Global Trends and Projections for Avoidable Visual Impairment among Working-Age Individuals: A Population-Based Study

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• PURPOSE: **Visual impairment (VI) in working-age individuals significantly impacts public health and the economy. However, the avoidable causes, defined as cataract and refraction disorders, have not been extensively investigated. This study aims to quantify global trends, inequalities, and projections for avoidable VI among this demographic.**

• DESIGN: **Retrospective, observational, population-based trend study.**

• METHODS: **We derived data on avoidable VI prevalence and population size data in working age from the Global Burden of Disease (GBD) 2021 study. We employed the joinpoint regression analysis to assess trends from 1990 to 2021 by age, sex, sociodemographic index (SDI), type, and severity at the global, regional, and national levels. Cross-country inequalities were evaluated using the slope index of inequality and the health inequality concentration index. Subsequently, we performed Bayesian age-period-cohort modeling to estimate the avoidable BVL burden in working age by 2040.**

• RESULTS: **The prevalence of avoidable VI in working age decreased overall from 1990 to 2021, driven primarily by reductions in refraction disorders, with an average annual percentage change (AAPC) of -0.15 (95% confidence interval [CI], -0.18 to -0.12; P<0.001). We observed significant declines in severe vision loss and blindness, while moderate vision loss remained stable. Females exhibited a heavier burden of avoidable VI, but showed slower improvement compared to males. Socioeconomic disparities persisted, with lower SDI regions bearing a disproportionate burden, whereas the high SDI region showed an unfavorable increasing trend. From 1990 to 2021, the inequality slope index increased from 574.45 (95% CI, 914.95 to 233.95) to 652.27 (95% CI, 932.95 to 371.58), while the health inequality concentration index improved from -0.21 (95% CI, -0.26 to -0.17) to -0.17 (95% CI, -0.2 to -0.14). We project a continued decline in the global prevalence of avoidable working-age VI, but a 23.4% increase in avoidable VI cases by 2040, reaching approximately 146 million.**

• CONCLUSIONS: **Despite overall declines in avoidable VI among working-age individuals, significant improvement opportunities and disparities persist. The anticipated increase in avoidable VI cases necessitates integrated eye health strategies, substantial investment in eye care services to enhance accessibility and affordability, and fair employment policies for the visually impaired. (Am J Ophthalmol 2025;271: 304–315. © 2024 Elsevier Inc. All rights are reserved, including those for text and data mining, AI training, and similar technologies.)**

INTRODUCTION

The World Health Organization reports that over 2.2 billion individuals globally experience visual impairment (VI), significantly affecting people, families, and society as a whole.[1] As a special age group in the population, VI among working-age people has important public health implications. According to the US Bureau of Labor Statistics, only 29% of working-age individuals with VI in the US are employed.[2] This employment gap perpetuates poverty and exacerbates developmental inequalities. From a societal perspective, estimates place the global annual productivity loss due to VI among working-age individuals at $410.7 billion in 2020.[3] However, prior research on avoidable VI has predominantly concentrated on vulnerable populations, such as children and older adults, while paying little regard to the working-age demographic.[2]

Previous research based on the Global Burden of Disease (GBD) 2019 study highlighted that although the prevalence of VI among working-age adults has slightly declined over the past decades, the cases in this group have increased by 91.46% due to ageing and population growth.[2] In order to improve overall health and development, it is essential to alleviate the negative effects and consequences of VI in individuals of working age. As a group of diseases with effective treatment options, cataract and refraction disorders are avoidable causes of VI, which could

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be addressed through highly cost-effective interventions like spectacles and cataract surgery.[3] Increased implementation efforts and government financial commitment are required to ensure that working-age individuals with avoidable VI benefit from these treatments. However, prior investigations regarding avoidable VI were mainly focused on older adults;[3] epidemiology patterns for avoidable VI among working-age individuals have not been extensively investigated, and the improvement potentials are largely unknown.

In this study, we aim to explore the epidemiology of avoidable VI within the working-age population from 1990 to 2021 by age, sex, sociodemographic index (SDI), type, and severity at the global, regional, and national levels, utilizing the most latest data from the GBD 2021. Furthermore, we evaluated the cross-country inequalities of avoidable VI in the working-age and provided projections until 2040. The outcomes of our investigation may provide valuable benchmarks in the domains of epidemiology and socioeconomics for policymakers.

METHODS

• **STUDY DESIGN:** This study conducted a retrospective analysis of population-based repeated cross-sectional data from the GBD 2021, which was collected from the Global Health Data Exchange database.[4] This extensive dataset encompasses the global burden of 371 diseases and injuries, spanning over 21 GBD regions and 204 countries and territories from 1990 to 2021. The approach used in the GBD 2021 has been well described in previous publications.[5] This research adhered to the standards specified in the Declaration of Helsinki and closely followed the Guidelines for Accurate and Transparent Health Estimates Reporting statement. Access to and use of these datasets are authorized in line with the Non-Commercial User Agreement granted by the Institute for Health Metrics and Evaluation (Supplementary File 1). The GBD research is conducted using a publicly available secondary database, which does not contain any personal identification information. This is in compliance with US Decree number 7724 of May 16, 2012, and Resolution number 510 of April 7, 2016; accordingly, there was no need to obtain approval from a research ethics committee for this study.

• **CASE DEFINITION AND DATA COLLECTION:** In accordance with a prior publication, the current investigation has defined avoidable VI as cataract and refraction disorders.[3] These conditions may be efficiently treated by the implementation of cataract surgery and the provision of glasses.[3] The working age individuals were defined as ages of 20 and 64, referred to previous study.[6] According to GBD 2021, cataract is characterized as the opacification of the eye's lens caused by the accumulation of proteins, resulting in impaired vision, aligning with the International Classification of Disease, Tenth Revision (ICD-10) codes H25-H26.9, H28-H28.8.[5] Refraction disorders refer to a condition where blurry vision occurs as the lens is unable to focus properly, corresponding to ICD-10 codes H52-H52.7.[5] VI can be categorized into 3 levels of severity according to the presenting visual acuity: moderate (presenting visual acuity of <6/18, meaning the individual can see at within 6 meters what someone with normal vision sees at 18 meters), severe (presenting visual acuity of <6/60, meaning the individual can see at within 6 meters what someone with normal vision sees at 60 meters), and blindness (presenting visual acuity of <3/60, meaning the individual can see at within 3 meters what someone with normal vision sees at 60 meters, or a central visual field of ≤10%).[5]

We collected diseases and severity data of avoidable VI on working-age individuals aged 20–64 years for both sexes across nine 5-year age groups, 5 sociodemographic index (SDI) groups, 21 region groups based on geographical and epidemiological similarity, and 204 countries and territories.[5] The SDI served as a metric that captured the social and economic factors that impact health outcomes. The SDI calculation was derived using the geometric mean of the total fertility rate among persons under 25 years old, the average years of education for those aged 15 years and above, and the lag-distributed income per capita as calculated by GBD.[5,7] A lower SDI signifies a lower degree of education, lower income per capita, and a higher fertility rate.[5,7] The 5 sociodemographic index (SDI) groups defined in GBD 2021 are as follows: Low SDI (0 to 0.47), Low-Middle SDI (0.47 to 0.62), Middle SDI (0.62 to 0.71), High-Middle SDI (0.71 to 0.81), and High SDI (0.81 to 1). A detailed classification of countries and territories is available on the GBD website.[8]

• **TREND ANALYSIS:** We used joinpoint regression analysis to assess the trends in avoidable burden of VI from 1990 to 2021. This strategy first persumes a straight-line progression in the magnitude of illness impact over the duration of the investigation. An inflection point, also known as a joinpoint, is inserted to symbolize a shift in this pattern. A permutation test is used to compare the joinpoint model with the null model in order to evaluate its statistical significance. The joinpoint is kept if it is shown to be statistically significant. The Bonferroni correction is used to account for multiple comparisons in this method, which involves selecting the best joinpoints from the Monte Carlo permutation test.[9-11] Unlike traditional linear regression, which assumes a consistent trend across the dataset, joinpoint regression identifies distinct points where significant trend changes occur, allowing for a segmented analysis that better captures shifts over time or conditions.[9-11]

We analyzed the inflection points and accompanying weights to characterize both non-linear and linear trends using this technique. The extent of change was measured using annual percentage change (APC) and average APC

(AAPC) values, along with their accompanying 95% confidence intervals (CIs). The APC is a statistical metric that quantifies the rate of change between distinct inflection points. It represents the slope for each specified time period. The AAPC is a quantitative metric calculated by the duration-weighted average APC and offers a comprehensive overview of the trend for a certain timeframe, indicating whether the trend has seen growth, decline, or stability.[9-11] The statistical significance was assessed using a significance threshold of 0.05.

• **CROSS-COUNTRY INEQUALITY ANALYSIS:** The burden of preventable VI across different countries was assessed using the slope index of inequality and the health inequality concentration index.[12, 13] These metrics, recommended by the World Health Organization, measure absolute and relative inequality, respectively.[14]

The slope index of inequality was computed through regression analysis. The age-standardized prevalence rates at the level of countries and territories were used as the dependent variable. The midpoint of the cumulative class interval of the population sorted by the SDI was used to determine the relative social position scale, which served as the independent variable.[12] We employed a robust regression model that included repeated reweighted least squares with a Huber weighting function in order to address the heteroskedasticity problem.[12] The health inequality concentration index was calculated by using a Lorenz concentration curve to represent the cumulative relative distributions of the population, which were ordered based on SDI and the burden of avoidable VI.[12] The region bounded by the curve was then subjected to numerical integration in order to calculate the index.[12]

• **PROJECTION ANALYSIS:** The previous assessments have concentrated on the burden of avoidable VI throughout the last several decades. In order to improve the development of public health policy and the allocation of healthcare resources, a Bayesian age-period-cohort (BAPC) model was used to provide further predictions on the avoidable VI burden till 2040. This model uses the integrated nested Laplace approximation (INLA) and posits that the logit risk of burden in a period and age group is determined by a linear combination of an intercept and an age-period-cohort effect.[15] The BAPC model takes into account population aging, birth cohorts, and time periods, which allows for a better understanding and projection of the future burden of avoidable VI compared to other prediction approaches.[15] Integration of INLA with the BAPC model can provide an estimation of approximate marginal posterior distributions.[16] This approach can help circumvent the mixing and convergence issues often encountered when using the Markov Chain Monte Carlo sampling methodology in standard Bayesian methods.[16,17]

Analyses were performed using the R (version 4.2.2, Vienna, Austria) and Joinpoint Trend Analysis Software (version 5.0.2; National Cancer Institute, Bethesda, MD, USA), developed by the National Cancer Institute.[11]

RESULTS

• **TRENDS OF AVOIDABLE VI IN WORKING AGE:** Globally, the prevalence rates of avoidable VI decreased from 1990 to 1995 and 2000 to 2014, followed by intermittent rises from 1995 to 2000 and 2014 to 2021, showing an overall decreasing trend during the study period, as reflected by the AAPC of -0.15 (95% confidence interval [CI], -0.18 to -0.12; P < .001). The prevalence of refraction disorders VI exhibited a similar pattern, with an AAPC of -0.18 (95% CI, -0.24 to -0.13; P < .001), whereas the prevalence of cataract VI remained stable (Figure 1A, Table 1). Among severity levels, avoidable blindness and severe vision loss exhibited significant declines, with AAPCs of -1.66 (95% CI, -1.74 to -1.58; P < .001) and -0.19 (95% CI, -0.25 to -0.13; P < .001), whereas the prevalence of avoidable moderate vision loss remained stable (Figure 1B, Table 1).

Regarding sex, females seem to have a heavier avoidable VI burden than males, while males exhibited a faster decreasing trend than females, with AAPCs of -0.21 (95% CI, -0.23 to -0.18; P < .001) and -0.1 (95% CI, -0.14 to -0.07; P < .001), respectively. In terms of age, the prevalence increased with age, with adults aged 60—64 years exhibiting the highest prevalence of 8050.51 (95% uncertainty interval [UI], 6182.61-10605.13) in 2021. From 1990 to 2021, individuals aged 30—34 and 45 and above showed significant decreases in prevalence, whereas the decreasing trends among younger working-age adults were not substantial (Table 1).

Among SDI groups, the low-middle SDI group seemed to have the highest prevalence at 3958.95 (95% UI, 3011.65-5104.13). However, an unfavorable increasing trend in prevalence was observed in the high SDI group [AAPC: 0.11 (95% CI, 0.06 to 0.15); P < .001]. The overall decreasing trends for prevalence were relatively consistent across middle-, low-middle-, and low SDI groups, although the degree of change varied (Table 1).

The burden and trends of avoidable VI among the working age varied significantly across regions. South Asia showed the highest prevalence in 2021, with a prevalence of 4871.84 (95% UI, 3689.33-6294.42). In contrast, High-income North America had the lowest prevalence at 1158.99 (95% UI, 871.35-1495.53). From 1990 to 2021, South Asia exhibited the highest decreases, with an AAPC of -0.83 (95% CI, -0.89 to -0.77; P < .001). Conversely, Western Sub-Saharan Africa showed the most substantial increases, with an AAPC of 0.44 (95% CI, 0.36 to 0.52; P < .001) (Table 2).

At the country/territory level, Oman had the highest prevalence in 2021 [5160.6 (95% UI, 3882.41-6735.61)]. In contrast, Sweden had the lowest values [764.39 (95% UI,

TABLE 1. Join Point Regression Analysis of the Global Prevalence of Avoidable Vision Impairment in Working Age From 1990 to 2021 Overall and by Sex, Age, SDI, Disease and Severity

	Cases (n), 1990	Prevalence (per 100000 Population), 1990	Cases (n), 2021	Prevalence (per 100000 Population), 2021	AAPC, 1990-2021	P value
Worldwide	68074951.66 (52493683.31-86598397.63)	2693.45 (2077.58-3427.73)	118629020.06 (90531455.6-152754325.72)	2557.39 (1951.9-3291.68)	-0.15 (-0.18 to -0.12)	<.001
Sex						
Male	32519699.05 (25036780.15-41396357.37)	2558.54 (1970.43-3258.38)	55143738.27 (41966801.64-71072499.72)	2390.69 (1819.71-3080.78)	-0.21 (-0.23 to -0.18)	<.001
Female	35555252.61 (27456832.45-45231067.21)	2829.66 (2185.58-3600.78)	63485281.8 (48525412.13-81666714.44)	2722.21 (2080.96-3499.62)	-0.1 (-0.14 to -0.07)	<.001
Age group						
20-24	5575007.63 (4263710.54-7007292.64)	1132.93 (866.45-1423.99)	6748066.87 (5159504.68-8476690.43)	1130.03 (864.01-1419.51)	0.01 (-0.04 to 0.06)	.703
25-29	5182515.82 (4047178.51-6495102.14)	1170.87 (914.37-1467.42)	6839556.3 (5363683.9-8601500.05)	1162.51 (911.66-1461.99)	0 (-0.07 to 0.06)	.891
30-34	4914390.12 (3718516.9-6427926.66)	1275.07 (964.79-1667.76)	7442211.41 (5599458.63-9759425.78)	1231.18 (926.33-1614.52)	-0.14 (-0.2 to -0.08)	<.001
35-39	5338922.42 (4171851.74-6672952.51)	1515.69 (1184.36-1894.41)	8426667.44 (6524323.97-10603635.88)	1502.44 (1163.26-1890.58)	0.01 (-0.08 to 0.09)	.892
40-44	5829332.61 (4335955.12-7429010.63)	2034.8 (1513.52-2593.19)	9856695.83 (7287471.95-12707451.1)	1970.35 (1456.76-2540.22)	-0.07 (-0.24 to 0.1)	.429
45-49	7170457.22 (5596716.62-8991922.9)	3088.11 (2410.35-3872.57)	13343510.83 (10276297.45-16831244.76)	2818.03 (2170.26-3554.61)	-0.27 (-0.34 to -0.21)	<.001
50-54	9271948.35 (7087128.94-11764669.89)	4361.8 (3334-5534.45)	17641168.1 (13262454.81-22656136.02)	3964.99 (2980.84-5092.15)	-0.28 (-0.4 to -0.16)	<.001
55-59	11480695.78 (8890765.01-14580801.24)	6199.08 (4800.63-7873)	22565661.59 (17270947.78-29176738.13)	5702.32 (4364.35-7372.93)	-0.24 (-0.33 to -0.15)	<.001
60-64	13311681.71 (10381859.94-17228719.01)	8288.24 (6464.05-10727.1)	25765481.7 (19787312.42-33941503.55)	8050.51 (6182.61-10605.13)	-0.11 (-0.21 to 0)	.047

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TABLE 1. (*continued*)

	Cases (n), 1990	Prevalence (per 100000 Population), 1990	Cases (n), 2021	Prevalence (per 100000 Population), 2021	AAPC, 1990-2021	P value
SDI group						
High SDI	7270052.89 (5497998.54-9360051.59)	1379.77 (1043.85-1774.63)	9783549.1 (7408477.03-12651578.47)	1416.18 (1076.51-1819.77)	0.11 (0.06 to 0.15)	<.001
High-middle SDI	11847737.29 (9056181.28-15188728.86)	1981.51 (1514.41-2540.09)	18184379.11 (13793210.6-23528109.64)	1967.03 (1493.79-2537.18)	0.04 (-0.08 to 0.17)	.471
Middle SDI	21265691.27 (16355791.4-27053765.4)	2800.56 (2154.57-3567.13)	41637881.61 (31844066.21-53485673.43)	2700.71 (2066.19-3468.19)	-0.09 (-0.13 to -0.05)	<.001
Low-middle SDI	21902998.72 (16982529.71-27684455.69)	5022.31 (3901.14-6344.38)	37225145.2 (28297681.01-47965627.73)	3958.95 (3011.65-5104.13)	-0.76 (-0.82 to -0.7)	<.001
Low SDI	5737387.04 (4470728.27-7245283.61)	3455.9 (2699.43-4360.28)	11721700.63 (8924545.96-15091655.31)	3028.29 (2309.24-3905.67)	-0.43 (-0.46 to -0.4)	<.001
Disease						
Cataract	14574469.7 (11288349.34-18591723.82)	612.19 (474.28-780.72)	29047762.98 (21949197.67-38103013.93)	610.95 (461.65-801.58)	0 (-0.12 to 0.12)	.997
Refraction disorders	53500481.96 (41205333.97-68006673.8)	2081.26 (1603.3-2647)	89581257.08 (68582257.94-114651311.79)	1946.44 (1490.25-2490.1)	-0.18 (-0.24 to -0.13)	<.001
Severity						
Moderate vision loss	57081000.42 (42442494.5-74747350.16)	2243.42 (1665.95-2942.65)	102816941.64 (75896174.26-135624288.97)	2220.46 (1640.05-2926.68)	-0.01 (-0.05 to 0.02)	.419
Severe vision loss	5044769.69 (3550924.67-6863518.06)	206.74 (145.61-281.35)	9081712.05 (6368998.13-12394723.5)	193.34 (135.55-263.82)	-0.19 (-0.25 to -0.13)	<.001
Blindness	5949181.56 (4342197.32-8014041.65)	243.29 (177.93-327.25)	6730366.37 (4793450.67-9198880.24)	143.6 (102.2-196.38)	-1.66 (-1.74 to -1.58)	<.001

AAPC, average annual percentage change; SDI, sociodemographic index.

TABLE 2. Join Point Regression Analysis of the Global Prevalence of Avoidable Vision Impairment in Working Age From 1990 to 2021 by Geographic Region

	Cases (n), 1990	Prevalence (per 100000 Population), 1990	Cases (n), 2021	Prevalence (per 100000 Population), 2021	AAPC, 1990-2021	P value
Andean Latin America	592693.9 (450676.47-764605.29)	3807.13 (2888.18-4926.11)	1280120.28 (969369.85-1656473.98)	3532.99 (2673.29-4577.49)	-0.25 (-0.32 to -0.19)	<.001
Australasia	161904.58 (122324.72-208235.4)	1377.71 (1040.93-1771.48)	257153.76 (190986.15-335564.75)	1391.41 (1037.37-1806.6)	0.02 (0 to 0.05)	.064
Caribbean	395250.24 (296353.06-512333.6)	2321.82 (1737.09-3019.92)	600744.71 (448273.88-784037.67)	2156.06 (1610.08-2810.66)	-0.23 (-0.25 to -0.21)	<.001
Central Asia	776254.73 (575668.51-1017864.33)	2464.25 (1825.35-3234.14)	1307597.21 (962243.3-1731544.99)	2358.82 (1736-3121.64)	-0.13 (-0.15 to -0.12)	<.001
Central Europe	1087256.35 (803791.88-1432736.11)	1392.28 (1030.9-1829.64)	1112872.55 (819296.21-1473432.07)	1364.61 (1007.23-1796.86)	-0.05 (-0.08 to -0.03)	<.001
Central Latin America	2093460.97 (1594737.25-2685043.14)	3092.37 (2353.85-3977.6)	4160716.91 (3138937.7-5386875.89)	2840.31 (2142.84-3677.97)	-0.26 (-0.36 to -0.17)	<.001
Central Sub-Saharan Africa	313753.69 (234488.23-408253.29)	1691.91 (1264.88-2206.12)	852336.92 (636974.96-1107429.86)	1730.51 (1293.44-2255.99)	0.04 (-0.08 to 0.15)	.521
East Asia	9193837.25 (7071779-11774223.44)	1519.77 (1169.25-1948.58)	17349454.13 (13163030.36-22467943.72)	1556.18 (1181.57-2011.19)	0.25 (-0.03 to 0.53)	.085
Eastern Europe	3634309.03 (2739331.88-4745228.2)	2459.66 (1856.82-3198.39)	3607382.93 (2714068.86-4699415.96)	2419.58 (1824.17-3135.98)	-0.05 (-0.06 to -0.04)	<.001
Eastern Sub-Saharan Africa	1205130.7 (951663.95-1498943.37)	2051.13 (1627.01-2543.33)	2764222.79 (2130440.42-3512335.07)	1906.94 (1475.12-2421.85)	-0.24 (-0.25 to -0.22)	<.001
High-income Asia Pacific	1363004.99 (1032440.39-1753562.25)	1281.16 (971.76-1645.74)	1450720.75 (1089313.01-1892330.52)	1284.45 (968.96-1662.92)	0.02 (0.01 to 0.03)	.004
High-income North America	1907517.51 (1436067.53-2454732.84)	1156.41 (870.51-1488.35)	2552710.26 (1914065.42-3313297.12)	1158.99 (871.35-1495.53)	0.01 (-0.01 to 0.03)	.444

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TABLE 2. (*continued*)

	Cases (n), 1990	Prevalence (per 100000 Population), 1990	Cases (n), 2021	Prevalence (per 100000 Population), 2021	AAPC, 1990-2021	P value
North Africa and Middle East	4009131.05 (3105788.63-5087144.38)	2977.62 (2306.01-3785.2)	9384450.73 (7115822.34-12151551.13)	2839.18 (2150.32-3688.2)	-0.17 (-0.19 to -0.14)	<.001
Oceania	87001.94 (65680.07-113173.76)	3727.17 (2817.57-4857.74)	216698.56 (161430.47-286603)	3647.44 (2718.08-4833.69)	-0.09 (-0.12 to -0.06)	<.001
South Asia	26281696.16 (20300286.11-33315597.49)	6318.47 (4892.75-7999.62)	45683635.8 (34560084.65-59027423.27)	4871.84 (3689.33-6294.42)	-0.83 (-0.89 to -0.77)	<.001
Southeast Asia	5623801.43 (4308761.55-7207168.84)	2915.69 (2233.71-3742.49)	10522720.04 (8169300.04-13327841.07)	2474.92 (1921.5-3134.9)	-0.54 (-0.57 to -0.52)	<.001
Southern Latin America	572139.1 (428251.73-743292.39)	2198.07 (1644.19-2857.15)	855139.61 (638778.37-1116878.16)	2110.34 (1578.08-2751.42)	-0.13 (-0.15 to -0.12)	<.001
Southern Sub-Saharan Africa	402587.71 (310304.56-511533.3)	2032.73 (1571.82-2582.66)	763841.4 (580882.97-981443.73)	1882.08 (1432.34-2418.39)	-0.25 (-0.33 to -0.17)	<.001
Tropical Latin America	2708587.3 (2090732.37-3432897.73)	3770.88 (2910.55-4784.61)	4953179.43 (3796559.57-6322970.74)	3522.81 (2700.99-4494.91)	-0.28 (-0.65 to 0.09)	.144
Western Europe	4202912.31 (3167445.82-5425848)	1797.51 (1356.04-2315.46)	4695118.88 (3514022-6102907.3)	1772.4 (1331.74-2288.71)	-0.06 (-0.08 to -0.03)	<.001
Western Sub-Saharan Africa	1462720.72 (1136292.98-1863511)	2264.76 (1761.58-2887.18)	4258202.4 (3246407.94-5494782.86)	2623.37 (2001.51-3392.98)	0.44 (0.36 to 0.52)	<.001

AAPC, average annual percentage change.

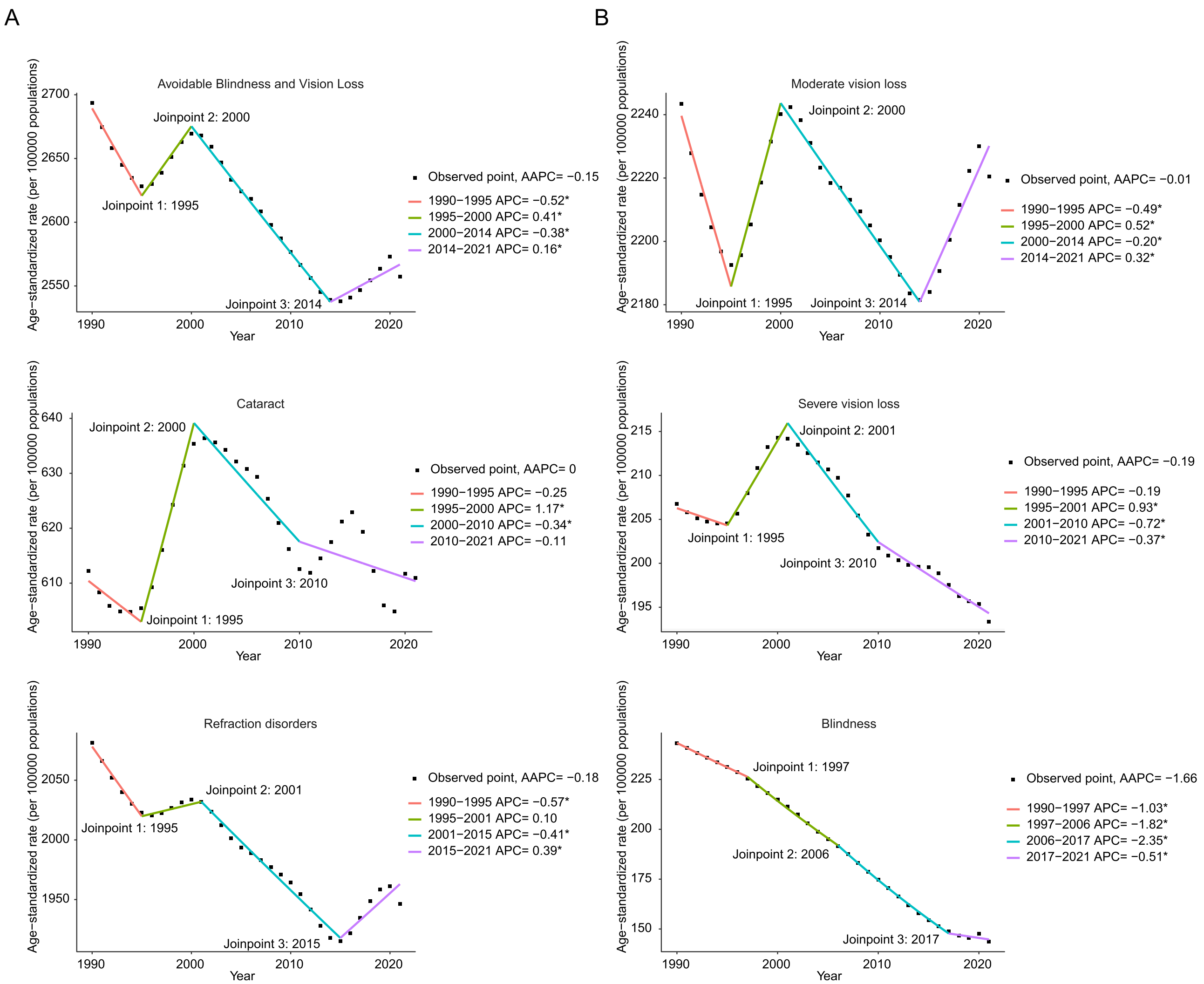

FIGURE 1. Joinpoint regression analysis of the global prevalence of avoidable vision impairment in working age from 1990 to 2021 overall and by cause (A) and severity (B).
APC, annual percentage change; AAPC, average annual percentage change.

554.98-1019.67)]. From 1990 to 2021, Equatorial Guinea exhibited the highest decreases [AAPC: -1.01 (95% CI, -1.03 to -0.98); $P < .001$]. Conversely, Côte d'Ivoire showed the most substantial increases [AAPC: 3.4 (95% CI, 3.22 to 3.59); $P < .001$] (Figure 2, Supplementary Table 1).

• **CROSS-COUNTRY INEQUALITIES OF AVOIDABLE VI IN WORKING AGE:** Our analysis revealed substantial inequalities in the prevalence of avoidable VI among working-age individuals across the 204 countries and territories examined. These disparities were both absolute and relative to the SDI, with a greater burden of VI seen in countries and territories with lower SDI. In 1990, the slope index of inequality indicated an excess of 574.45 (95% CI, 914.95 to 233.95) between countries with the lowest and highest SDIs. By 2021, this excess had climbed to 652.27 (95% CI, 932.95 to 371.58). The health inequality concentration index indicated a relative gradient inequality of -0.21 (95% CI, -0.26 to -0.17) ($P < .05$) in 1990 and -0.17 (95% CI, -0.2 to -0.14) ($P < .05$) in 2021. In 2021, the burden of avoidable VI among working age individuals is still mostly found in less-developed countries and territories with lower SDIs. Additionally, there has been a rise in absolute inequality while a reduction in relative inequality. The inequalities in refraction disorders VI across different regions followed a similar trend to the total avoidable VI burden. However, there seemed to have a modest reduction in both the absolute and relative inequalities for cataract VI (Figure 3).

• **PROJECTION OF AVOIDABLE VI IN WORKING AGE:** According to the BAPC model, the global prevalence of preventable VI is projected to decline from 2557.39 (95% CI, 1951.9-3291.68) in 2021 to 2467.5 (95% CI, 1551.87 to

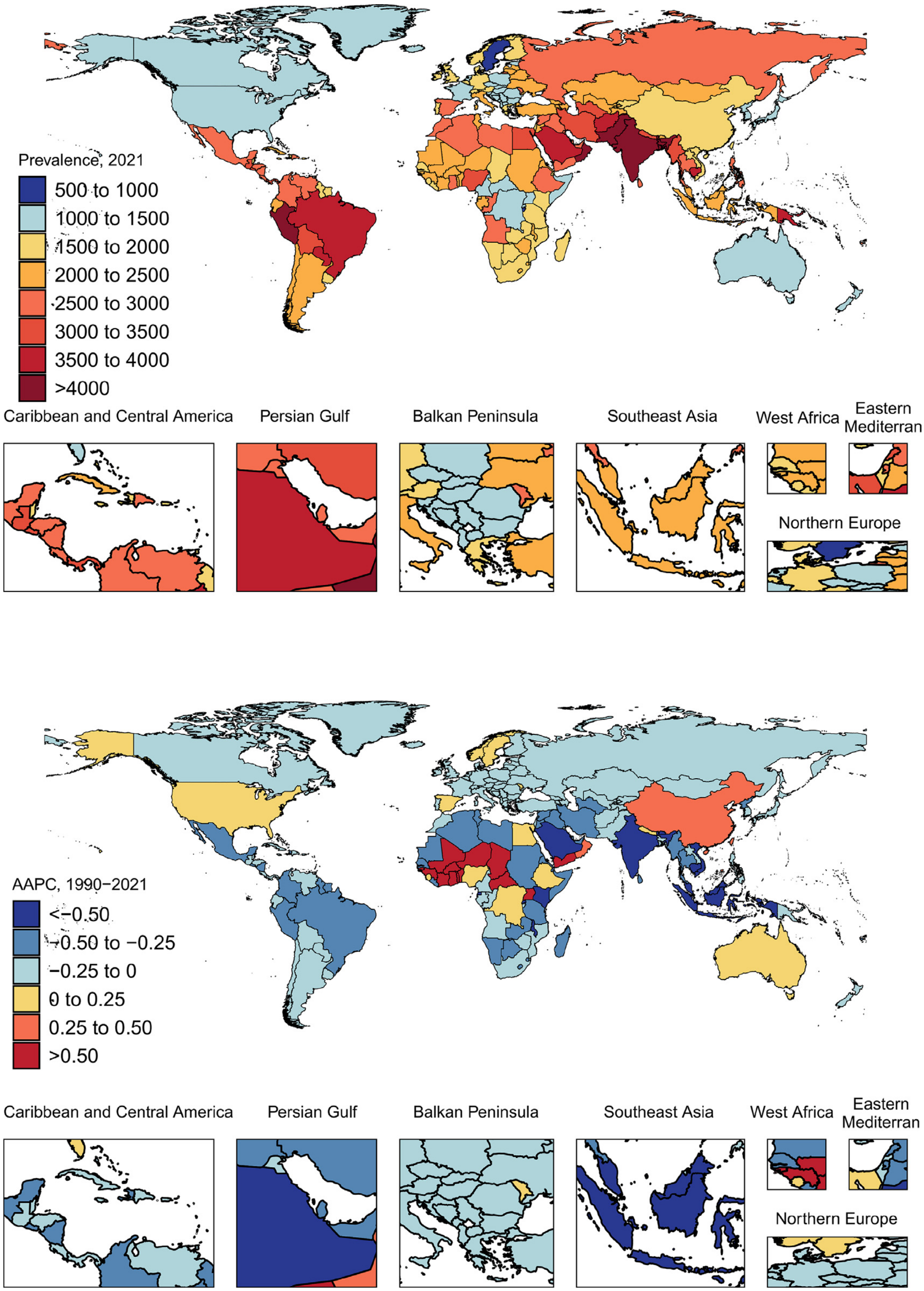

FIGURE 2. Global prevalence of avoidable vision impairment in working age in 2021 and corresponding AAPC from 1990 to 2021.
AAPC, average annual percentage change.

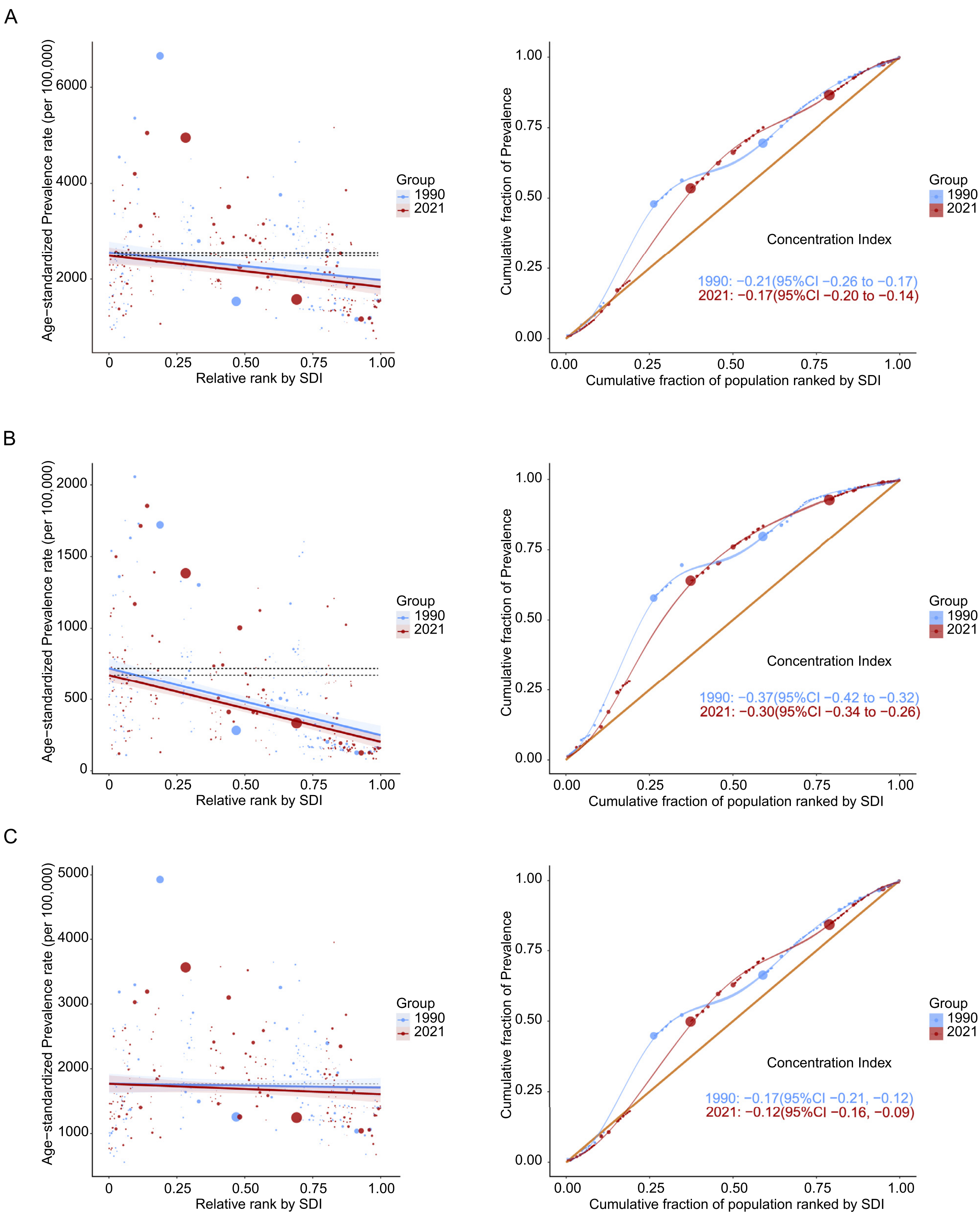

FIGURE 3. Inequalities in the burden of avoidable visual impairment in working age based on development status measured by the sociodemographic index. (A) Health inequality regression curves (left) and health inequality concentration curves (right) of avoidable visual impairment; (B) Health inequality regression curves (left) and health inequality concentration curves (right) of cataract; (C) Health inequality regression curves (left) and health inequality concentration curves (right) of refraction disorders. SDI, sociodemographic index.

3383.12) in 2040. Nevertheless, its cases are projected to rise by nearly 23.4% from 2021 to 2040, reaching around 146 million. The projected trends were relatively consistent across different age groups, sexes, and levels of severity, but the extent of variation differed. Regarding the cause, the prevalence of refraction disorders VI is expected to decrease, whereas the prevalence of cataract VI is anticipated to rise (Supplementary Table 2).

DISCUSSION

This study comprehensively described the avoidable VI burden among working age individuals between 1990 and 2021. Our study had several key findings: (1) Avoidable VI has declined over the past decades, mainly due to reductions in refraction disorders. Severe vision loss and blindness showed significant decreases. (2) Cataract-related VI, moderate vision loss, and VI among younger adults remained stable. (3) Gender disparities persist, with females bearing more of the burden and showing slower improvement. (4) Socio-economic disparities persist, with the burden disproportionately high in lower SDI regions. Over the past decades, absolute inequality has increased, while relative inequality has seen a reduction. (5) Despite a continued decline in overall VI prevalence, we anticipate a 23.4% rise in total VI cases to reach around 146 million, complicating future public health efforts.

Refraction disorders are a major cause of VI globally. Despite an overall increase in crude prevalence from 1990 to 2021 due to population aging and growth, the AAPC shows a decline of -0.18. This reduction can be linked to initiatives like VISION 2020 by WHO and International Agency for the Prevention of Blindness (IAPB), which aimed to eliminate avoidable blindness, and advancements in treatments such as spectacles, contact lenses, and refractive surgery. Increased financial support for eye care have also contributed to this trend.[18] However, given the limited progress among younger working-age individuals, public health policies, such as regular vision screening programs in schools and communities, are becoming increasingly crucial for controlling refraction disorders.[19] However, despite improvements in treatment strategies, the prevalence of cataract VI remained stable from 1990 to 2021. Hesitancy among patients with comorbidities towards surgery, along with misunderstandings about post-operative recovery, has led to delays in cataract improvement.[20]

From 1990 to 2021, there was a global decrease in the health inequality concentration index, indicating a relative reduction in disparities between countries and territories. This trend aligns with advancements in healthcare availability, economic development, poverty alleviation, and global welfare measures.[2] However, the reduction in inequalities for cataract-related VI was minimal, and the overall reduction in avoidable VI disparities is primarily due to improvements in refraction disorders. Low socioeconomic status often correlates with poor awareness of VI, a shortage of ophthalmologists and optometrists, limited access to vision correction, and the inability to afford appropriate glasses.[2] Since the late 1990s, many countries with low SDI have achieved significant economic development, supported by healthcare system reforms that improved access and coverage.[12] Despite these advances, the slope index of inequality for avoidable VI among working-age individuals remains high. From an economic perspective, sustainable development relies on economic productivity at individual, familial, and national levels.[2] Unemployment or underemployment among working-age individuals reduces the labor force, diminishing an economy's capacity to produce goods and services.[21] The significant burden of visual impairment in underdeveloped areas can perpetuate poverty and exacerbate existing disparities and inequalities in development. These findings highlight the crucial need for implementing proportionate universalism and promoting ongoing international cooperation. This involves establishing multiple health system building blocks and focusing on enhancing eye health services in underdeveloped regions.[18]

Although avoidable VI in working-age individuals is decreasing in general, the total number of VI cases is projected to increase by 23.4%, reaching 146 million in 2040, posing challenges for public health. Integrating eye health into national health plans and ensuring coordinated actions across sectors is essential. Addressing shortages in eye health personnel, especially in lower SDI countries, and improving training quality based on population needs are crucial.[18] Treatments for cataracts and refraction disorders can meet over 90% of unmet needs, offering significant health and economic benefits. Therefore, urgent financial investment in comprehensive eye health services for avoidable VI, including promotion, prevention, treatment, and rehabilitation, is needed.[18] The application of advanced technologies like telemedicine, mHealth, and AI may also improve the accessibility, quality, efficiency, and affordability of eye care services.[18] On the other hand, fair employment policies for visually impaired individuals, supported by both government and private entities, are also needed. These policies could potentially reduce poverty and social inequalities while enhancing economic productivity.[2]

This study has some limitation. While GBD methodologies are renowned for their robustness, and reliability, their accuracy is constrained by the quality of the underlying data. In locations with limited data availability, the GBD employed mathematical modeling techniques to generate estimates, which can introduce bias.[5] Secondly, the GBD study has taken uncertainty into account for different kinds of data and processes. In the secondary analysis using the joinpoint method, we took the UIs into account based on the non-constant variance assumption. Even with these efforts, it is still difficult to account for all the uncertainty across the whole burden estimation process.[5]

In conclusion, this study reveals that while avoidable VI among working-age individuals has generally declined, significant gender-related and socio-economic-related disparities remain. From 2021 to 2040, the total number of VI cases in working-age is projected to increase by 23.4%, reaching 146 million. To address these challenges, it is essential to further integrate eye health into national health strategies and invest in related services to enhance accessibility and affordability. Additionally, implementing fair employment policies is crucial for reducing poverty and social inequalities.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

YING ZHANG: Conceptualization, Writing – original draft. **JIANQI CHEN:** Writing – review & editing, Methodology. **LIRONG LIAO:** Writing – review & editing. **XIAOHU DING:** Writing – review & editing.

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