Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis

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Summary

Background Global and regional prevalence estimates for blindness and vision impairment are important for the development of public health policies. We aimed to provide global estimates, trends, and projections of global blindness and vision impairment.

Methods We did a systematic review and meta-analysis of population-based datasets relevant to global vision impairment and blindness that were published between 1980 and 2015. We fitted hierarchical models to estimate the prevalence (by age, country, and sex), in 2015, of mild visual impairment (presenting visual acuity worse than 6/12 to 6/18 inclusive), moderate to severe visual impairment (presenting visual acuity worse than 6/18 to 3/60 inclusive), blindness (presenting visual acuity worse than 3/60), and functional presbyopia (defined as presenting near vision worse than N6 or N8 at 40 cm when best-corrected distance visual acuity was better than 6/12).

Findings Globally, of the 7·33 billion people alive in 2015, an estimated 36·0 million (80% uncertainty interval [UI] 12·9–65·4) were blind (crude prevalence 0·48%; 80% UI 0·17–0·87; 56% female), 216·6 million (80% UI 98·5–359·1) people had moderate to severe visual impairment (2·95%, 80% UI 1·34–4·89; 55% female), and 188·5 million (80% UI 64·5–350·2) had mild visual impairment (2·57%, 80% UI 0·88–4·77; 54% female). Functional presbyopia affected an estimated 1094·7 million (80% UI 581·1–1686·5) people aged 35 years and older, with 666·7 million (80% UI 364·9–997·6) being aged 50 years or older. The estimated number of blind people increased by 17·6%, from 30·6 million (80% UI 9·9–57·3) in 1990 to 36·0 million (80% UI 12·9–65·4) in 2015. This change was attributable to three factors, namely an increase because of population growth (38·4%), population ageing after accounting for population growth (34·6%), and reduction in age-specific prevalence (–36·7%). The number of people with moderate and severe visual impairment also increased, from 159·9 million (80% UI 68·3–270·0) in 1990 to 216·6 million (80% UI 98·5–359·1) in 2015.

Interpretation There is an ongoing reduction in the age-standardised prevalence of blindness and visual impairment, yet the growth and ageing of the world's population is causing a substantial increase in number of people affected. These observations, plus a very large contribution from uncorrected presbyopia, highlight the need to scale up vision impairment alleviation efforts at all levels.

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Introduction

Universal Eye Health: a Global Action Plan 2014–2019 was adopted by WHO member states at the World Health Assembly in 2013.[1] Its goals are to reduce vision impairment as a global public health problem and to secure access to rehabilitation for people with vision impairment. The initiative has the global target of reducing the prevalence of avoidable vision impairment by 25% from 2010 to 2019. One of the key objectives of the Global Action Plan is to generate evidence on the magnitude of vision impairment, which is required to evaluate the success of this and similar initiatives.

Previously, we reported the results of a systematic review of published literature and some unpublished data from population-based studies that reported the prevalence of blindness and vision impairment from 1980, using a continuously updated database of population-based studies (the Global Vision Database). Globally, we estimated that 32·4 million people were blind in 2010, and that 191 million people had moderate and severe vision impairment. Additionally, the age-standardised prevalence of blindness and moderate and severe vision impairment decreased between 1990 and 2010.[2] Country-specific data were made available online, searchable by level of vision impairment, age, and sex.

Vision impairment and age-related eye diseases affect economic and educational opportunities,[3] reduce

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See **Online** for appendices

For more on the **Global Vision Database** see http://www.globalvisiondata.org

Research in context

Evidence before this study

The first systematic review of published literature (1980–2012) involved extraction of data on both presenting and best-corrected visual acuity from only population-based studies that reported prevalence of vision impairment and a definition of vision impairment for which we could develop a method for inclusion. These data formed the Global Vision Database from which estimates for global prevalence of vision impairment and blindness were calculated for 2010. This was the most comprehensive global meta-analysis of its kind, with important advances on previous WHO reports that had not investigated sex differences or age distributions in blindness and vision impairment. The study also permitted, for the first time, a temporal analysis from 1990 to 2010 that showed a decline in the age-standardised prevalence of blindness and vision impairment, but an increase in crude prevalence (due to population growth and ageing).

Added value of this study

This study updates the global, regional, and country-level blindness and vision impairment prevalence estimates to 2015, incorporating important developments since 2010, namely more data sources (61 new studies from 35 different countries) including more precise data (individual-level data for many

studies), improved statistical analysis, the inclusion of estimates of functional presbyopia, and projections of blindness and vision impairment burden to 2020 and 2050.

Implications of all the available evidence

Our study has shown that in 2015, an estimated 36 million people were blind, 217 million were moderately or severely vision impaired, and 188 million had mild vision impairment. 1·09 billion people aged 35 years or older are affected by near-vision impairment due to uncorrected presbyopia. The interval improvement (in terms of a reduction in prevalence of distance vision impairment) since 1990 and 2010, after accounting for population growth and ageing, suggests that investments made in the alleviation of vision impairment during this period have reaped considerable dividends. Such dividends would include improvements in quality of life, and large economic benefits as people work rather than living with unnecessary disability. Yet the growth and change in age structure of the world's population is causing a substantial increase in the number of people with blindness and vision impairment, which appears to be accelerating. This finding highlights the need to scale up our current efforts at global, regional, and country level.

quality of life,[4] and increase the risk of death.[5,6] Previously, we reported principally on blindness and moderate and severe vision impairment, with minimal detail beyond a global estimate for mild vision impairment because data were sparse for this vision impairment category, in which a person has a presenting (with usual optical correction) visual acuity less than 6/12 but 6/18 or better in the better eye.[7] This degree of vision impairment, despite being classified as mild, has a substantial effect on quality of life. For example, in many countries, an individual with this level of vision would be barred from driving.[8]

Uncorrected presbyopia is the most common cause of vision impairment,[9] hence WHO has recommended measurement of near vision in population-based surveys (eg, the *Consultation on development of standards for characterization of vision loss and visual functioning* in 2003). In some contexts, impairment of near vision is at least as detrimental to quality of life as impairment of distance vision, regardless of the environment, lifestyle, or sociodemographic status of the affected individuals.[10]

Improvements to the Global Vision Database that broadened its capabilities enabled us to provide global estimates of the 2015 global burden of vision impairment, including functional presbyopia; to report trends in vision impairment from 1990 to 2015 by country, sex, and age; and to make projections to 2020 and 2050 regarding the number of people with vision impairment.

Methods

Study design

Using data from the Global Vision Database, we estimated trends in prevalence of vision impairment and their uncertainties, by sex, for 188 countries in the 21 Global Burden of Disease (GBD) regions, from 1990 to 2015 (appendix 1). Using definitions and an analytical framework similar to that of our previous publication[2] (appendix 1), we used statistical models to estimate the prevalence of two of the core categories of vision impairment: blindness (presenting visual acuity worse than 3/60) and a combined grouping called moderate and severe vision impairment (presenting visual acuity worse than 6/18 to 3/60 inclusive; table 1).[2] We did our analysis in seven steps: data identification and extraction; conversion of vision impairment data to two core levels (blindness and moderate and severe vision impairment); estimation of age-specific vision impairment prevalence when data were not reported by age; selection and use of a statistical model to estimate the prevalence of blindness and moderate and severe vision impairment by country, age, sex, and year; estimation of severe, moderate, and mild vision impairment based on crosswalk from our estimates of blindness and moderate and severe vision impairment; estimation of functional presbyopia prevalence; and forecasting of prevalence of blindness and vision impairment to 2020 and 2050.

Data identification and extraction

We commissioned a systematic review of population-based studies published between Jan 1, 1980, and July 8, 2014, by York Health Economics Consortium and unpublished data identified by members of the Vision Loss Expert Group who convened for the 2010 GBD study, to find data on distance vision impairment.

Our systematic review used the same search terms of a previous systematic review,[7] but we extended the review to include studies published up to July 8, 2014 (appendix 1). The methods for this extended systematic review are described in appendix 1 as a PRISMA flowchart and checklist.

Briefly, studies that were included in the Global Vision Database met the following requirement criteria. Reported prevalence of blindness, visual impairment, or both, was measured from random sample cross-sectional surveys of representative populations of any age of a country or area of a country. Studies using hospital or clinic case series, blindness registries, and interview studies with self-reported vision status were not included. Definitions of visual impairment or blindness were clearly stated, used thresholds of visual acuity in the better eye that matched or could be later modelled to match the definitions given in appendix 1. Best-corrected or presenting visual acuity was stated. Procedures used for measurement of visual acuity were clearly stated. We extracted data on both presenting and best-corrected visual acuity. Appendix 1 includes a full list of data sources for distance blindness, vision impairment, and presbyopia.

Conversion to core definitions of visual acuity

Similar to the strategy in our previous systematic review,[2] we standardised all prevalence data to the definitions of vision impairment selected for this study (appendix 1). We used four regressions to convert two commonly used definitions of blindness (visual acuity <6/60 and visual acuity ≤6/60) to our definition of blindness, and to convert two commonly reported definitions of vision impairment (visual acuity <6/18 and visual acuity <6/12) to our definition of moderate and severe vision impairment (appendix 1).

Estimation of age-specific data

Our statistical model is based on the age-specific prevalence of vision impairment for 5-year age intervals (eg, 20–24-year-olds). In cases when studies reported the prevalence of vision impairment for a wider age group—such as all ages or adults older than 50 years—we converted these to 5-year age groups as follows. We fitted two universal age patterns, one for the prevalence of blindness and one for the prevalence of moderate and severe vision impairment, meta-analysing from aggregated studies that reported prevalence for the narrower age groups. We then applied the fitted age patterns to the wide age group aggregated dataset, to calculate prevalence by 5-year age intervals. We ensured that the age-specific prevalence values summed to the reported wide age range prevalence when weighted by the country's population by age. Further details are available in appendix 1.

	Presenting visual acuity* in the better eye
Mild vision impairment	<6/12 but 6/18 or better
Moderate and severe vision impairment	<6/18 but 3/60 or better
Blindness	<3/60
Presbyopia	Near vision worse than N6 or N8 at 40 cm and best corrected visual acuity ≥6/12 (20/40)

*Snellen visual acuity or the equivalent calculated from published logarithm of the minimum angle of resolution values.

Table 1: Categories of vision impairment with corresponding visual acuity

Statistical analysis of vision impairment data

We fitted two hierarchical Bayesian logistic regressions to estimate vision impairment prevalence over time, by age group, sex, and country, with one model for the prevalence of blindness and one model for the prevalence of moderate and severe vision impairment. Using fully Bayesian statistical inference,[11] our posterior estimates of vision impairment were able to flexibly borrow strength such that country-specific estimates were informed by study data from the same country, where available, and by study data from other countries in the same region or the same year. Variance parameters for the random and fixed effects in the model, which were themselves assigned prior values, enabled the model to flexibly learn the degree to which data were pooled between countries in the same region and over time.

We used a model in which vision impairment levels in countries were modelled hierarchically to be nested into each of the 21 GBD regions, which were in turn nested in the seven GBD world super-regions (appendix 1). We modelled hierarchical linear trends over time, allowing for region-specific trends in prevalence of vision impairment in the seven world super-regions. A sex effect was likewise modelled hierarchically by seven world super-regions, thus allowing for differences in sex disparities by region. We modelled age as a three-piece linear spline with knots at age 40 years and age 70 years.

To account for potential variability resulting from non-homogeneous study designs and from some studies being only subnationally or locally representative, we included study-specific error terms, which we interacted with an indicator of whether the study was national or not. This approach permitted nationally representative studies to have a greater influence on estimates. We also included a fixed effect indicator for urban versus rural studies. We included a fixed effect indicator for whether the study measured prevalence on the basis of best-corrected or presenting distance visual acuity, and we allowed this difference to vary in the south Asia region, for reasons we have previously described.[2]

To help with issues of data sparsity, we included two time-varying covariates: mean years of adult education by age group[12] and an index of access to health care.[13] Our model was developed on the basis of previous work and on the leave-one-out measure of model fit similar to cross-validation.[14,15]

We fitted our blindness and moderate and severe vision impairment models using Bayesian inference, sampling from the posterior distribution over the parameters using Hamiltonian Monte Carlo, a Markov chain Monte Carlo method, as implemented in the RStanArm package (version 2.11.1), which relies on Stan.[16] We used a leave-one-out measure to assess model fit and compare various modelling specifications (appendix 1).

Each model was run with four chains for 1000 iterations each, with 500 warm-up iterations. After fitting the model, posterior predictions were made for each country–year–age–sex group. Prevalence estimates are given in the context of 80% uncertainty intervals (UIs). Complete details of our model and a graphical representation of the model fits are provided in appendix 1.

Estimation of visual impairment
We fitted logistic regressions to convert the prevalence of blindness and moderate and severe vision impairment to mild, moderate, and severe vision impairment (appendix 1), and applied the logistic regressions to each sampled prediction drawn from the Bayesian posterior, thus obtaining a set of samples of mild, moderate, and severe vision impairment by country–year–age–sex group. To obtain global and regional estimates, we calculated the means and the tenth and 90th percentiles of the posterior uncertainty intervals for each country prediction, age, and sex, then we combined these, weighting each country prediction by its population in the relevant age–sex category. We also reported age-standardised estimates using the WHO reference population,[17] and the raw numbers of people with vision impairment by category. We calculated trends of age-standardised vision impairment by world region, with UIs, by calculating the difference between the 1990 and 2015 age-standardised prevalence. The statistical code is available on request from the corresponding author. We investigated the attribution of change in age-standardised vision impairment to three factors, namely percentage change because of population growth, population ageing after accounting for population growth, and change in age-specific prevalence.

Estimation of functional presbyopia
To estimate the prevalence of near vision impairment due to uncorrected presbyopia (functional presbyopia), we included studies in which presbyopia was defined as presenting near vision worse than N6 or N8 at 40 cm, regardless of distance refractive status. For broad estimates of vision impairment, including both distance and near presenting impairment, we only included data from people whose best-corrected visual acuity was 6/12 (20/40) or better, to avoid double counting those with both distance and near vision impairment associated with non-refractive causes. For most of the studies, the prevalence of functional presbyopia was reported, as well as data regarding near spectacle correction, the latter of which we excluded. For other studies in which this approach was not possible, we used presenting near vision data if reported. For a multisite study that reported presenting visual acuity for which we had access to microdata,[18,19] we included all participants with presenting visual acuity worse than 6/12 at near vision and subtracted the number of people with best-corrected visual acuity worse than 6/12. All included studies only included participants older than 35 years.

We developed a similar model to the main model used for blindness and moderate and severe vision impairment. We used a hierarchical generalised linear modelling framework with a negative binomial observation model and logistic link function. Because of data sparsity, we did not include country-level covariates or indicators. The model included an intercept term and random offsets for ten age categories, 21 GBD regions, seven world super-regions, and each study, in which each set of random offsets was assigned a common Bayesian prior to enable partial pooling.[20] The age categories were given by 5-year age bands, with an indicator variable for each age group starting with 35–39 years, and then continuing by 5-year age bands until a final age band of older than 80 years. Observations that covered wider age bands were incorporated by population-weighted averaging. For example, for a study reporting prevalence for ages 35–44 years, the model's predicted estimates for 35–39 years and 40–44 years were averaged on the basis of the appropriate country-year population distribution, and this average was then linked to the observed prevalence.

Forecasting the prevalence of blindness and vision impairment
We applied our model to forecast prevalence of blindness and moderate and severe vision impairment. These forecasts projected possible scenarios rather than as fully probabilistic forecasts, so we have not reported UIs. Our model relies on health status and education as covariates. Since it is impossible to predict how these will evolve decades into the future, we extrapolated these covariates to the year 2020 (appendix 1) and then held them constant to 2050. Since our model gives estimates of crude prevalence for country-years, we relied on the UN Population Division's forecasts to 2050 to derive crude numbers affected and age-standardised prevalence.[21] Thus, our estimates are also contingent on the assumptions regarding future fertility and mortality that underpin the UN Population Division's estimates.

Role of the funding source
The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of

Figure 1: Population-based prevalence studies of blindness and vision impairment in the Global Vision Database
Volume of new studies by region and reporting by vision loss severity are presented with a comparison to those in the original systematic review.[8] New studies were obtained from Afghanistan, Bhutan, Burundi, China, Egypt, Eritrea, Ethiopia, Ghana, Honduras, India, India, Iran, Jordan, Kenya, Laos, Libya, Madagascar, Moldova, Mozambique, Nepal, Nigeria, Norway, Panama, Saudi Arabia, South Africa, South Korea, Taiwan, Tanzania, Timor-Leste, Turkey, Uganda, Vietnam, and Zambia. Black bubbles indicate the number of studies.

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.

Results

In total, 61 new studies were added to the Global Vision Database and included in the meta-analysis, giving a total of 288 studies contributing data from 98 countries.[2] The volume of new studies by region and reporting by blindness or vision impairment severity are illustrated in figure 1, with comparison to those in the original systematic review.[7] Globally, of the 7·33 billion people alive in 2015, 36·0 million (80% UI 12·9–65·4) were blind (0·49%, 80% UI 0·18–0·89), of whom 20·1 million (80% UI 7·1–36·8) were female (56%; table 2).

The largest number of blind people resided in south Asia (11·7 million, 80% UI 4·1–21·7), followed by east Asia (6·2 million, 2·1–11·5) and southeast Asia (3·5 million, 1·3–6·3). The crude prevalence of blindness ranged from 0·24% (80% UI 0·10–0·42) in Australasia to 0·70% (0·24–1·29) in south Asia (appendix 1).

Moderate and severe vision impairment affected 216·6 (80% UI 98·5–359·1) million people (2·95%, 80% UI 1·34–4·89) of the global population, of whom 118·9 million (55%) were female. The largest number of people with moderate to severe vision impairment also

resided in south Asia (61·2 million, 80% UI 29·6–98·6), followed by east Asia (52·9 million, 23·2–89·6), and southeast Asia (20·8 million, 9·8–33·9). The prevalence of moderate and severe vision impairment varied from 1·57% (80% UI 0·67–2·66) in southern sub-Saharan Africa to 3·69% (1·62–6·25) in east Asia.

An estimated 188·5 (80% UI 64·5–350·2) million people had mild vision impairment (2·57%, 80% UI 0·88–4·77), 101·4 million (54%) of whom were female.

Presenting functional presbyopia was estimated to affect 1094·7 (80% UI 581·1–1686·5) million people aged 35 years and older, including 666·7 (364·9–997·6) million people aged 50 years and older. The crude prevalence of functional presbyopia was 35·6% (18·9–54·9) for people aged 35 years and older, and 40·3% (22·0–60·4) for people aged 50 years and older (appendix 1).

The burden of vision impairment was greatest in those aged 50 years and older: 31 million (86%) of 36 million blind people, 172·3 million (80%) of 216·6 million people with moderate and severe vision impairment, 140·3 million (74%) of 188·5 million people with mild vision impairment, and 666·7 (61%) of 1094·7 million people with functional presbyopia were within this age category (table 2; appendix 1).

Given the strong association of vision impairment with age, prevalence of impairment varied by region because of

	World population (millions)	Blind		Moderate and severe vision impairment		Mild vision impairment	
		Prevalence (%)	Number (millions)	Prevalence (%)	Number (millions)	Prevalence (%)	Number (millions)
Men							
0–49 years	2920	0·08 (0·03–0·15)	2·46 (0·81–4·52)	0·74 (0·30–1·29)	21·66 (8·67–37·61)	0·81 (0·21–1·62)	23·61 (6·20–47·21)
50–69 years	613	0·93 (0·32–1·70)	5·69 (1·95–10·40)	6·78 (2·98–11·45)	41·57 (18·30–70·23)	6·46 (2·14–12·26)	39·65 (13·10–75·21)
≥70 years	169	4·55 (1·74–8·09)	7·72 (2·95–13·73)	20·33 (10·55–31·75)	34·53 (17·91–53·92)	14·05 (6·05–23·47)	23·85 (10·28–39·86)
Women							
0–49 years	2780	0·09 (0·03–0·17)	2·56 (0·82–4·79)	0·82 (0·31–1·44)	22·68 (8·65–39·97)	0·89 (0·23–1·79)	24·64 (6·30–49·70)
50–69 years	634	1·03 (0·34–1·91)	6·52 (2·17–12·14)	7·48 (3·18–12·77)	47·46 (20·18–80·99)	6·99 (2·30–13·29)	44·35 (14·59–84·27)
≥70 years	222	4·97 (1·87–8·92)	11·06 (4·16–19·86)	21·87 (11·13–34·29)	48·71 (24·79–76·35)	14·57 (6·28–24·23)	32·45 (13·99–53·95)

Data are % (80% uncertainty interval) or number (80% uncertainty interval).

Table 2: Global numbers affected and crude prevalence of vision impairment by age and sex, 2015

differences in regional age structures, as well as other differences. To compare patterns and trends in the prevalence of vision impairment without being confounded by the age structure, we calculated age-standardised prevalence, focusing on older adults (aged ≥50 years), who had the largest burden of vision impairment.

In 2015, the age-standardised prevalence of blindness and moderate and severe vision impairment and mild vision impairment among older adults was far higher in some developing regions than in high-income regions (figure 2; appendix 1). The prevalence of blindness in older adults was 4% or greater in three developing regions in 2015: western sub-Saharan Africa (5·1%, 80% UI 2·0–8·9), eastern sub-Saharan Africa (4·3%, 1·7–7·4), and south Asia (4·0%, 1·5–7·3). By contrast, blindness prevalence was 0·5% or less in all high-income regions (figure 2; appendix 1). For moderate and severe vision impairment, the age-standardised prevalence was highest in south Asia (17·5%, 80% UI 9·1–27·2), North Africa and the Middle East (17·2%, 8·6–26·8), western sub-Saharan Africa (16·0%, 8·0–25·3), central sub-Saharan Africa (14·4%, 6·3–24·5), and southeast Asia (14·1%, 6·9–22·3). Similarly, the prevalence of moderate and severe vision impairment was lowest (<5·1%; highest 80% UI upper bound 8·79%) in all four high-income regions, where it was one-third that of south Asia (figure 2; appendix 1). The age-standardised prevalence of mild vision impairment was highest in south Asia (12·2%, 80% UI 4·9–21·2), North Africa and the Middle East (11·9%, 4·7–20·5), western sub-Saharan Africa (11·2%, 4·4–19·4), and central sub-Saharan Africa (10·8%, 3·9–19·3). Mild vision impairment prevalence was 5% or less in all four high-income regions and in central Europe (figure 2; appendix 1). Among the seven super-regions, the age-standardised prevalence of functional presbyopia was highest in older adults of south Asia (63·8%, 80% UI 50·9–76·6), sub-Saharan Africa (58·5%, 42·6–73·8) and central Europe, eastern Europe, and central Asia (51·9%, 22·3–81·3), and lowest in the high-income super-region (12·2%, 3·6–24·8).

More women than men had vision impairment. When controlling for age, within the constraints of residual confounding due to longer survival of women and hence over-representation in very high age groups, female prevalence of blindness was greater than for men in all world regions. The world female-to-male age-standardised prevalence ratio among adults was 1·05 for blindness, 1·07 for moderate and severe vision impairment, and 1·05 for mild vision impairment.

The age-standardised prevalence of blindness in older adults was highest, exceeding 7% in Afghanistan, then Ethiopia, Yemen, Chad, Cameroon, and Niger (appendix 2). The highest age-standardised prevalence of moderate and severe vision impairment, which exceeded 21% in the older adult population, was in Afghanistan, Nepal, Eritrea, Turkey, Laos, Pakistan, and Myanmar (appendix 2).

The global age-standardised all-age prevalence of blindness decreased from 0·75% (80% UI 0·25 to 1·41) in 1990 to 0·48% (0·17 to 0·87) in 2015, a decrease of 0·27 (–0·61 to 0·00) percentage points in the age-specific burden of disease (90% posterior probability of a true decline). During the same time period, the global age-standardised, all-age prevalence of moderate and severe vision impairment decreased from 3·83% (1·66 to 6·42) to 2·90% (1·31 to 4·80), a decrease of 0·93 (–2·29 to –0·43) percentage points (83% posterior probability of a true decline; appendix 1). The largest absolute decreases in blindness prevalence occurred in North Africa and the Middle East and south Asia (≥0·7 percentage points), and in the same two regions plus the GBD super-region of southeast Asia, east Asia, and Oceania for moderate and severe vision impairment (all experienced declines of at least 1·3 percentage points).

Between 1990 and 2015, the absolute number of blind people increased by 17·9%, from 30·6 million in 1990 to 36·0 million in 2015. This increase was attributable to three factors, namely percentage change because of population growth (38·4%), population ageing after
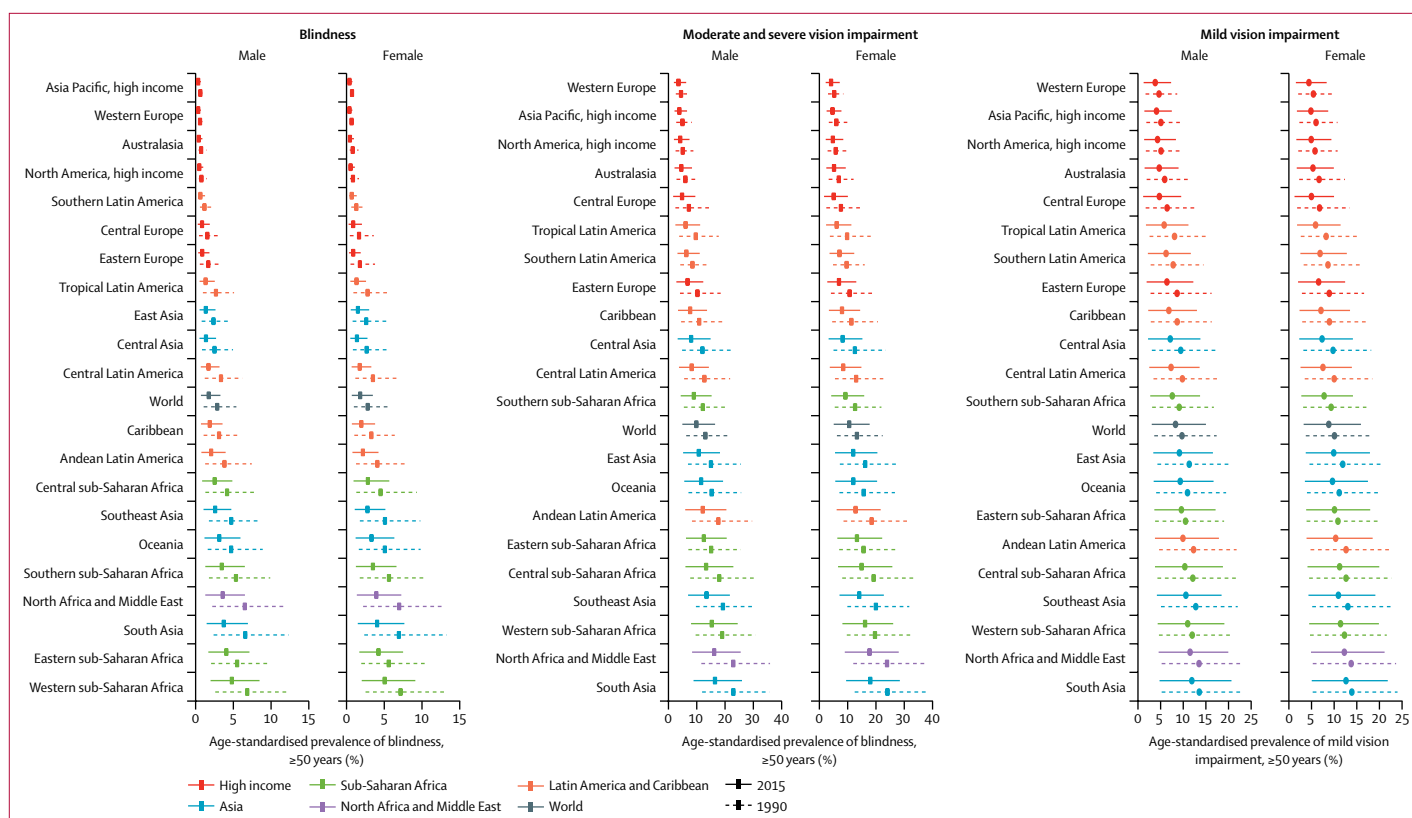
Figure 2: Age-standardised prevalence of blindness, moderate and severe vision impairment, and mild vision impairment by subregion and sex for 2015, in adults aged 50 years and older

accounting for population growth (34·6%), and change in age-specific prevalence (–36·7%). The number of people with moderate and severe vision impairment similarly increased, from 159·9 million to 216·6 million (35·5%), and the proportion accounted for by each of these three factors were similar (38·4% increase due to population growth, 29·2% increase due to population ageing, and 24·2% decrease in age-specific prevalence). More detail about this global trend is given in table 3. We also examined the change between 2010 and 2015 for each of these three factors for blindness (6·0%, 7·7%, and –7·3%, respectively) and moderate and severe vision impairment (6·1%, 6·7%, and –3·9%, respectively; data not shown).

We projected that an estimated 38·5 million people (80% UI 13·2–70·9; 0·50%, 80% UI 0·17–0·92) would be blind in 2020 (of a total global population of 7·75 billion) and 114·6 million people (23·39–229·0; 1·18%, 0·24–2·36) people would be blind in 2050 (of a total global population of 9·69 billion). For moderate and severe vision impairment, the estimates were 237·1 million people (101·5–399·0; 3·06%, 1·31–5·15) in 2020 and 587·6 million people (155·9–1093·8; 6·06%, 1·61–11·29) in 2050. Global predictions of numbers of people who will be blind or moderately or severely vision impaired, for each decade between 2020–50, are shown in figure 3.

Discussion

In 2015, an estimated 36 million people were blind (visual acuity worse than 3/60), 217 million had moderate or severe vision impairment (worse than 6/18 but 3/60 or better), and 188 million had mild vision impairment (worse than 6/12 but 6/18 or better). Most people who were blind or who had moderate and severe vision impairment resided in south Asia, east Asia, and southeast Asia, whereas the age-standardised prevalence of blindness was highest in western sub-Saharan Africa, eastern sub-Saharan Africa, and south Asia. Although sparsity of data for presbyopia prevented a meaningful analysis of its prevalence in 2010, we could estimate that 666·7 million people aged 50 years and older and 1·09 billion people aged 35 years and older are affected by near vision impairment due to uncorrected presbyopia. Whereas we only presented a global estimate for mild vision impairment because of limited data sources in 2010, the advent of more recently published data for this category means we can now present more detailed regional estimates for this disability, which has an impact on quality of life.

The interval improvement (in terms of a reduction in age-standardised prevalence of distance vision impairment) since 1990 and since 2010, after accounting for population growth and ageing, suggests that modest

	Blind	Moderate and severe vision impairment
Number of people in 1990 (millions)	30·6	159·9
Number expected with 2015 population, 1990 population age structure, and 1990 prevalence (millions)	42·3	221·3
Number expected with 2015 population, 2015 population age structure, and 1990 prevalence (millions)	56·9	285·9
Number of people in 2015 (millions)	36·0	216·6
Change from 1990 because of population growth (%)	38·4%	38·4%
Change from 1990 because of population ageing (having already included population growth, %)	34·6%	29·2%
Change from 1990 because of change in age-specific prevalence (%)	−36·7%	−24·2%
Change from 1990 to 2015	17·9%	35·5%

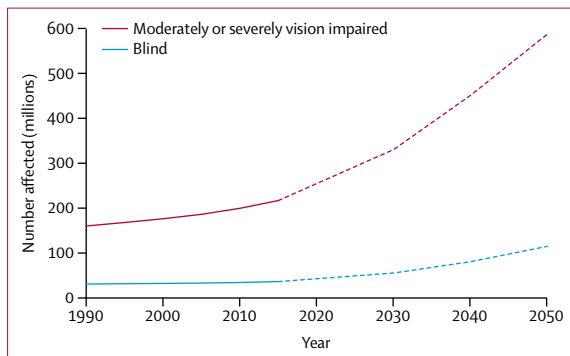*Table 3*: Global trends in numbers of people blind or visually impaired, 1990–2015

Figure 3: Global trends and predictions of numbers of people who are blind or moderately and severely vision impaired, from 1990–2050

investments that were made in the alleviation of impairment during this period have reaped considerable dividends. Such dividends include improvements in quality of life and large economic benefits, because people work rather than living with or caring for those living with unnecessary vision impairment.[22,23]

Although this study does not directly assess the causes of vision impairment, the large disparities between regions—as well as results from previous reports that directly addressed the question[24]—suggest that most cases of vision impairment in lesser-developed countries could be prevented or reversed. Although additional alleviation efforts will be needed everywhere, the regions with the largest prevalence and absolute burden of vision impairment should receive targeted attention. Given that a large proportion of blindness or vision impairment will require individual-level care by trained practitioners, areas such as those in sub-Saharan Africa with high age-standardised prevalence of vision impairment and younger population age structures represent particularly important

places in which to scale up training, in preparation for the predicted demographic expansion in older age groups.

The growth and change in age structure of the world's population is causing a substantial increase in the number of people with blindness and vision impairment, which appears to be accelerating. Concurrently, the observed decline in crude prevalence appears to be becoming less marked, particularly with regard to severe, moderate, and mild vision impairment. Although there are limitations to the modelling projections, the projected increase in prevalence and the global numbers affected by blindness and vision impairment, for example the numbers of blind people increasing to 38·5 million by 2020 and 115 million by 2050, indicates the scale of the challenge. The observed reductions in age-standardised prevalence of visual impairment in areas that received modest investments in blindness alleviation suggest that further investment is likely to mitigate these trends.

The finding that women bear the majority of blindness and vision impairment in population-based studies has been widely reported. A review of inequity in vision loss[25] concluded that insufficient data for analysis of inequality remains a problem in eye care and highlights the need for equity-relevant goals, targets, and indicators for eye health-care programmes. There are many other reasons for health inequality between population groups, between and within countries, which could include unfair distribution of power and resources and global governance dysfunction, these factors being judged as root causes in recent reports by the Commissions on Social Determinants of Health and the recent Global Governance for Health.[26,27] Doubtless, some of these root causes would be responsible for the considerable variation in crude and age-standardised prevalence of blindness and vision impairment that we observed between countries, and the very high prevalence of older adult blindness in Afghanistan, Ethiopia, Yemen, Chad, Cameroon, and Niger.

Since 2010, we have added 61 new studies reporting distance vision impairment to the Global Vision Database, the dataset that underpins these analyses. Several principal investigators have contributed more disaggregated data than was available in their previous publications, which have been added to the Global Vision Database. Additionally, the expansion of Rapid Assessment of Avoidable Blindness population-based eye surveys and the recently created online repository for these data have been a valuable contribution and resource for the Global Vision Database. Most studies that were newly added originated from east Asia, south Asia, North Africa and the Middle East, and east sub-Saharan Africa, whereas only a few new studies came from high-income North America, Latin America, Europe, and Australasia. In view of all available data, gaps are still present for central and southern Sub-Saharan Africa, eastern and central Europe, central Asia, and the Caribbean (figure 1).

Limitations of our study have to be taken into account. First, the availability of data sources varied between the

world regions, with major gaps as described previously. Second, the studies underlying our meta-analysis have varied definitions of blindness and vision impairment. Although we statistically corrected for differences between the studies, this difference increased the uncertainty of the estimates. We appeal for a worldwide reporting standardisation of definitions of blindness and vision impairment.[28] For instance, under-corrected presbyopia, until recently, has mostly been neglected, even in major population-based studies in ophthalmology, with the result that precision of estimates is weaker. Specifically, in terms of studies involving uncorrected presbyopia, there are limitations that involve differences between studies in which some measure objective and others functional presbyopia, with differences in test distance and font size. Fourth, many studies were not done on a national level. Although we took into account the level of representativeness of the data in the statistical model, for many countries only regionally assessed data on blindness and vision impairment were available. Although the so-called national level is arbitrary, it is a natural level for ascertainment of vision impairment burden since policy is typically made at a national level. Fifth, most underlying population-based studies included only participants who could access the examination centre whereas institutionalised (often elderly) individuals usually did not fully participate in the studies. This dynamic could have biased blindness and vision impairment estimates downward, since many eye diseases are age-related.[29,30] Sixth, caution must be exercised in the interpretation of the forecast of blindness and vision impairment. For example, it is assumed that the UN population projections for the future[21] are correct and that the covariates that we used in our model for access to health care[13] and literacy,[12] which have not been modelled into the future, will remain unchanged after 2015. Clearly, the level of provision of services will not remain the same, especially in areas such as cataract surgery and spectacles correction, but it is difficult to forecast what these changes will be.

By contrast with the previous modelling approach we took for 2010 estimates,[2] we have taken a fully Bayesian inference approach to modelling and posterior inference in this analysis. We used Markov chain Monte Carlo methods to fit our model, thus obtaining full posterior distributions for all parameters and quantities of interest (eg, age-standardised prevalence in a given country-year and change in prevalence from 1990 to 2015). We summarised these distributions by reporting 80% posterior uncertainty intervals surrounding the mean, rather than bootstrapped confidence intervals, as previously reported.[2] In the Bayesian framework, these uncertainty intervals reflect our probabilistic belief (posterior credibility) in our posterior mean predictions. Our models also changed slightly from the previous publication because we followed the 2015 GBD's slightly revised regional groupings.

Vision interventions provide some of the largest returns on investment[31] and are some of the most feasibly implemented interventions in less developed areas because of limited needs for infrastructure, lower costs, and relatively high potential for cost recovery in certain subdomains (eg, cataract surgery), compared with other health interventions. Although this report substantiates the ongoing reduction in the age-standardised prevalence of blindness and vision impairment noted in 2010, the growth and ageing of the world's population is causing a substantial increase in the number of people with blindness and vision impairment, which appears to be accelerating. These observations highlight the need to respond to WHO's Global Action Plan by scale-up of our current efforts at global, regional, and country levels, to eliminate the burden of unnecessary blindness and vision impairment.

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Declaration of interests
We declare no competing interests.

References
1 WHO. Draft action plan for the prevention of avoidable blindness and visual impairment 2014–2019. Universal eye health: a global action plan 2014–2019. Geneva: World Health Organization, 2013.
2 Stevens G, White R, Flaxman SR, et al, for the Vision Loss Expert Group. Global prevalence of visual impairment and blindness: magnitude and temporal trends, 1990–2010. *Ophthalmology* 2013; **120:** 2377–84.
3 Eckert KA, Carter MJ, Lansingh VC, et al. A simple method for estimating the economic cost of productivity loss due to blindness and moderate to severe visual impairment. *Ophthalmic Epidemiol* 2015; **22:** 349–55.
4 Ramrattan RS, Wolfs RC, Panda-Jonas S, et al. Prevalence and causes of visual field loss in the elderly and associations with impairment in daily functioning: the Rotterdam Study. *Arch Ophthalmol* 2001; **119:** 1788–94.
5 McCarty CA, Nanjan MB, Taylor HR. Vision impairment predicts 5 year mortality. *Br J Ophthalmol* 2001; **85:** 322–26.
6 Taylor HR, Katala S, Muñoz B, Turner V. Increase in mortality associated with blindness in rural Africa. *Bull World Health Organ* 1991; **69:** 335–38.
7 Bourne R, Price H, Taylor H, et al, for the Global Burden of Disease Vision Loss Expert Group. New systematic review methodology for visual impairment and blindness for the 2010 Global Burden of Disease study. *Ophthalmic Epidemiol* 2013; **20:** 33–39.
8 Keeffe JE, Jin CF, Weih LM, McCarty CA, Taylor HR. Vision impairment and older drivers: who's driving? *Br J Ophthalmol* 2002; **86:** 1118–21.
9 Holden BA, Tahhan N, Jong M, et al. Towards better estimates of uncorrected presbyopia. *Bull World Health Organ* 2015; **93:** 667.
10 Tahhan N, Papas E, Fricke TR, Frick KD, Holden BA. Utility and uncorrected refractive error. *Ophthalmology* 2013; **120:** 1736–44.
11 Gelman A, Carlin JB, Stern HS, Dunson DB, Vehtari A, Rubin DB. Bayesian data analysis, 3rd edn. London: Chapman & Hall/CRC Press, 2013.
12 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.
13 GHME Conference Organizing Committee. Shared innovations in measurement and evaluation. *Lancet* 2011; **377:** 969–70.
14 Vehtari A, Gelman A, and Gabry J. loo: Efficient leave-one-out cross-validation and WAIC for Bayesian models. R package version 1.0.0. 2016. https://github.com/stan-dev/loo (accessed June 30, 2017).
15 Vehtari A, Gelman A, Gabry J. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Stat Comput* 2017; **27:** 1413–32.
16 Stan Development Team. 2016. Stan Modeling Language Users Guide and Reference Manual, Version 2.11.1. http://mc-stan.org
17 Ahmad O, Boschi-Pinto C, Lopez AD, Murray CJL, Lozano R, Inoue M. Age standardization of rates: a new WHO standard. GPE Discussion Paper Series: no 31. Geneva: World Health Organization, 2001.
18 He M, Abdou A, Ellwein LB, et al. Age-related prevalence and met need for correctable and uncorrectable near vision impairment in a multi-country study. *Ophthalmology* 2014; **121:** 417–22.
19 He M, Abdou A, Naidoo KS, et al. Prevalence and correction of near vision impairment at seven sites in China, India, Nepal, Niger, South Africa, and the United States. *Am J Ophthalmol* 2012; **154:** 107–16.
20 Gelman A, Hill J. Data analysis using regression and multilevel/hierarchical models. Cambridge: Cambridge University Press, 2006.
21 UN. World population prospects: the 2015 revision. New York: United Nations, 2015.
22 Frick KD, Foster AF. The magnitude and cost of global blindness: an increasing problem that can be alleviated. *Am J Ophthalmol* 2003; **135:** 471–76.
23 Chakravarthy U, Biundo E, Saka RO, Fasser C, Bourne R, Little JA. The economic impact of blindness in Europe. *Ophthalmic Epidemiol* 2017; **24:** 239–47.
24 Bourne R, Stevens GA, White RA, et al, for the Vision Loss Expert Group. Causes of vision loss worldwide, 1990–2010: a systematic analysis. *Lancet Glob Health* 2013; **1:** e339–49.
25 Ramke J, Zwi AB, Palagyi A, Blignault I, Gilbert CE. Equity and blindness: closing evidence gaps to support universal eye health. *Ophthalmic Epidemiol* 2015; **22:** 297–307.
26 Commission on Social Determinants of Health. Closing the gap in a generation: health equity through action on the social determinants of health. Final report of the Commission on Social Determinants of Health. Geneva: World Health Organization, 2008.
27 Ottersen OP, Dasgupta J, Blouin C, et al. The political origins of health inequity: prospects for change. *Lancet* 2014; **383:** 630–67.
28 Resnikoff S, Keys TU. Future trends in global blindness. *Indian J Ophthalmol* 2012; **60:** 387–95.
29 Mitchell P, Hayes P, Wang JJ. Visual impairment in nursing home residents: the Blue Mountains Eye Study. *Med J Aust* 1997; **166:** 73–76.
30 Van der Pols JC, Bates CJ, McGraw PV, et al. Visual acuity measurements in a national sample of British elderly people. *Br J Ophthalmol* 2000; **84:** 165–70.
31 Brown MM, Brown GC, Lieske HB, Lieske PA. Financial return-on-investment of ophthalmic interventions: a new paradigm. *Curr Opin Ophthalmol* 2014; **25:** 171–76.