17·2–27·6)	46·5% (37·4–53·1)	6·6% (4·6–9·5)	2·4% (1·7–3·4)	2·6% (1·9–3·6)	0	20·1% (15·8–25·7)
Caribbean	22·8% (18·4–27·4)	43·4% (35·6–50·4)	0·74% (0·57–1·0)	3·0% (2·2–4·1)	1·5% (1·2–2·1)	0·02% (0·01–0·03)	28·6% (23·8–34·0)
Europe, central	26·6% (21·9–31·7)	45·2% (36·1–52·1)	4·7% (3·4–6·5)	2·5% (1·9–3·3)	2·0% (1·5–2·7)	0	19·1% (15·8–23·4)
Europe, eastern	26·4% (20·4–32·1)	44·8% (36·6–51·3)	4·3% (2·7–6·9)	2·7% (1·8–4·2)	2·0% (1·4–3·2)	0	19·8% (14·8–26·0)
Europe, western	24·1% (19·9–28·8)	46·6% (37·9–53·0)	4·1% (3·3–5·2)	2·3% (1·8–3·0)	2·5% (2·0–3·3)	0	20·5% (17·2–24·5)
Latin America, Andean	22·9% (17·8–28·6)	43·4% (35·0–50·8)	1·4% (0·99–2·2)	2·1% (1·4–3·0)	1·6% (1·1–2·4)	0	28·7% (23·4–34·8)
Latin America, central	21·6% (17·3–26·0)	43·9% (35·6–50·8)	1·7% (1·2–2·5)	2·5% (1·9–3·7)	1·6% (1·2–2·2)	0	28·7% (24·0–34·4)
Latin America, southern	26·5% (21·1–32·6)	44·4% (35·6–51·5)	4·2% (2·9–6·2)	2·4% (1·7–3·7)	3·1% (2·3–5·0)	0	19·3% (14·6–24·7)
Latin America, tropical	22·0% (16·0–28·3)	44·2% (36·0–50·9)	2·8% (1·7–4·6)	2·7% (1·6–4·5)	1·7% (1·1–2·8)	0	26·6% (20·5–32·8)
North Africa/Middle East	25·1% (20·8–29·4)	41·4% (33·1–49·2)	1·8% (1·4–2·6)	1·4% (1·1–1·9)	1·6% (1·3–2·1)	3·7% (2·0–5·0)	25·0% (21·3–29·7)
North America, high income	21·1% (16·6–26·1)	47·8% (38·7–54·3)	4·5% (3·2–6·1)	2·4% (1·7–3·4)	2·4% (1·8–3·5)	0	21·9% (17·3–27·8)
Oceania	25·2% (20·1–31·5)	43·5% (35·4–50·6)	1·4% (0·99–2·1)	0·73% (0·51–1·1)	0·82% (0·56–1·3)	0	28·3% (22·7–33·9)
Sub-Saharan Africa, central	27·1% (22·2–32·4)	44·5% (35·5–51·3)	1·9% (1·3–2·9)	1·0% (0·71–1·5)	1·7% (1·2–2·5)	0·46% (0·20–0·85)	23·4% (19·6–28·6)
Sub-Saharan Africa, east	22·7% (19·3–26·6)	44·0% (35·4–50·6)	2·5% (1·9–3·2)	0·95% (0·76–1·2)	1·3% (1·0–1·7)	8·0% (6·5–9·6)	20·6% (17·3–24·6)
Sub-Saharan Africa, southern	24·2% (19·3–29·6)	45·9% (36·7–52·6)	2·8% (2·0–4·2)	1·5% (1·1–2·3)	1·7% (1·3–2·6)	0·85% (0·40–1·6)	22·9% (18·4–28·6)
Sub-Saharan Africa, west	24·3% (20·0–28·2)	43·8% (35·0–50·4)	1·4% (1·1–1·9)	0·93% (0·71–1·3)	1·6% (1·3–2·3)	4·3% (3·7–5·3)	23·7% (19·7–29·1)
Worldwide	25·6% (22·7–28·4)	51·1% (45·6–56·0)	1·9% (1·6–2·4)	1·2% (1·1–1·5)	1·3% (1·2–1·6)	1·3% (0·97–1·5)	17·6% (15·4–20·3)
2010							
Asia Pacific, high income	15·2% (8·2–22·1)	48·1% (38·6–54·4)	6·0% (3·8–9·8)	3·7% (2·3–6·9)	3·1% (2·0–5·4)	0	23·9% (17·3–30·6)
Asia, central	18·7% (13·9–23·5)	46·5% (37·2–52·7)	5·0% (3·5–7·5)	3·6% (2·6–5·4)	2·8% (2·1–4·6)	0	23·4% (19·4–28·5)
Asia, east	13·4% (8·0–19·7)	46·1% (37·2–52·8)	5·2% (3·3–8·0)	1·6% (0·94–2·5)	0·84% (0·49–1·6)	1·2% (0·99–1·7)	31·6% (25·2–39·0)
Asia, south	21·4% (16·1–24·2)	65·4% (62·0–72·0)	1·0% (0·7–1·6)	1·6% (1·0–2·6)	2·1% (1·2–3·7)	0·08% (0·06–0·14)	8·6% (6·0–11·6)
Asia, southeast	22·7% (17·9–27·4)	44·2% (35·2–50·7)	1·8% (1·3–2·7)	1·8% (1·3–3·0)	1·2% (0·91–1·9)	0·10% (0·07–0·17)	28·1% (22·8–34·2)
Australasia	13·7% (8·4–20·8)	47·1% (37·7–53·5)	8·0% (5·1–12·6)	3·2% (1·9–5·9)	2·9% (1·8–5·9)	0	25·1% (17·4–32·4)
Caribbean	15·9% (11·4–21·3)	44·6% (36·3–51·2)	1·2% (0·90–1·9)	4·3% (3·1–6·4)	2·0% (1·5–3·2)	0·01% (0·00–0·02)	32·0% (25·7–38·4)
Europe, central	18·1% (13·2–23·4)	46·2% (36·7–52·7)	7·4% (5·2–11·0)	3·9% (2·8–6·0)	2·5% (1·8–4·0)	0	22·0% (17·5–27·0)
Europe, eastern	18·4% (11·8–26·2)	46·1% (37·1–52·6)	6·8% (4·0–10·9)	4·5% (2·6–7·7)	2·8% (1·8–5·2)	0	21·3% (14·4–29·1)
Europe, western	13·8% (10·3–18·3)	47·3% (38·5–53·7)	5·4% (4·1–7·5)	3·4% (2·5–4·9)	3·0% (2·4–4·5)	0	27·1% (22·5–32·9)
Latin America, Andean	14·8% (10·2–20·1)	44·6% (36·0–51·6)	3·1% (2·0–5·1)	4·5% (2·9–7·5)	2·2% (1·5–3·8)	0	30·8% (24·0–38·2)
Latin America, central	13·9% (9·9–18·8)	45·2% (36·2–51·6)	3·2% (2·2–5·0)	4·6% (3·2–7·1)	2·1% (1·6–3·5)	0	30·9% (24·7–37·3)
Latin America, southern	17·3% (10·7–23·2)	45·4% (36·5–52·0)	7·2% (4·5–11·5)	4·0% (2·5–6·3)	4·0% (2·6–6·8)	0	22·1% (15·9–28·7)
Latin America, tropical	13·9% (8·5–20·7)	45·4% (36·7–51·9)	6·0% (3·7–9·2)	5·2% (3·2–8·4)	2·2% (1·4–3·6)	0	27·3% (20·3–34·0)
North Africa/Middle East	18·0% (13·3–22·6)	43·2% (34·5–50·1)	4·1% (3·0–6·2)	3·0% (2·1–4·7)	2·4% (1·8–3·9)	2·1% (1·1–3·1)	27·1% (21·8–32·5)
North America, high income	13·0% (7·8–19·5)	48·1% (38·9–54·4)	5·5% (3·5–8·0)	3·4% (2·3–5·4)	2·8% (1·9–4·7)	0	27·3% (21·4–33·8)
Oceania	18·2% (12·1–25·4)	44·5% (35·8–51·3)	2·7% (1·7–4·8)	1·4% (0·85–2·5)	1·2% (0·77–2·3)	0	32·0% (24·2–40·1)
Sub-Saharan Africa, central	18·8% (12·8–24·3)	45·9% (36·8–52·4)	3·6% (2·1–6·2)	1·9% (1·2–3·3)	2·3% (1·6–4·0)	0·25% (0·10–0·53)	27·3% (21·4–35·4)
Sub-Saharan Africa, east	19·6% (15·8–23·6)	44·8% (36·0–51·0)	4·0% (3·0–5·5)	1·5% (1·1–2·2)	1·8% (1·4–2·6)	5·3% (4·2–6·9)	23·1% (19·0–28·0)
Sub-Saharan Africa, southern	17·8% (12·3–23·9)	46·7% (37·4–53·2)	4·8% (2·8–7·7)	2·6% (1·8–4·0)	2·5% (1·6–4·6)	0·47% (0·24–0·96)	25·2% (19·7–32·4)
Sub-Saharan Africa, west	15·6% (11·4–20·5)	44·8% (35·8–51·2)	2·9% (2·0–4·3)	1·8% (1·3–2·7)	2·7% (1·9–4·5)	2·5% (2·1–3·5)	29·6% (23·9–35·3)
Worldwide	18·4% (15·8–20·9)	52·9% (47·2–57·3)	3·1% (2·7–4·0)	2·2% (2·0–2·8)	1·9% (1·6–2·7)	0·71% (0·56–0·91)	20·8% (18·4–23·8)

Data are proportions (95% uncertainty intervals).

***Table 3*: Causes of moderate and severe vision impairment in 21 regions and worldwide in 1990 and 2010**

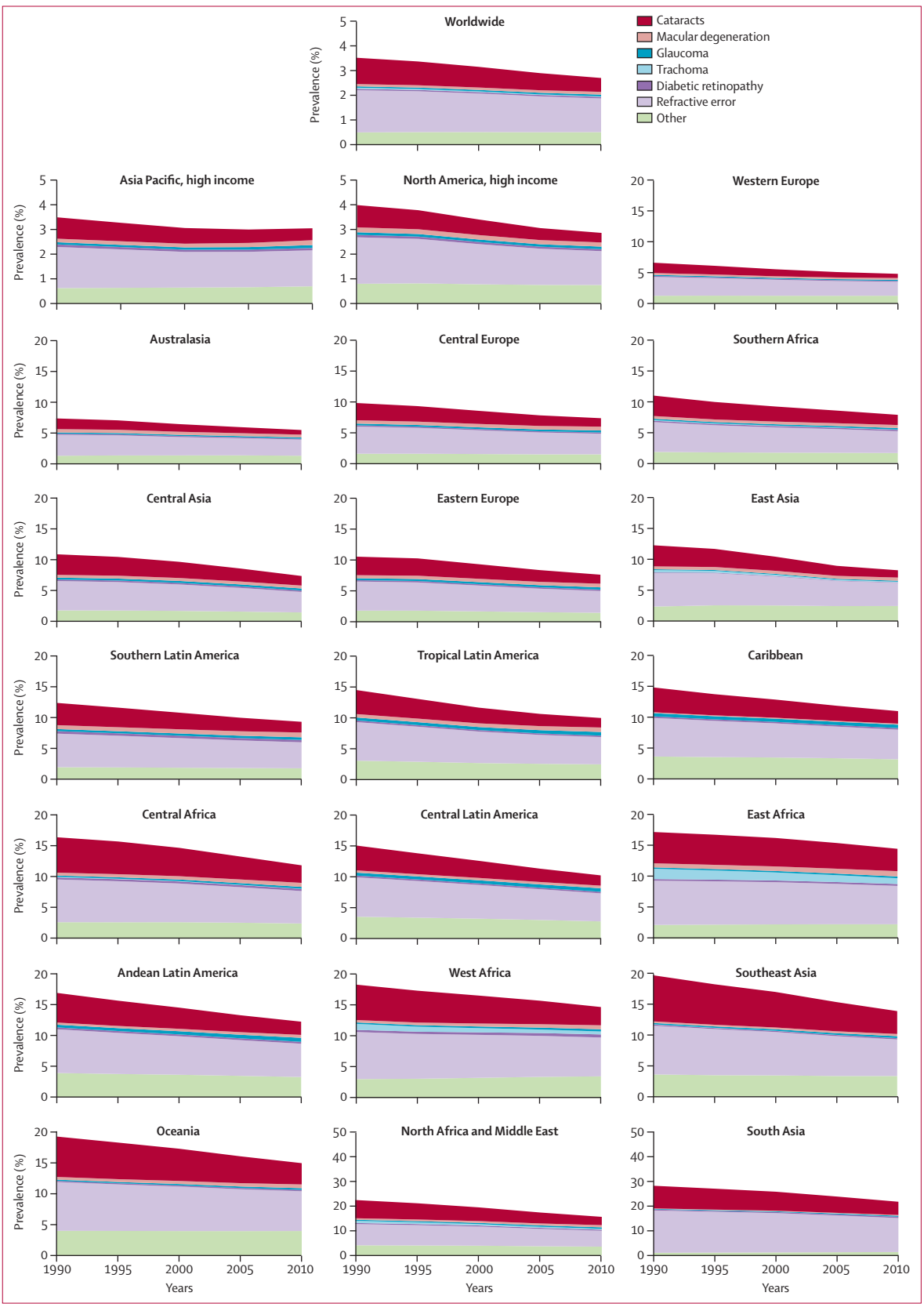

Figure 2: **Prevalence of moderate and severe vision impairment in adults aged 50 years and older, by cause, in 21 regions and worldwide, from 1990 to 2010**

prevalence of blindness and vision impairment caused by trachoma-related corneal scarring, it contributed only 5% to overall decline worldwide in blindness and 3% to overall decline worldwide in MSVI. Nevertheless, the reduction in corneal scarring from trachoma did make important contributions to decline in vision impairment in some regions, most notably in the east sub-Saharan Africa region, where it contributed 30% to decline in blindness and 21% to the decline in MSVI.

Discussion

We found that the major causes of blindness in 2010 were, in order, cataract, uncorrected refractive error, and macular degeneration and for MSVI were uncorrected refractive error, cataract, and macular degeneration. Thus, despite the numbers of people affected by blindness and MSVI due to cataract and trachoma decreasing and the number of people with uncorrected refractive error and age-related diseases, such as glaucoma, macular degeneration, and diabetic retinopathy, increasing, the leading causes were the same as in 1990. Causes of blindness differed substantially by region, with the prevalence of cataract being lowest and that of macular degeneration being greatest in highest-income regions. Worldwide and in all regions, the proportion of blindness or MSVI caused by cataract and macular degeneration was higher in women than in men.

Avoidable vision loss due to preventable or treatable causes can be defined as any vision loss due to cataract, uncorrected refractive error, trachoma, glaucoma, and diabetic retinopathy. With this definition, of the 31·8 million people blind in 1990, 68% (95% UI 65–70) had preventable or treatable causes. By 2010, the proportion had decreased to 65% (61–68) of 32·4 million blind, which was a significant change. Some of the blindness assigned to other causes, which comprised 29% (26–31) of blindness in 2010, might also be preventable or treatable. For example, onchocerciasis is among the infectious preventable causes of blindness. Additionally, 76% (73–79) of MSVI in 2010 was preventable or treatable compared with 80% (78–83) in 1990.

Our findings are in agreement with those of previous studies that assessed the causes for vision loss within countries, regions, or worldwide. The combined data from studies done in Australia show that age-related macular degeneration was the major cause of severe vision impairment or blindness (defined as visual acuity in the better eye of less than 2/200), affecting 0·45% of the population.[2] In a study in the Netherlands, myopic degeneration and optic neuropathy were the main causes of impaired vision among people younger than 75 years, whereas among people aged 75 years or older, age-related macular degeneration was the major cause of blindness.[3] In the Beijing Eye Study,[18] the most frequent causes of blindness or MSVI were cataract, degenerative myopia, glaucoma, corneal opacity, and other optic-nerve damage. Age-related macular degeneration and diabetic retinopathy caused only a few cases. Studies in Latin America, central India, and east Asia also confirm the large proportion of presenting vision impairment due to uncorrected refractive errors (eg, 30% in Ecuador and 72% in Brazil).[19–22]

This study is an extension of a series of meta-analysis investigations that started with a study by Thylefors and colleagues,[5] which formed the basis for the 1999 launch of the Global Initiative for the Elimination of Avoidable Blindness, also known as VISION 2020: the Right to Sight.[5] Since the publication of these worldwide data on blindness in 1995, population-based studies on the prevalence of blindness and vision impairment have been done in all WHO regions. Nevertheless, there remains a dearth of such information from regions such as central Africa, central and eastern Europe, and the Caribbean.[11] Our study expands the data derived from a literature review published by WHO, which used the WHO program Prevention of Blindness and Deafness Programme for estimates.[8] In that study, data from 2000 to 2010 were assessed, and the analysis was limited to three age groups, with no breakdown by sex, and provided a point estimate for 2010 and estimates for the six WHO epidemiological world subregions.[8] By contrast, we achieved a greater degree of granularity in our analysis by presenting data in 5-year age groups and by sex, we calculated time-series estimates for the period 1990–2010, and make estimates for 21 regions. Thus, our estimates of prevalence of vision impairment have increased detail and show temporal changes.

The design of our study has potential limitations. First, as in our previous study on the global prevalence of vision loss,[12] a major limitation was that data were unavailable or those that were available were at a subnational level for many country-years (appendix pp 3–18). Only a few national studies reported vision loss for all ages and all causes. Second, some data sources did not report prevalence by age (appendix pp 3–18). To use these data, we imputed age-specific proportions for causes, based on the assumption that the age pattern of vision impairment in the study matched the modelled pattern in the country where the study was done.[12] Third, the definition of the diseases varied between studies. For instance, some studies defined glaucoma according to the criteria of the International Society for Geographical and Epidemiological Society,[23] whereas in others the appearance of the optic-nerve head was the main criterion, independent of the presence of visual-field defects. In terms of glaucoma, differences in diagnostic criteria have led to a 12-fold difference in reported prevalence.[24] Fourth, the classification for macular degeneration included any macular disease and, therefore, we could not necessarily differentiate between age-related macular degeneration, myopic maculopathy, and other retinal or macular disorders. Since myopic retinopathy is ranked among the three most common causes of vision impairment and blindness in some studies from east Asia, this mixed

grouping might prove important. The data from this analysis, therefore, cannot be used to reflect the role of myopic retinopathy, including myopic maculopathy, in vision impairment. Fifth, unidentified or other causes generally represented 20–30% of cause for MSVI and 20–35% for blindness. Sixth, for 20 countries that are deemed by WHO to be endemic for trachoma, data on the prevalence of trachoma or trichiasis were not available. We had, therefore, to assume a conservative proportion of zero. This approach could have led to an underestimation of the prevalence of trachoma as cause for blindness and MSVI. Seventh, protocol dictates that population-based studies will report one principal cause per an individual assessed to arrive at the causal prevalence. When individuals had multiple disorders that could have contributed equally to visual loss, only the one deemed most readily curable or most easily preventable was recorded.[25] This approach has the potential to underestimate the contribution of diabetic retinopathy, glaucoma, or other diseases with cataracts at presentation and to underestimate the burden of cataract when patients also have an uncorrected refractive error.[26] Finally, some studies have small sample sizes, which leads to large confidence intervals for cause-specific prevalence estimates. Our methods take into account sample size, which should lessen the effect of small studies on the estimates compared with that of large studies.

The strengths of our study include the amount of population-based data accessed and used; analysis of trends in the causes of vision impairment; incorporation of non-linear age trends and the taking account of data that were not reported by age; and systematic quantitative analysis and reporting of uncertainty. The large network of ophthalmological researchers involved in identification and assessment of data sources ensured that we were able to access unpublished as well as published data: unpublished data were from 48 population-based studies, four government reports, and 44 rapid assessment of cataract surgical services and rapid assessment of avoidable blindness surveys. These data meant that studies for which investigators had published only summary data could be included. Thus, we assessed all major studies of vision impairment and included only those studies that met our inclusion criteria for representativeness of the population and clarity of visual acuity procedures and definitions.

In conclusion, cataract or uncorrected refractive error led to 54% of blindness and 71% of MSVI in 2010. Both causes are easily and completely treatable. Glaucoma, macular degeneration, and trachoma were less frequent causes of vision loss. The proportions of vision impairment caused by cataract and trachoma decreased in the study period of 20 years; those for glaucoma, macular degeneration, and diabetic retinopathy increased; and that for uncorrected refractive error changed little. These temporal changes in cause-specific prevalence of blindness and vision impairment are important for the setting of priorities, development of policies, and for planning (panel). Additionally, our data provide a resource for advocacy efforts to mobilise resources for eye-care services from governments, donors, and civil society.

Contributors

RRAB, GAS, JLS, and HP prepared the vision impairment survey data. GAS, RAW, JLS, and SRF analysed the data. RRAB, GAS, and JBJ wrote the first draft of the report. All authors contributed to the study design, analysis, and writing of the report. RRAB oversaw the research.

Conflicts of interest

We declare that we have no conflicts of interest.

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