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Global estimates on the number of people blind or visually impaired by Uncorrected Refractive Error: a meta-analysis from 2000 to 2020

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BACKGROUND: Uncorrected refractive error (URE) is a readily treatable cause of visual impairment (VI). This study provides updated estimates of global and regional vision loss due to URE, presenting temporal change for VISION 2020

METHODS: Data from population-based eye disease surveys from 1980–2018 were collected. Hierarchical models estimated prevalence (95% uncertainty intervals [UI]) of blindness (presenting visual acuity (VA) < 3/60) and moderate-to-severe vision impairment (MSVI; 3/60 ≤ presenting VA < 6/18) caused by URE, stratified by age, sex, region, and year. Near VI prevalence from uncorrected presbyopia was defined as presenting near VA < N6/N8 at 40 cm when best-corrected distance (VA ≥ 6/12).

RESULTS: In 2020, 3.7 million people (95%UI 3.10–4.29) were blind and 157 million (140–176) had MSVI due to URE, a 21.8% increase in blindness and 72.0% increase in MSVI since 2000. Age-standardised prevalence of URE blindness and MSVI decreased by 30.5% (30.7–30.3) and 2.4% (2.6–2.2) respectively during this time. In 2020, South Asia GBD super-region had the highest 50+ years age-standardised URE blindness (0.33% (0.26–0.40%)) and MSVI (10.3% (8.82–12.10%)) rates. The age-standardized ratio of women to men for URE blindness was 1.05:1.00 in 2020 and 1.03:1.00 in 2000. An estimated 419 million (295–562) people 50+ had near VI from uncorrected presbyopia, a +75.3% (74.6–76.0) increase from 2000

CONCLUSIONS: The number of cases of VI from URE substantively grew, even as age-standardised prevalence fell, since 2000, with a continued disproportionate burden by region and sex. Global population ageing will increase this burden, highlighting urgent need for novel approaches to refractive service delivery.

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INTRODUCTION

Uncorrected refractive error (URE) is the leading cause of vision impairment globally among both adults and children, and contributes to reduced educational and economic opportunities [1–6], decreased quality of life [7] and an increased burden of mortality [8–10]. Visual impairment is a significant global health concern and the financial burden with global productivity losses is estimated to be 411 billion US dollars annually [11]. URE is readily treated with spectacles, making it one of the most cost-effective healthcare interventions, alongside cataract surgery [12–15]. Thus, it is a global priority to improve access to refraction services [11], as set out in 'Towards universal eye health: Global Action Plan 2014–2019 of the World Health Assembly (WHA) in 2013 [16]. and more recently in the 'World Report on Vision' by the World Health Organisation (WHO) in 2019 [17], which called for the routine measurement of refractive error services coverage as a means to address the United Nations (UN) Sustainable Development Goals [18] target 3.8 to "achieve universal health coverage, including financial risk protection, access to quality essential healthcare services and access to safe, effective, quality and affordable essential medicines and vaccines for all". Furthermore, these recommendations have been adopted in a resolution by the 73rd WHA member states in 2021, which set global targets for a 40% increase in effective refractive error coverage (eREC) by 2030. As we transition from the efforts of VISION 2020: the Right to Sight initiative to tackle avoidable blindness, these focused targets are fundamental to eliminate avoidable vision loss in future.

Refractive error is a common ocular condition which occurs throughout the lifespan [19], and chiefly falls into the following categories: myopia (affecting mostly distance vision), hyperopia (potentially causing impaired vision at distance and near), which may both be accompanied by an astigmatic component, and presbyopia (characterised by poor near vision). The last 20 years have seen rapid increases in the prevalence of myopia across the world, particularly in East Asia [20–23].

Nearly all individuals, even those without significant refractive error in childhood and earlier adult years will acquire presbyopia by the 5th decade of life, necessitating refractive correction for near work. Presbyopia occurs due to reduced flexibility of the human crystalline lens to accommodate (focus) on near targets, resulting in blurred near vision. It is an essentially universal phenomenon, with age of onset determined by factors such as the presence of latent hyperopia. Without refractive correction, vision deteriorates for near activities, resulting in near visual impairment. Where uncorrected hyperopia is common, due to

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lack of access to both education (which induces myopia [24]) and refractive services, the onset of presbyopia may even occur in the 30 s, which is a critical working age for those in industries such as garments and textiles [25, 26]. With an ageing global population, the burden of presbyopia and near visual impairment will increase. Coupled with the impact of the increased prevalence of myopia, the burden of URE is likely to grow in the future.

The Vision Loss Expert Group (VLEG) curate a comprehensive, continuously updated, online database of ophthalmic epidemiological data and have made important contributions to knowledge about the burden and causes of vision impairment and blindness globally [27–29]. These estimates have been used in the WHO Report on Vision in 2019 [17] and the recent Lancet Global Health commission on Global Eye Health Report [15]. Updated analyses are required to reflect rapidly increasing sources of new population data, and to monitor progress in reduction of avoidable sight loss. The need for new population data on vision impairment has been emphasised in a recent paper highlighting the grand challenge priorities for global eye health [30], and will be vital to monitor and measure success against the WHA global target of a 40% increase in eREC.

Thus, the aim of the current study is to provide updated estimates of the global burden of vision loss due to URE, disaggregated by sex, age, year and region, for the period from 2000 to 2020 covered by VISION 2020: The Right to Sight initiative. For the first time, temporal trends will be calculated to present the burden of visual impairment resulting from uncorrected presbyopia in those 50+ years.

METHODS

A systematic review of population-based studies of vision impairment and blindness published between Jan 1, 1980, and Oct 1, 2018, was carried out, which included grey literature sources. Eligible studies from this review were then combined with data from Rapid Assessment of Avoidable Blindness (RAAB) studies and finally, data from the US National Health and Nutrition Examination Survey and the WHO Study on Global Ageing and Adult Health were added. More detailed methods are published elsewhere [30, 31], and outlined below.

In total, the VLEG review identified 243 studies (73% were rapid studies) across 73 countries from which data relating to the contribution of URE to vision loss could be extracted: with 70 studies from the 2010 review [28], and a further 173 studies in an extension of the literature review to 2018 [29]. Studies were primarily national and subnational cross-sectional surveys. By the seven World Global Burden of Disease (GBD) super regions, 43 studies were from Sub-Saharan Africa, 100 from Southeast Asia, East Asia, and Oceania, 44 from South Asia, 16 from North Africa and the Middle East, 25 from Latin America and the Caribbean, 9 from High income, and 6 from Central Europe, Eastern Europe, and Central Asia. Additionally, the VLEG commissioned the preparation of 5-year age-disaggregated RAAB data from the RAAB repository. Studies were included if they met the following criteria: visual acuity data had to be measured using a test chart that could be mapped to the Snellen scale, and the sample had to be representative of the population. Studies based on self-report of vision loss were excluded. The International Classification of Diseases 11th edition [32] criteria for vision loss, as suggested by WHO, was employed, categorizing individuals according to vision in their better eye on presentation. This classification defines moderate vision loss as visual acuity of 6/60 or better but less than 6/18, severe vision loss as a visual acuity of 3/60 or better but less than 6/60, and blindness as visual acuity of less than 3/60 or less than 10° visual field around central fixation (although the visual field definition is rarely used in population-based eye surveys). Moderate and severe visual impairment (MSVI) was combined to present prevalence data. Vision impairment from uncorrected presbyopia was defined as presenting near vision of worse than <N6 or <N8 at 40 cm where best-corrected distance visual acuity was 6/12 or better. Prevalence of near VI from uncorrected presbyopia was based on 25 studies.

The global and regional prevalence and burden of blindness and MSVI due to URE were gathered from the all-cause meta-analysis and modelling. First, we separated raw data into datasets including so-called vision loss envelopes (see Flaxman et al. [28]. for explanation) for all-cause mild, moderate, and severe vision loss, and blindness. Data were input into a mixed-effects meta-regression tool developed by the Institute for Health Metrics and Evaluation and called MR-BRT (meta-regression; Bayesian; regularised; trimmed) [33]. Presenting vision impairment was the reference definition for each level of severity. Prevalence data for URE were extracted directly where available and otherwise calculated by subtracting best-corrected vision impairment from presenting vision impairment prevalence for each level of severity in studies that reported both measures for a given location, sex, age group, and year. All other causes were quantified as part of the best-corrected estimates of vision impairment at each level of severity.

We modelled distance vision impairment and blindness attributable to the following causes: cataract, URE, age-related macular degeneration, myopic macular degeneration, glaucoma, diabetic retinopathy, and other causes of vision impairment (in aggregate).

We produced location-, year-, age-, and sex-specific estimates of MSVI and blindness using Disease Modelling Meta-Regression (Dismod-MR) 2.1 [34]. The details of the data processing steps are described elsewhere [29]. Briefly, Dismod-MR 2.1 models were run for all vision impairment stratified by severity (moderate, severe, blindness) regardless of cause and, separately, for MSVI and blindness due to each modelled cause of vision impairment. Then, models of MSVI due to specific causes were split into moderate and severe vision loss estimates using the ratio of overall prevalence in the all-cause moderate presenting vision impairment and severe presenting vision impairment models. Next, prevalence estimates for all causes stratified by severity were scaled to the models of all-cause prevalence by severity. This produced final estimates by age, sex, year, and location for each individual cause of vision impairment stratified by severity, including refractive error. Model projection was to the year 2020, coincident with the end of VISION 2020: the Right to Sight initiative, and estimates were age-standardised using the GBD standard population [35]. All generated estimates for visual impairment due to URE are accompanied by 95% uncertainty intervals (UI), which represent the 25th and 975th ordered estimates of 1000 draw estimates of the posterior distribution. We considered estimates to be significantly different if the 95% UIs did not overlap. Data are presented for the total population and also for individuals aged 50+ years, as data sources such as RAAB surveys are major sources of data for low-income and low- or middle-income countries (LICs and LMICs) and these surveys are conducted on individuals aged 50 years and older. The data estimates reported in this study were produced in compliance with the Guidelines for Accurate and Transparent Health Estimates Reporting [36].

Data are presented for the seven World super-regions based on the GBD regional classification system [37], and sub-divided into the 21 GBD world regions. These seven super regions are drawn together based on two criteria: epidemiological similarity and geographic proximity.

RESULTS

We used 243 data sources from 73 countries to calculate the global and regional prevalence and burden of blindness and MSVI due to URE. Table 1 presents the number of people, men and women, with blindness (<3/60) or MSVI (<6/18 to >/=3/60) due to URE in 2020 in the seven super-regions based on the GBD classification system. Appendix 1 contains supplementary tables for all 21 GBD world regions in 2020. These estimates reveal that in 2020, 3.70 million people (95% UI 3.10–4.29 million) in the world were blind and 157 million (95% UI 140–175 million) had MSVI due to URE. Focusing on those 50+ years of age, 2.29 million people (95% UI 1.79–2.80 million) were blind due to URE globally and 86.1 million (95% UI 74.2–101 million) had MSVI.

As a percentage of all types of blindness, the burden of blindness due to URE globally is 8.60% (95% UI 7.22–9.99%) and is greatest for the super regions of South Asia (12.71%, 95% UI 10.58–14.82%) and Southeast Asia, East Asia and Oceania (9.34%, 95% UI 7.67–10.94%). These updated data estimate that URE is the leading cause of MSVI globally, accounting for 53.39% (95% UI 47.56–59.51%) of all cases. Focusing on blindness due to URE in those aged 50+ years, South Asia accounts for the largest age-standardised prevalence (0.33% (95% UI 0.26–0.40%)), followed by the super-regions of Southeast Asia, East Asia and Oceania (0.15% (95% UI 0.12–0.18%)) and Sub-Saharan Africa (0.11% (95% UI 0.09–0.14%)).

Table 1. Number and age-standardised prevalence of people with blindness (<3/60) or MSVI (<6/18 to >/=3/60) due to URE in 7 Super Regions in 2020.

	GLOBAL	**Central Europe, Eastern Europe, and Central Asia**	**High income**	**Latin America and Caribbean**	**North Africa and Middle East**	**South Asia**	**Southeast Asia, East Asia, and Oceania**	**Sub-Saharan Africa**
Total population 2020 (thousands)	7,890,000	417,000	1,090,000	602,000	632,000	1,840,000	2,190,000	1,110,000
Number of people with blindness (thousands)	**3700 (3100–4290)**	**29.4 (23.3–36.0)**	**80.0 (63.6–97.6)**	**218 (180–258)**	**190 (156–229)**	**1520 (1260–1770)**	**1410 (1150–1650)**	**254 (212–303)**
Number of Men with blindness (thousands)	1750 (1480–2020)	13.7 (10.8–17.1)	36.9 (29.1–44.8)	96.1 (78.6–114)	90.4 (73.6–109)	728 (606 –847)	657 (539–769)	123 (102–146)
Number of Women with blindness (thousands)	1950 (1620–2280)	15.7 (12.4–19.2)	43.1 (34.6–52.3)	122 (101–144)	99.8 (81.8–120)	789 (658–925)	750 (616–879)	132 (110–157)
Number of people with blindness aged 50+ years (thousands)	**2290 (1790–2800)**	**16.8 (12.8–21.1)**	**46.1 (35.7–56.9)**	**126 (97.5–153)**	**84.2 (63.8–103)**	**976 (762–1190)**	**933 (728–1140)**	**111 (84.5–136)**
Number of Men with blindness aged 50+ years (thousands)	1050 (816–1270)	7.05 (5.27–8.88)	21.1 (16.2–26.1)	53.8 (41.3–65.7)	39.3 (29.6–48.3)	459 (358–558)	415 (325–509)	52.5 (40.2–65.0)
Number of Women with blindness aged 50+ years (thousands)	1250 (975 –1520)	9.76 (7.35–12.4)	25.0 (19.3–30.9)	72.5 (56.4–87.6)	44.9 (34.1–55.3)	517 (402–633)	518 (406–632)	58.2 (44.3–71.9)
Age-standardised prevalence of blindness	**0.04% (0.04–0.05)**	**0.01% (0.00–0.01)**	**0.01% (0.00–0.01)**	**0.04% (0.03–0.04)**	**0.03% (0.03–0.04)**	**0.10% (0.08–0.12)**	**0.05% (0.04–0.06)**	**0.04% (0.03–0.04)**
Age-standardised prevalence of blindness: Men	0.04% (0.04–0.05)	0.01% (0.00–0.01)	0.01% (0.00–0.01)	0.03% (0.03–0.04)	0.03% (0.03–0.04)	0.10% (0.08–0.11)	0.05% (0.04–0.06)	0.04% (0.03–0.05)
Age-standardised prevalence of blindness: Women	0.05% (0.04–0.05)	0.01% (0.00–0.01)	0.01% (0.00–0.01)	0.04% (0.03–0.04)	0.04% (0.03–0.04)	0.10% (0.09–0.12)	0.06% (0.05–0.06)	0.04% (0.03–0.04)
Age-standardised prevalence of blindness 50+ years	**0.12% (0.10–0.15)**	**0.01% (0.01–0.02)**	**0.01% (0.01–0.01)**	**0.09% (0.07–0.11)**	**0.09% (0.07–0.11)**	**0.33% (0.26–0.40)**	**0.15% (0.12–0.18)**	**0.11% (0.09–0.14)**
Age-standardised prevalence of blindness in Men 50+ years	0.12% (0.09–0.14)	0.01% (0.01–0.02)	0.01% (0.01–0.01)	0.09% (0.07–0.11)	0.08% (0.06–0.10)	0.32% (0.25–0.38)	0.14% (0.11–0.17)	0.12% (0.09–0.14)
Age-standardised prevalence of blindness in Women 50+ years	0.13% (0.10–0.15)	0.01% (0.01–0.01)	0.01% (0.01–0.01)	0.10% (0.08–0.12)	0.09% (0.07–0.12)	0.34% (0.27–0.42)	0.16% (0.12–0.19)	0.11% (0.09–0.14)
Percentage of all blindness	**8.60% (7.22–9.99)**	**2.07% (1.64–2.54)**	**2.66% (2.11–3.24)**	**5.96% (4.92–7.04)**	**6.15% (5.03–7.40)**	**12.71% (10.58–14.82)**	**9.34% (7.67–10.94)**	**5.00% (4.17–5.96)**
Number of people with MSVI (thousands)	**157,000 (140,000–176,000)**	**9660 (8560–10,900)**	**17,100 (15,200–18,900)**	**14,700 (13,000–16,300)**	**12,800 (11,400–14,400)**	**53,900 (47,800–60,900)**	**39,700 (35,400–44,600)**	**9620 (8480–10,900)**
Number of Men with MSVI (thousands)	73,300 (65,400–81,900)	3830 (3380–4310)	8240 (7300–9150)	6550 (5820–7300)	6380 (5660–7120)	25,600 (22,700–28,900)	18,200 (16,200–20,400)	4520 (3970–5120)
Number of Women with MSVI (thousands)	84,100 (74,900–93,900)	5830 (5180–6600)	8850 (7900–9810)	8140 (7180–9070)	6460 (5740–7240)	28,200 (25,000–31,900)	21,500 (19,200–24,200)	5100 (4500–5760)

Table 1. continued

	GLOBAL	Central Europe, Eastern Europe, and Central Asia	High income	Latin America and Caribbean	North Africa and Middle East	South Asia	Southeast Asia, East Asia, and Oceania	Sub-Saharan Africa
Number of people with MSVI aged 50+ years (thousands)	**86,100 (74,200–101,000)**	**6340 (5400–7480)**	**8940 (7680–10,400)**	**5780 (4950–6780)**	**4680 (3960–5550)**	**32,150 (27,500–37,900)**	**25,050 (21,500–29,300)**	**3210 (2730–3800)**
Number of Men with MSVI aged 50+ years (thousands)	39,000 (33,600–45,810)	2270 (1920–2710)	3720 (3200–4310)	2610 (2240–3070)	2280 (1900–2690)	15,600 (13,300–18,400)	11,100 (9550–13,100)	1480 (1260–1750)
Number of Women with MSVI aged 50+ years (thousands)	47,100 (40,600–55,200)	4070 (3470–4780)	5220 (4490–6010)	3170 (2720–3710)	2400 (2030–2840)	16,600 (14,200–19,500)	13,900 (12,000–16,200)	1730 (1470–2050)
Age-standardised prevalence of MSVI	**1.91% (1.71–2.13)**	**1.85% (1.65–2.06)**	**1.37% (1.21–1.53)**	**2.39% (2.12–2.65)**	**2.24% (2.00–2.50)**	**3.37% (2.99–3.81)**	**1.60% (1.43–1.78)**	**1.24% (1.10–1.38)**
Age-standardised prevalence of MSVI: Men	1.83% (1.63–2.04)	1.69% (1.50–1.88)	1.41% (1.25–1.60)	2.22% (1.97–2.46)	2.17% (1.93–2.42)	3.25% (2.89–3.65)	1.49% (1.33–1.66)	1.21% (1.08–1.35)
Age-standardised prevalence of MSVI: Women	2.00% (1.78–2.23)	1.98% (1.76–2.22)	1.31% (1.16–1.47)	2.56% (2.27–2.86)	2.32% (2.07–2.59)	3.51% (3.11–3.97)	1.70% (1.52–1.90)	1.27% (1.12–1.42)
Age-standardised prevalence of MSVI 50+ years	**4.58% (3.96–5.37)**	**4.51% (3.85–5.31)**	**1.94% (1.67–2.25)**	**4.28% (3.68–5.00)**	**4.73% (4.02–5.54)**	**10.28% (8.82–12.06)**	**3.94% (3.39–4.56)**	**3.16% (2.73–3.70)**
Age-standardised prevalence of MSVI in Men 50+ years	4.41% (3.80–5.16)	3.97% (3.41–4.70)	1.80% (1.55–2.10)	4.21% (3.62–4.92)	4.57% (3.88–5.36)	10.19% (8.74–11.89)	3.66% (3.16–4.26)	3.13% (2.70–3.65)
Age-standardised prevalence of MSVI in Women 50+ years	4.75% (4.09–5.56)	4.89% (4.18–5.76)	2.05% (1.76–2.38)	4.35% (3.74–5.09)	4.88% (4.14–5.72)	10.40% (8.93–12.18)	4.19% (3.62–4.87)	3.19% (2.74–3.74)
Percentage of all MSVI	**53.39% (47.56–59.51)**	**53.69% (47.61–60.63)**	**55.00% (49.02–60.95)**	**60.00% (53.21–66.69)**	**58.76% (52.21–65.72)**	**55.99% (49.64–63.32)**	**47.84% (42.61–53.69)**	**47.06% (41.49–53.29)**

Data are presented for the whole population (bold), by sex breakdown and for those 50+ years. Figures in parentheses reflect 95% uncertainty intervals. Count data are presented to three significant figures, and percentages to two decimal places.

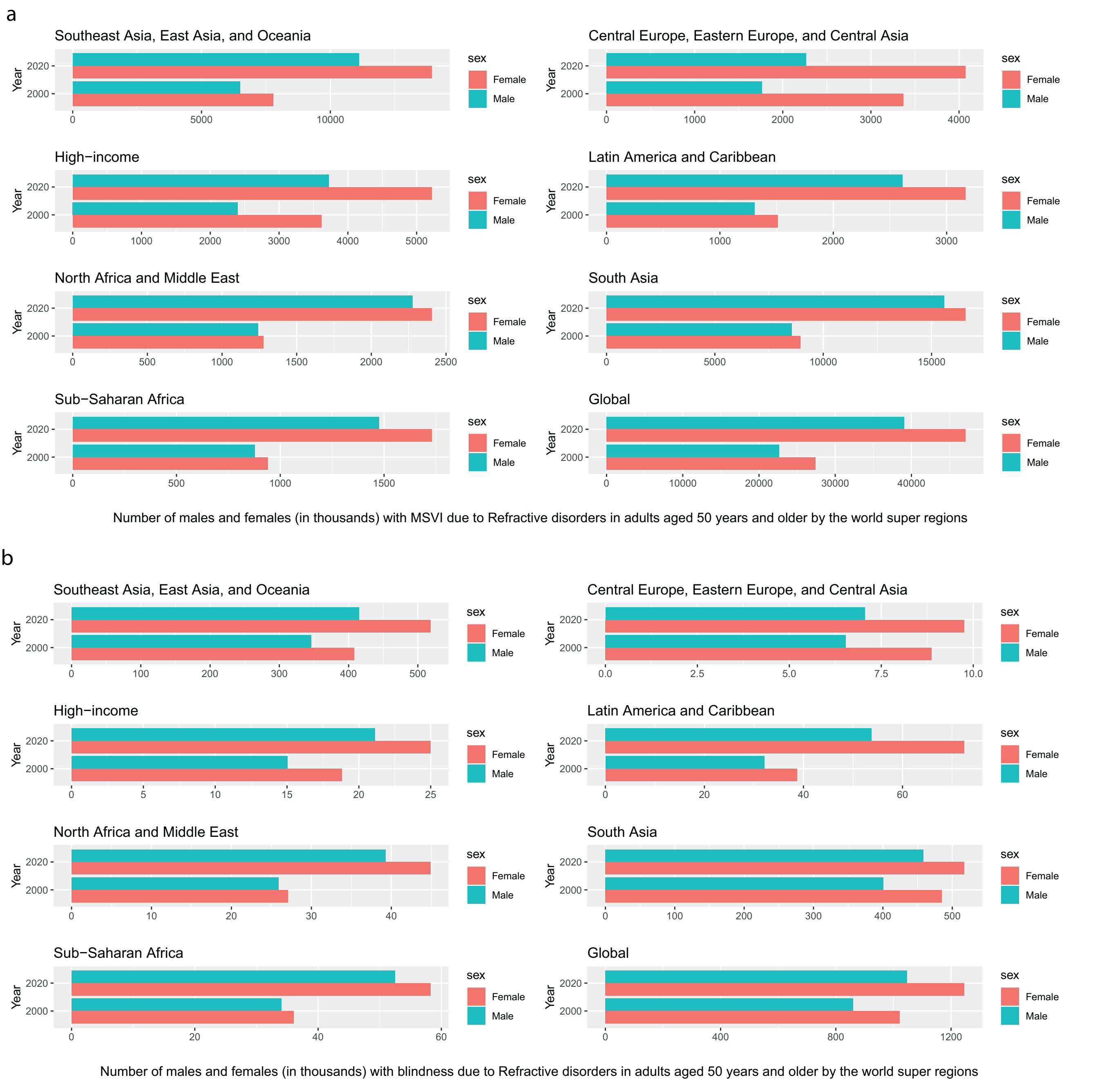

Fig. 1 Bar charts demonstrating the number of men and women with blindness and MSVI due to URE in 2000 and 2020 by seven World GBD super-regions and globally. a indicates numbers for MSVI and **b** blindness. Note that scales (values should be multiplied by 1000) are not the same between charts, but rather serve to highlight the differences across the time period and sex differences within GBD super-regions.

The overall age-standardised prevalence of blindness due to URE in those aged 50+ years was 0.12% (95% UI 0.10–0.15%), and 4.58% for MSVI (95% UI 3.96–5.37%). Figure 1 shows the number of men and women aged 50+ years with blindness and MSVI due to URE in 2020 in the seven World GBD super regions, and includes the global total for overall comparison. Figure 2 presents the crude prevalence of blindness and MSVI due to URE in 2020 across super regions.

Table 2 presents the percentage change in crude prevalence of MSVI and blindness due to URE in men and women aged 50 years and older between 2000 and 2020 for the seven World GBD super regions (see Appendix 1 for all 21 GBD World regions). Over this time period the number of cases of blindness and MSVI increased by +21.8% and +72.0%% respectively, with the greatest increase in the Latin America and Caribbean super-region for both blindness and MSVI. However, the age-standardised prevalence of URE blindness in those 50+ years decreased significantly, by −30.5% (95% UI −30.7 to −30.3) during this time period. The global age-standardised prevalence of MSVI due to URE in those aged 50+ years modestly decreased by −2.4% (95% UI −2.6 to −2.2%) between 2000 and 2020, but with some regional variations. The Latin America and Caribbean super-region demonstrated a slight increase in age-standardised prevalence of MSVI due to URE of +0.8% (95% UI + 0.7 to +1.0%), and the High-Income super-region had no change (+0.1%, 95% UI −0.1 to +0.3).

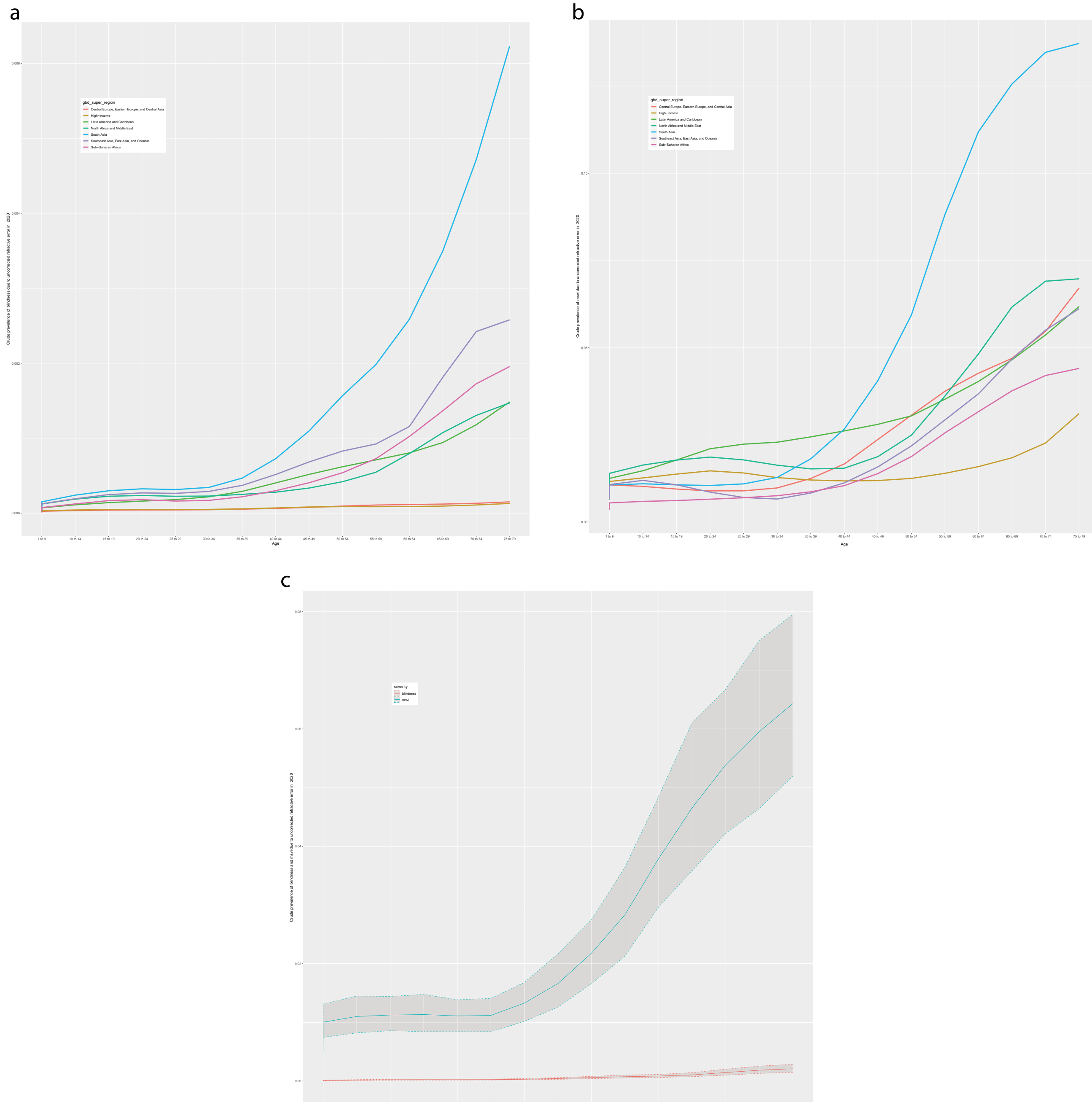

Fig. 2 Crude prevalence of blindness and MSVI due to URE by region and globally by age. a Crude prevalence of blindness due to URE in 2020 by seven World GBD super regions by age. **b** Crude prevalence of MSVI due to URE in 2020 by seven World GBD super regions by age. **c** Crude prevalence of Blindness (red) and MSVI (cyan) due to URE in 2020 globally by age, with 95% UI indicated as shading.

By a clear margin, South Asia had the highest regional 50+ years age-standardised URE blindness and MSVI prevalence in 2020 (blind: 0.3%, 95% UI 0.3–0.4; MSVI: 10.3%; 95% UI 8.8–12.1%) (Table 1), but also demonstrated the greatest reductions in age-standardised URE blindness between 2000 and 2020 (−46.3% (95% UI −46.5 to −46.2%)) (Table 2).

Globally, the age-standardized ratio of women to men for URE blindness was 1.05:1.00 in 2020 and 1.03:1.00 in 2000. For MSVI, this ratio was 1.08:1.00 in 2020 and 1.06:1.00 in 2000. Thus, in 2020, women continue to suffer an excess burden, with the age-standardized prevalence of women exceeding that of men by 4.76% for URE blindness and 7.40% for URE MSVI. Men exhibited a greater 20-year reduction in age-standardised prevalence compared to women for both blindness and MSVI: MSVI −3.0% (95% UI −3.1 to −2.8) in men, −2.0% (95% UI −2.2 to −1.8) in women; blindness −31.6% (95% UI −31.8 to −31.4) in men, −29.9% (95% UI −30.0 to −29.7) in women. Regionally, women have made smaller gains than men in the reduction of age −standardised prevalence of MSVI due to URE, particularly in the super regions of Central Europe, Eastern Europe and Central Asia, North Africa and Middle East, and Latin America and Caribbean. In the High-Income super-region, age-standardised prevalence of blindness has actually increased modestly for woman at +1.0% (95% UI 0.8 to 1.2%) compared to men −0.1% (95% UI −0.3 to 0.0). However, it is notable that in South Asia, there has been a greater reduction in age-standardised prevalence of both

Table 2. Percentage change in crude prevalence, case number and age-standardised prevalence of MSVI and blindness due to URE in adults aged 50 years and older in the 7 Super Regions between 2000 and 2020.

	MSVI caused by URE									Blindness caused by URE								
	Percentage change in Crude Prevalence between 2000 and 2020			Percentage Change in Number of Cases between 2000 and 2020			Percentage Change in Age-standardised prevalence between 2000 and 2020			Percentage Change in Crude Prevalence between 2000 and 2020			Percentage Change in Number of Cases between 2000 and 2020			Percentage Change in Age-standardised prevalence between 2000 and 2020		
Region	Men	Women	**Both**	Men	Women	**Both**	Men	Women	**Both**	Men	Women	**Both**	Men	Women	**Both**	Men	Women	**Both**
GLOBAL	−2.2% (−2.4 to −2.0)	−2.3% (−2.5 to −2.1)	**−2.3% (−2.5 to −2.1)**	+72.5% (72.2 to 72.8)	+71.6% (71.3 to 71.9)	**+72.0% (71.7 to 72.3)**	−3.0% (−3.1 to −2.8)	−2.0% (−2.2 to −1.8)	**−2.4% (−2.6 to −2.2)**	−31.0% (−31.2 to −30.8)	−30.6% (−30.8 to −30.5)	**−30.8% (−31.0 to −30.6)**	+21.7% (21.4 to 22.1)	+21.9% (21.6 to 22.2)	**+21.8% (21.5 to 22.2)**	−31.6% (−31.8 to −31.4)	−29.9% (−30.0 to −29.7)	**−30.5% (−30.7 to −30.3)**
Central Europe, Eastern Europe & Central Asia	−1.1% (−1.3 to −0.9)	−2.2% (−2.4 to −2.0)	**−2.1% (−2.3 to −1.9)**	+28.3% (28.1 to 28.6)	+21.0% (20.7 to 21.2)	**+23.5% (23.3 to 23.7)**	−2.3% (−2.5 to −2.1)	−2.3% (−2.5 to −2.2)	**−2.8% (−2.9 to −2.6)**	−16.8% (−17.0 to −16.5)	−11.1% (−11.4 to −10.8)	**−13.5% (−13.8 to −13.2)**	+8.0% (7.6 to 8.3)	+10.0% (9.7 to 10.4)	**+9.2% (8.8 to 9.5)**	−17.4% (−17.8 to −17.5)	−10.7% (−10.4 to −11.1)	**−13.8% (−14.1 to −14.4)**
High Income	+5.3% (5.1 to 5.5)	+3.6% (3.4 to 3.8)	**+4.0% (3.8 to 4.2)**	+55.0% (54.7 to 55.2)	+44.3% (44.1 to 44.6)	**+48.6% (48.3 to 48.8)**	−0.1% (−0.3 to 0.0)	+1.0% (0.8 to 1.2)	**+0.1% (−0.1 to 0.3)**	−4.6% (−4.9 to −4.3)	−4.6% (−4.9 to −4.4)	**−4.7% (−4.9 to −4.4)**	+40.4% (40.0 to 40.8)	+32.9% (32.5 to 33.2)	**+36.2% (35.8 to 36.6)**	−7.9% (−8.2 to −7.7)	−6.9% (−7.1 to −6.8)	**−7.2% (−7.5 to −7.0)**
Latin America and Caribbean	+1.4% (1.2 to 1.6)	+2.3% (2.1 to 2.5)	**+1.9% (1.8 to 2.1)**	+99.8% (99.4 to 100.2)	+109.4% (109.1 to 109.8)	**+105.0% (104.6 to 105.4)**	+0.4% (0.2 to 0.5)	+1.2% (1.0 to 1.4)	**+0.8% (0.7 to 1.0)**	−15.0% (−15.2 to −14.8)	−8.5% (−8.7 to −8.3)	**−11.3% (−11.5 to −11.1)**	+67.5% (67.1 to 68.0)	+87.3% (86.8 to 87.8)	**+78.3% (77.9 to 78.8)**	−15.9% (−16.1 to −15.7)	−10.4% (−10.6 to −10.1)	**−12.7% (−12.9 to −12.5)**
North Africa and Middle East	−11.8% (−12.0 to −11.6)	−9.6% (−9.8 to −9.4)	**−10.7% (−10.9 to −10.5)**	+83.2% (82.9 to 83.6)	+88.1% (87.8 to 88.5)	**+85.7% (85.4 to 86.1)**	−9.0% (−9.2 to −8.8)	−8.1% (−8.3 to −7.9)	**−8.5% (−8.7 to −8.3)**	−27.0% (−27.2 to −26.8)	−20.2% (−20.5 to −20.0)	**−23.5% (−23.8 to −23.3)**	+51.7% (51.3 to 52.2)	+66.0% (65.5 to 66.4)	**+59.0% (58.5 to 59.5)**	−23.2% (−23.4 to −23.0)	−18.3% (−18.5 to −18.1)	**−20.7% (−20.9 to −20.5)**
South Asia	−3.3% (−3.5 to −3.2)	−8.5% (−8.7 to −8.3)	**−5.9% (−6.1 to −5.7)**	+82.4% (82.1 to 82.8)	+85.0% (84.7 to 85.4)	**+83.8% (83.4 to 84.1)**	−4.3% (−4.5 to −4.1)	−8.9% (−9.1 to −8.8)	**−6.7% (−6.8 to −6.5)**	−39.4% (−39.5 to −39.2)	−47.2% (−47.4 to −47.1)	**−43.6% (−43.7 to −43.4)**	+14.5% (14.2 to 14.8)	+6.7% (6.4 to 7.0)	**+10.2% (9.9 to 10.5)**	−42.1% (−42.2 to −41.9)	−50.0% (−50.2 to −49.9)	**−46.3% (−46.5 to −46.2)**
Southeast Asia, East Asia and Oceania	−13.5% (−13.7 to −13.4)	−12.2% (−12.3 to −12.0)	**−12.7% (−12.8 to −12.5)**	+71.0% (70.7 to 71.3)	+79.2% (78.9 to 79.5)	**+75.5% (75.1 to 75.8)**	−14.9% (−15.1 to −14.8)	−12.3% (−12.5 to −12.2)	**−13.5% (−13.7 to −13.4)**	−39.4% (−39.5 to −39.2)	−37.8% (−37.9 to −37.6)	**−38.4% (−38.6 to −38.3)**	+19.9% (19.6 to 20.2)	+27.0% (26.6 to 27.3)	**+23.7% (23.4 to 24.0)**	−39.8% (−39.9 to −39.6)	−37.6% (−37.8 to −37.5)	**−38.8% (−38.9 to −38.6)**
Sub−Saharan Africa	−4.9% (−5.1 to −4.7)	−5.2% (−5.3 to −5.0)	**−4.9% (−5.1 to −4.7)**	+68.3% (68.0 to 68.6)	+84.0% (83.6 to 84.4)	**+76.4% (76.1 to 76.8)**	−3.7% (−3.8 to −3.5)	−3.3% (−3.5 to −3.1)	**−3.4% (−3.5 to −3.2)**	−12.8% (−13.0 to −12.6)	−16.7% (−17.0 to −16.5)	**−14.8% (−15.1 to −14.6)**	+54.3% (53.8 to 54.7)	+61.5% (61.1 to 62.0)	**+58.0% (57.6 to 58.4)**	−10.6% (−10.8 to −10.4)	−14.0% (−14.2 to −13.7)	**−12.5% (−12.7 to −12.2)**

Percentage change to 1 decimal place and figures in parentheses reflect 95% uncertainty intervals. Data in bold indicate totals for both sexes.

Table 3. Number and age-standardised prevalence of people with uncorrected presbyopia aged 50+ years (>N6/N8 at 40 cm when best-corrected distance visual acuity was 6/12 or better) in 7 Super Regions in 2020.

	GLOBAL	Central Europe, Eastern Europe, and Central Asia	High income	Latin America and Caribbean	North Africa and Middle East	South Asia	Southeast Asia, East Asia, and Oceania	Sub-Saharan Africa
Total population 2020 (thousands)	7,890,000	417,000	1,090,000	602,000	632,000	1,840,000	2,190,000	1,110,000
Number of people with uncorrected presbyopia (aged 50+ years) (thousands)	**419,000 (295,000–562,000)**	**39,800 (28,300–53,500)**	**11,400 (7700–15,900)**	**24,910 (17,600–33,600)**	**12,200 (8410–16,800)**	**124,000 (86,600–166,000)**	**169,000 (118,000–227,000)**	**37,800 (27,200–49,700)**
Number of Men with uncorrected presbyopia (thousands)	186,000 (130,000–251,000)	14,500 (10,200–19,600)	5020 (3400–6970)	11,200 (7820–15,100)	5800 (3900–8020)	57,900 (40,500–78,300)	75,000 (52,000 to 102,000)	17,000 (12,200–22,400)
Number of Women with uncorrected presbyopia (thousands)	233,000 (164,000–311,000)	25,300 (18,200–33,900)	6350 (4300–8900)	13,700 (9700–18,500)	6440 (4470–8770)	66,300 (46,310 to 88,100)	93,700 (66,000–125,000)	20,700 (15,000 to 27,200)
Age-standardised prevalence of uncorrected presbyopia	**22.33% (15.81–29.91)**	**27.81% (19.89–37.41)**	**2.37% (1.59–3.31)**	**18.85% (13.33–25.38)**	**13.18% (9.23–17.89)**	**38.89% (28.30–53.17)**	**26.63% (18.81–35.78)**	**37.54% (27.33–49.08)**
Age-standardised prevalence of uncorrected presbyopia: Men	21.11% (14.92–28.29)	25.89% (18.51–34.58)	2.35% (1.57–3.28)	18.66% (13.19–25.16)	12.60% (8.72–17.27)	37.78% (26.71–50.35)	24.71% (17.51–33.29)	36.30% (26.31–47.28)
Age-standardised prevalence of uncorrected presbyopia: Women	23.43% (16.52–31.36)	29.10% (20.93–39.08)	2.38% (1.60–3.33)	19.01% (13.44–25.69)	13.74% (9.66–18.68)	41.93% (29.63–55.68)	28.36% (19.94–38.00)	38.62% (28.12–50.22)

Data in parentheses are 95% uncertainty intervals. Count data are presented to three significant figures, and percentages to two decimal places. Data in bold indicate totals for both sexes.

blindness and MSVI for women compared to men (percentage reduction blindness; women −50.0% (95% UI −50.2 to −49.9), men −42.1% (95% UI −42.2 to −41.9): percentage reduction MSVI; women −8.9% (95% UI −9.1 to −8.8), men −4.3% (95% UI −4.5 to −4.1)), although the burden remains substantial.

Table 3 presents the number of people, men and women with near VI from uncorrected presbyopia in the seven super regions. In 2020, an estimated 419 million (95% UI 295–562 million) people aged 50+ had near VI from uncorrected presbyopia globally, with an age-standardised prevalence of 22.3% (95% UI 15.8–29.9%). Approximately 70% of global near VI from presbyopia occurred in two super regions: South Asia and Southeast Asia, East Asia and Oceania (293 million).

Table 4 presents the percentage change in crude prevalence of near VI due to uncorrected presbyopia in men and women aged 50 years and older between 2000 and 2020. Over this time period, the number of cases of near VI due to presbyopia increased substantially (+75.3% (95% UI + 74.6 to +76.0)), while the crude prevalence demonstrated a modest reduction for men (−1.8% (95% UI −2.2 to −1.4%)), but an increase of +0.8% (95% UI 0.4–1.2%) for women. Figure 3 further illustrates these sex differences across super regions, demonstrating significant increases in the number of cases in the 20-year period, with a disproportionate increase for women. The number of cases of near VI due to presbyopia increased in all super regions, ranging from 25.5% (95% UI + 25.0 to +25.9%) in Central Europe, Eastern Europe, and Central Asia to 101% (95% UI + 100.2 to +101.7%) in Latin America and Caribbean super-region. However, the percentage change in crude prevalence decreased in all super regions over the 20-year period except for the High-Income super-region which had a +4.3% (95% UI + 3.9 to +4.7) increase.

DISCUSSION

This study provides up-to-date global and regional, sex-specific and age-specific estimates and temporal trends for vision impairment due to URE, both for distance and near vision impairment. Our study reveals that URE remains a leading cause of MSVI, affecting 157 million individuals worldwide in 2020, and MSVI due to URE accounts for 57% of all MSVI globally. Notably, although there is some variation across the super regions, the percentage of MSVI due to URE remains above 47% in all areas, underscoring the persistent and substantial global burden of avoidable vision loss caused by URE.

In the 20-year period up to 2020, VISION 2020: the Right to Sight initiative sought to prevent avoidable sight loss, and the subsequent Global Action Plan adopted by the WHA in 2013 set a target for a 25% reduction in the prevalence of avoidable vision impairment by 2019 from the baseline of 2010. While progress in reducing the global burden has been made, this target was not achieved [29], highlighting the need for continued focus and effort to eliminate avoidable sight loss.

Encouragingly, the age-standardised prevalence of blindness due to URE in those aged 50+ years has decreased substantially from 2000 to 2020, potentially reflecting the targeted efforts countries have adopted to tackle severe sight loss. This may in part be explained by the increased use of intra-ocular lenses in cataract surgery over the last 20–30 years, leading to a reduction in blindness due to aphakia [38]. In contrast, the age-standardised prevalence of MSVI due to URE in those aged 50+ years only decreased modestly between 2000 and 2020.

The reductions we observed in age-standardised prevalence are counterbalanced by a striking increase in the unadjusted burden of blindness and MSVI due to URE, meaning that the total number of affected persons in the world has risen. This is driven by two key factors: continued global population growth, which is estimated to reach 10.4 billion in 2100, and an ageing population [39]. In common with the majority of vision-impairing ocular diseases, the likelihood of MSVI and blindness due to URE rapidly increases with age, as shown in Fig. 2. UN projections report that between 2020 and 2050 the global population of those aged 65+ years is expected to double from 703 million to 1.5 billion, and that by 2050, one in six people in the world will be aged ≥ 65 years [40].

The super-region of South Asia, comprising countries including India and Pakistan, had the greatest burdens of blindness and MSVI, with a disproportionately high prevalence of older age groups. While globally there was a reduction in age-standardised prevalence of MSVI due to URE, the super-region of Latin America and Caribbean actually demonstrated an increase of +0.8% (95% UI 0.4–1.3). These regional differences in the prevalence of vision loss are likely due to variations in availability of affordable refractive services, particularly in rural locations, and in social conditions. This is evidenced by a recent study investigating the eREC across regions, which demonstrated substantial differences in eREC between super regions in 2021, with 79.1% coverage in the High-Income super-region (95% CI 72·4–85·0), compared to 6.7% in Sub-Saharan Africa (95% CI 3·1–9·0) and 9.0% in South Asia (95% CI 6·5–12·0%) [41].

New eyecare service development has not kept pace with the increasing population demands in any region of the world, and continued population ageing will further increase existing burdens. Alleviating this shortfall will require a combination of capacity-building of trained eyecare personnel, expansion of community-based screening services for diagnosis of refractive errors, development of infrastructure for spectacle provision, outreach efforts to drive demand, and novel technical approaches to allow more services to be delivered by available, less fully-trained cadres. The WHO World Report on Vision, 2019 [17] sets out four key areas to increase access to eyecare services: (i) Increase of the availability of services through training and improved infrastructure; (ii) Increase the accessibility of services to those who need them; (iii) Increase the affordability of services, and (iv) Increase of the acceptability of refractive services, through awareness raising.

While the burden of vision impairment increases with age, focusing only on the population aged 50 years and above provides an incomplete view of vision impairment due to URE, which also frequently affects younger persons. While we report that those aged 50+ years with MSVI total 86 million in 2020, this only accounts for 55% of all MSVI (167 million). For younger people, the burden of URE is likely driven by the concerning global increase in myopia [42], with recent evidence showing these trends are not only confined to Asian populations [43]. However, there remains a paucity of data on vision impairment due to URE in children and younger adults, which needs to be redressed.

A disproportionate number of women continue to be affected by vision impairment due to URE. This is observed globally and across the majority of super regions. Interestingly for presbyopia, while the global crude prevalence decreased for men by −1.8% (−2.2 to −1.4%) from 2000 to 2020, there was an increase for women of +0.8% (+0.4 to +1.2%). It is important to emphasise that these differences persist after age adjustment, and are not simply an artefact of women living longer. This unfair burden among women is likely driven by cultural and social inequities, with less financial autonomy, male prioritisation, and child- and home-care responsibilities [44]. This persistent gap must be addressed through targeted strategies to increase their access to refractive care.

The burden of near visual impairment due to uncorrected presbyopia is another critical area of concern highlighted by our study, with nearly 420 million people aged 50+ years affected by uncorrected presbyopia. There are huge disparities in the age-standardised prevalence of uncorrected presbyopia across super

Table 4. Percentage change in crude prevalence and case number of uncorrected presbyopia in adults aged 50 years and older in the 7 Super Regions between 2000 and 2020.

	Near VI caused by uncorrected presbyopia					
	Percentage Change in Crude Prevalence between 2000 and 2020			Percentage Change in Number of Cases between 2000 and 2020		
Region	Men	Women	Both	Men	Women	Both
GLOBAL	−1.8% (−2.2 to −1.4)	+0.8% (+0.4 to +1.2)	−0.4% (−0.8 to 0.0)	+73.2% (+72.5 to +73.8)	+77.1% (+76.4 to +77.7)	+75.3% (+74.6 to +76.0)
Central Europe, Eastern Europe & Central Asia	0.0% (−0.4 to +0.4)	−0.5% (−0.9 to -0.1)	−0.6% (−0.9 to −0.2)	+29.8% (+29.3 to +30.3)	+23.1% (+22.7 to +23.6)	+25.5% (+25.0 to +25.9)
High Income	+8.1% (+7.6 to +8.5)	+1.9% (+1.5 to +2.3)	+4.3% (+3.9 to +4.7)	+59.0% (+58.3 to +59.7)	+41.9% (+41.3 to +42.5)	+49.0% (+48.4 to +49.6)
Latin America and Caribbean	−1.2% (−1.6 to −0.8)	+0.8% (+0.4 to +1.2)	−0.1% (−0.4 to 0.3)	+94.8% (+94.0 to +95.5)	+106.3% (+105.5 to +107.1)	+101.0% (+100.2 to +101.7)
North Africa and Middle East	−11.2% (−11.6 to -10.9)	−10.1% (−10.5 to -9.8)	−10.7% (−11.0 to -10.3)	+84.5% (+83.7 to +85.2)	+87.0% (+86.2 to +87.7)	+85.8% (+85.0 to +86.6)
South Asia	−8.0% (−8.3 to −7.6)	−7.0% (−7.3 to -6.6)	−7.3% (−7.6 to −6.9)	+73.7% (+73.1 to +74.4)	+88.1% (+87.4 to +88.8)	+81.1% (+80.4 to +81.8)
Southeast Asia, East Asia and Oceania	−6.5% (−6.9 to −6.2)	−6.6% (−6.9 to -6.2)	−6.4% (−6.8 to −6.1)	+84.8% (+84.1 to +85.6)	+90.6% (+89.8 to +91.3)	+88.0% (+87.3 to +88.7)
Sub-Saharan Africa	−8.7% (−9.0 to −8.4)	−9.4% (−9.7 to -9.0)	−8.9% (−9.2 to −8.5)	+61.5% (+61.0 to +62.1)	+75.9% (+75.2 to +76.5)	+69.1% (+68.5 to +69.7)

Percentage change to 1 decimal place and figures in parentheses reflect 95% uncertainty intervals.

regions, with for example, only a 2.4% prevalence in the High-Income super-region compared with 38.9% in South Asia. This finding is supported by a systematic review reporting the greatest burden of presbyopia in rural areas in low-resource countries [45]. Looking at temporal data, some super regions demonstrated a reduction in crude prevalence but in all areas the number of cases increased significantly, likely due to the ageing population globally and also improvements in data availability in the last 20 years. It was not possible to generate age-standardised estimates due to sparsity of data. The combination of high, rapidly rising burden and the paucity of data underscores the need for more attention to presbyopia among both researchers and health service planners.

The large burden of uncorrected presbyopia may in part reflect a view that correction for near VI is somehow less important than for distance VI, but studies have shown that vision impairment from URE affects the quality of life to a similar degree whether at distance or near VI [14]. Furthermore, a recent study [46] reported on the considerable productivity loss from un- and under-corrected presbyopia in LICs and LMICs. Using GBD data, the authors estimated 238 million people of working age (15–65 years) in LMICs had uncorrected presbyopia, and estimated the resulting direct productivity loss at $54 billion dollars, using productivity-adjusted-life-years. The potential for presbyopic correction to improve real-world work productivity is underscored by recent trials [2].

The strengths of this updated review and data analysis up to 2020 include the addition of new data sources, particularly more RAAB surveys, which enable improvements in disaggregation by cause and a wider coverage of geographical regions in our analysis. This is also the first time we combine reports on the impact of distance and near visual impairment due to URE and presbyopia. However, there remain several LICs and LMICs in regions such as central sub-Saharan Africa, Central Asia, and central and eastern Europe, with scant population-based data where estimates rely on extrapolation from other regions. While our modelling has controlled for a range of confounding factors, it is possible that blindness and MSVI due to URE are under-reported. Furthermore, due to data sparsity, we did not include mild visual impairment in this dataset but used a definition of <6/18 for MSVI, so again these data underreport the potential burden of distance vision impairment compared to other studies. Finally, it is possible that the trajectory of the prevalence of vision impairment due to URE might be altered owing to the COVID-19 global pandemic, with reports emerging of an increase in the prevalence of myopia attributed to changes in lifestyle during the pandemic [47]. Future directions for research and policy should be develop population screening services, accurate reporting mechanisms and registries to effectively measure the burden of avoidable vision impairment due to URE, to strengthen data from younger populations, and focus efforts on developing refractive services in LICs and LMICs to fill the data gaps to achieve greater geographical coverage.

CONCLUSIONS

Data from the last 20 years show that the absolute number of people with URE is rising due to population growth and ageing. URE remains a leading global cause of MSVI among persons aged 50+ years, affecting 86 million individuals and accounting for 53.4% of the total figure. This, coupled with the huge burden of near vision impairment due to uncorrected presbyopia, highlights the urgent need for novel and fresh approaches to refractive service delivery. While progress has been made in the last two decades, a reduction in the burden of vision impairment from URE can be realised by adding refractive services to universal health coverage and otherwise improving availability of, and access to, spectacle provision. Though the

Fig. 3 Comparison of the number of men and women with near vision impairment due to uncorrected presbyopia in 2000 and 2020 by seven World GBD super regions, with Global total bottom right panel. Note scales (values should be multiplied by 1000) are not the same between charts, but rather serve to highlight the differences across the time period and sex differences within GBD super regions.

need is greater in some global regions, URE has not been fully addressed anywhere, and the resulting productivity losses and reduction in quality of life should not be overlooked for any country. Over this decade, the target set by the 73rd WHA member states in 2021, a 40% increase in eREC by 2030, will provide critical leverage to accelerate our efforts to tackle avoidable blindness due to URE.

URE remains the leading cause of MSVI, though spectacle provision is the simplest and least invasive treatment available for any ocular condition. This is a source of frustration after decades of work on VISION 2020, but it underscores the opportunity to accelerate progress towards what is arguably the most attainable goal in vision care, that of eliminating URE.

SUMMARY

What was known before

- Uncorrected refractive error (URE) is the leading cause of vision impairment globally among both adults and children, and contributes to reduced educational and economic opportunities, decreased quality of life and an increased burden of mortality
- Visual impairment is a significant global health concern, and the 'World Report on Vision' by the World Health Organisation in 2019 called for the routine measurement of refractive error services coverage as a means to address the UN Sustainable Development Goal 3.8 of universal health coverage
- Uncorrected refractive error (URE) is readily treated with spectacles, making it one of the most cost-effective healthcare interventions, both for distance visual impairment and near visual impairment due to presbyopia
- The need for new population data on vision impairment is vital to monitor and measure success against global targets to increase the coverage of refractive error services by 40% by 2030

What this study adds

- This study provides up-to-date global and regional, sex-specific and age-specific estimates and temporal trends for vision impairment due to uncorrected refractive error, both for distance and near vision impairment.
- We examined age-adjusted and sex-adjusted differences in the contribution of uncorrected refractive error to vision impairment, with a focus on older age groups
- We incorporated studies from an updated systematic review for a total of 243 sources from 73 countries
- Our study reveals that over the last 20 years, the absolute number of people with URE has risen due to population growth and ageing, with a continued disproportionate burden by region and sex
- Uncorrected refractive error (URE) remains a leading cause of MSVI, affecting 157 million individuals worldwide in 2020, and MSVI due to URE accounts for 57% of all MSVI globally
- Furthermore, an estimated 419 million people aged 50+ had near VI from uncorrected presbyopia globally in 2020
- These data underscore the persistent and substantial global burden of avoidable vision loss caused by uncorrected refractive error, highlighting the urgent need for novel and fresh approaches to refractive service delivery.

DATA AVAILABILITY

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the coordinator of the Vision Loss Expert Group (Professor Rupert Bourne; rb@rupertbourne.co.uk) upon reasonable request. Data are located in controlled access data storage at Anglia Ruskin University.

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