



Potential Lost Productivity Resulting from the Global Burden of Myopia

Systematic Review, Meta-analysis, and Modeling

Kovin S. Naidoo, PhD,^{1,2,3} Timothy R. Fricke, MSc,¹ Kevin D. Frick, PhD,⁴ Monica Jong, PhD,^{1,2} Thomas J. Naduvilath, PhD,¹ Serge Resnikoff, MD,^{1,2} Padmaja Sankaridurg, PhD^{1,2}

Purpose: We estimated the potential global economic productivity loss resulting from vision impairment (VI) and blindness as a result of uncorrected myopia and myopic macular degeneration (MMD) in 2015.

Clinical Relevance: Understanding the economic burden of VI associated with myopia is critical to addressing myopia as an increasingly prevalent public health problem.

Methods: We estimated the number of people with myopia and MMD corresponding to critical visual acuity thresholds. Spectacle correction coverage was analyzed against country-level variables from the year of data collection; variation in spectacle correction was described best by a model based on a human development index, with adjustments for urbanization and age. Spectacle correction and myopia data were combined to estimate the number of people with each level of VI resulting from uncorrected myopia. We then applied disability weights, labor force participation rates, employment rates, and gross domestic product per capita to estimate the potential productivity lost among individuals with each level and type of VI resulting from myopia in 2015 in United States dollars (US\$). An estimate of care-associated productivity loss also was included.

Results: People with myopia are less likely to have adequate optical correction if they are older and live in a rural area of a less developed country. The global potential productivity loss associated with the burden of VI in 2015 was estimated at US\$244 billion (95% confidence interval [CI], US\$49 billion–US\$697 billion) from uncorrected myopia and US\$6 billion (95% CI, US\$2 billion–US\$17 billion) from MMD. Our estimates suggest that the Southeast Asia, South Asia, and East Asia Global Burden of Disease regions bear the greatest potential burden as a proportion of their economic activity, whereas East Asia bears the greatest potential burden in absolute terms.

Conclusions: Even under conservative assumptions, the potential productivity loss associated with VI and blindness resulting from uncorrected myopia is substantially greater than the cost of correcting myopia. *Ophthalmology* 2019;126:338–346 © 2018 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).



Supplemental material available at www.aaojournal.org.

Myopia is an underappreciated but profound public health problem with tremendous potential economic impact, albeit with sparse data quantifying its impacts.¹ It is widely agreed that myopia is common and that the prevalence is increasing. For example, it has been estimated that by 2050, 50% and 10% of the global population will have myopia and high myopia by World Health Organization (WHO) definitions of ≤ -0.50 and ≤ -5.00 diopter (D) or less, respectively.^{1–3} Data are strongest in East Asia, resulting in greater confidence in the estimates there; however, there is reasonable evidence that all regions are following similar trends.^{1,2} High myopia is particularly concerning because it is associated with significantly higher rates of vision impairment (VI) and blindness via pathologic conditions such as myopic macular degeneration (MMD).^{4–8} Future high-myopia projections may be reduced by myopia control interventions; however, their

global uptake has been limited. Uncorrected myopia, resulting from the inability to access spectacles, also can result in VI or blindness.

Intense near work and lack of time outside seem to increase the prevalence of myopia and high myopia,^{2,4} and developed and emerging economies in East and Southeast Asia have recorded the highest prevalences.² However, lower health expenditure and other variables indicating resource scarcity seem to increase the risk of someone with myopia experiencing VI from lack of vision correction or pathologic complications such as MMD.^{9,10} Success in supplying vision correction is described by spectacle coverage, or the percentage of people who have vision corrected to a normal level by spectacles, among all those who need spectacles. Contreras and Ackland⁹ reported that distance-vision spectacle coverage ranged from 2% to 93% across the 27

countries around the world in which they were able to identify spectacle coverage data. Fricke et al¹⁰ estimated that the prevalence of VI and blindness resulting from MMD was highest in Southeast Asia because of the combined effects of high myopia prevalence, the age distribution of high myopia, and resource limitations.

Vision impairment resulting from either MMD or uncorrected myopia has the potential to diminish both quality of life and productivity significantly. Economic evaluations quantifying such impacts are scarce but given the number of working-age people with VI resulting from MMD, there is the potential for a profound burden on communities. The global productivity loss resulting from uncorrected refractive error has been estimated at \$202 billion United States dollars (US\$) per annum after adjustment for country-specific labor force participation and employment rates.^{11,12} This includes hyperopia and astigmatism as well as myopia and was based on uncorrected refractive error data from 2007. Economic evaluation of health care interventions provides valuable data for evidence-based advocacy, policy decisions, and patient care decisions. Given the apparent and predicted increases in myopia prevalence and the lack of data specific to productivity loss associated with myopia, we estimated the global economic productivity loss associated with the burden of VI and blindness resulting from uncorrected myopia and the pathologic consequences of myopia in 2015.

Methods

Estimating Vision Impairment Resulting from Uncorrected Myopia

We used WHO VI definitions: mild VI is worse than 20/40 but 20/60 or better, moderate VI is worse than 20/60 but 20/200 or better, severe VI is worse than 20/200 but 10/200 or better, and blindness

is worse than 10/200.^{13,14} Evidence suggests that uncorrected myopia of ≤ -0.75 D but > -1.00 D, ≤ -1.00 D but > -2.50 D, ≤ -2.50 D but > -4.00 D, and ≤ -4.00 D or less cause acuity levels that most closely match the WHO VI definitions.¹⁵ We estimated the prevalence of myopia in these brackets in each country, in each 5-year age group from 0 to 100 years or older, in urban and rural areas, using the methods of Holden et al.² Holden et al performed a systematic review that identified 145 studies covering 2.1 million participants; modelled myopia definition against prevalence to enable standardization of data sources; modelled myopia prevalence over time to enable standardization to a reference year of 2010 as well as projections forward and backward from there; meta-analyzed within regions, in 21 separate age groups, with separate urban and rural data; interpolated and extrapolated as needed between age groups and regions; and then combined prevalence with population data to calculate the number of people affected by myopia, as summarized in Figure S1 (available at www.aaajournal.org).² We searched for alternative models, but found no comparable evidence.

We extracted country-specific population data for 2015, in the same 5-year age groups from the United Nations World Population Prospects.¹⁶ Population data from the United States Census Bureau were used for a small number of low-population states aggregated within the available United Nations data.¹⁷ Country populations were split into urban and rural proportions using urbanization data from the United States' Central Intelligence Agency's World Factbook.¹⁸ Countries were grouped into the 21 Global Burden of Disease regions for the purpose of data presentation.¹⁹ Population, urbanization, and myopia prevalence estimates were combined to ascertain the number of people with myopia that, if uncorrected, would cause VI matching the visual acuity brackets with WHO disability weight data.

We performed a systematic search for myopia correction rates, coverage, or both on November 14, 2017, summarized in Figure 2. We included articles that (1) were population-based studies quantifying spectacle correction rates, coverage for distance refractive error, or both; (2) included a mechanism to differentiate people with VI resulting from eye disease rather than from uncorrected refractive error; (3) used sampling representative of entire communities; and (4) had a sample size of at least 400 participants. We

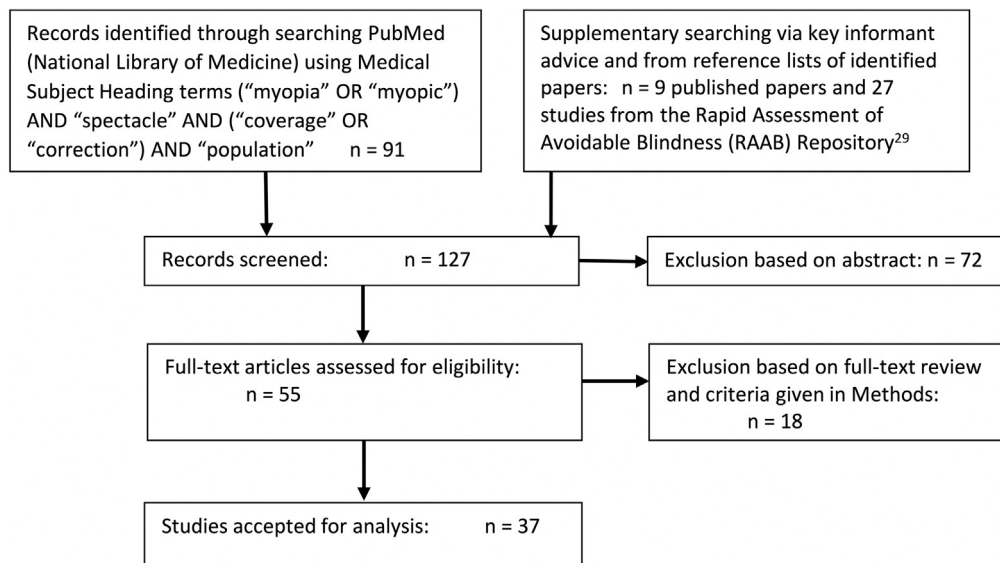


Figure 2. Flow diagram summarizing the systematic search and review process for identifying evidence regarding myopia correction rates. Inclusion and exclusion criteria are provided in the text.

Table 2. Estimated Number of People Affected Globally by Each Level of Vision Impairment Resulting from Uncorrected Myopia and Myopic Macular Degeneration, Together with the Estimate of the Potential Lost Productivity in Those with Vision Impairment Resulting from Uncorrected Myopia and Myopic Macular Degeneration

	No Vision Impairment	Mild Vision Impairment	Moderate Vision Impairment	Severe Vision Impairment	Blindness	Total	Care-Related Productivity Loss (United States Dollars)	Total Including Care (United States Dollars)
Visual acuity bracket	≥20/40	<20/40 but ≥20/60	<20/60 but ≥20/200	<20/200 but ≥10/200	<10/200	<20/40		
No. of people with VI caused by uncorrected myopia	0	53 909 952	234 146 213	124 503 383	125 025 629	537 585 177		
Lower 95% CI	0	54 652 862	115 944 069	59 107 849	52 244 036	281 948 817		
Upper 95% CI	0	204 952 517	423 269 413	234 104 213	253 776 658	1 116 102 802		
No. of people with VI caused by MMD	0	NA	6 951 621		3 374 015	10 325 636		
Lower 95% CI	0	NA	3 809 955		1 843 515	5 653 470		
Upper 95% CI	0	NA	16 389 447		7 979 864	24 369 311		
Lost productivity resulting from VI caused by uncorrected myopia	0	\$556 452 501	\$40 361 667 459	\$79 916 819 422	\$106 384 610 563	\$227 219 549 945	\$16 652 385 400	\$243 871 935 345
Lower 95% CI	0	\$267 534 741	\$10 343 814 871	\$18 452 220 966	\$17 005 144 314	\$46 068 714 892	\$3 140 316 223	\$49 209 031 116
Upper 95% CI	0	\$3 190 201 999	\$110 434 870 007	\$227 634 536 720	\$308 071 130 801	\$649 330 739 527	\$47 710 583 416	\$697 041 322 943
Lost productivity resulting from VI caused by MMD	0	NA	\$3 055 930 776		\$2 202 456 544	\$5 258 387 320	\$373 042 193	\$5 631 429 513
Lower 95% CI	0	NA	\$1 146 342 492		\$817 553 825	\$1 963 896 316	\$139 072 507	\$2 102 968 823
Upper 95% CI	0	NA	\$9 299 604 818		\$6 834 290 981	\$16 133 895 799	\$1 148 409 339	\$17 282 305 138
Sum of lost productivity resulting from VI caused by uncorrected myopia and MMD	0	\$556 452 501	\$123 334 417 657		\$108 587 067 106	\$232 477 937 265	\$17 025 427 593	\$249 503 364 858
Lower 95% CI	0	\$267 534 741	\$29 942 378 330		\$17 822 698 139	\$48 032 611 209	\$3 279 388 730	\$51 311 999 939
Upper 95% CI	0	\$3 190 201 999	\$347 369 011 545		\$314 905 421 783	\$665 464 635 326	\$48 858 992 755	\$714 323 628 082

CI = confidence interval; MMD = myopic macular degeneration; NA = not available; VI = vision impairment.

Estimated care-related productivity loss is also provided together with the sum of potential lost productivity in the individuals and care-related productivity loss.

excluded articles not available in English or that did not specify the number of eligible participants or participation rate, had unspecified or ambiguous definitions, had a participation rate of less than 70%, or were based on duplicate data used in other included studies. After applying inclusion and exclusion criteria and adding additional articles identified by key informants and reference lists of identified studies, we included 37 studies from 36 different countries, with a combined sample size of 174 736.^{20–31} The included studies are summarized in Table S1 (available at www.aaojournal.org).

Distance spectacle coverage data from the 37 accepted studies were analyzed against health and development indicators from the country and year of data collection. We assessed the relationship of spectacle coverage with gross domestic product (GDP) per capita (in US\$ and in international dollars adjusted for purchasing power parity),³² gross national income per capita (in both US\$ and international dollars),³² Gini coefficient,³² eye care practitioner need,¹¹ health expenditure per capita (in both US\$ and international dollars),³² ratio of public-to-total health expenditure,³² average years of education,³² adult literacy,³² Human Development Index (HDI),³³ Socio-Demographic Index,³⁴ annual per capita electric power consumption,⁵² and mobile or cellular telephone subscriptions (per 100 people).³² The equation providing the best explanation of variance was used to calculate country-specific spectacle coverage in 2015.

We also investigated the effect of urbanization and age on spectacle coverage within a country. From the identified correction coverage studies, 7 reported differences based on urbanization,^{21–24,27,30,35} whereas 6 reported differences based on age.^{23,24,30,36–38} We modelled this evidence to describe the effect of urbanization and age on spectacle coverage in countries at different levels of development.

The country-, urbanization-, and age-specific distance spectacle coverage estimates determined by these models were bound to

$$\text{Standard error} = \sqrt{(\text{intercept variance} + (\text{slope variance} \times \text{HDI}^4) - (2 \times \text{covariance} \times \text{HDI}^2))}.$$

lower and upper limits of 0% and 100% and were converted to the rate that refractive error remains uncorrected. The results were combined with the number of people with the relevant levels of myopia to estimate the number of people with mild, moderate, and severe VI and blindness from uncorrected myopia in 2015, as summarized in Figure S1 (available at www.aaojournal.org).

Estimating Vision Impairment Associated with Myopic Macular Degeneration

Even with refractive correction, higher myopia increases the risk of VI from a range of conditions including cataract, glaucoma, retinal pathologic features such as tears and detachment, and MMD.^{39–41} However, data disaggregation is difficult to achieve for most of these conditions, and we were able to separate only VI associated with MMD with any surety. Country-specific VI and blindness resulting from MMD prevalence data for 2015, in 5-year age groups from 0 to 90 years of age or older, were derived using the methods and data of Fricke et al.¹⁰ We combined population data with the MMD data to estimate the number of people with VI and blindness resulting from MMD in 2015, as summarized in Figure S1 (available at www.aaojournal.org).

Estimating Lost Productivity

The Global Health Estimates Technical Paper published by WHO was chosen as the most current and internationally accepted source

of disability weight data.¹³ The number of people with each level of VI, from each cause, within each age group, in each country was multiplied by the disability weight relevant to the impairment level (mild VI, moderate VI, severe VI, and blindness),¹³ age-specific labor force participation rates,^{32,42} employment rates,³² and GDP per capita for 2015 in US\$, as summarized in Figure S1 (available at www.aaojournal.org).³² Published disability weights aggregate urbanization effects at the global level, whereas labor force participation, employment, and GDP per capita aggregate urbanization effects at the country level. The result is an estimate of the potential productivity lost at each level and to each cause of VI in 2015 US\$.

Additionally, there is likely to be some “care cost” associated with each person with moderate VI, severe VI, or blindness that is likely to vary dramatically in nature and amount depending on impairment level, jurisdiction, and personal circumstance. To our knowledge, there are no studies quantifying care costs for people with a range of VI levels across different jurisdictions. Previous authors have conceptualized the care costs as assistance from an adult with normal sight who would lose productive time to the affected individual.^{12,43} We used their precedent of a 10% potential productivity loss for the care of each person with blindness and a 5% potential productivity loss for the care of each person with moderate or severe VI.^{12,43} We assumed that there would not be any productivity loss in the care of individuals with mild VI.

Confidence Intervals

Uncertainty in our cost estimates derived from 4 sources. First, the 95% confidence intervals (CIs) of the myopia prevalence estimates were entered into our calculations.² Second, uncertainty in spectacle coverage was estimated using the variance–covariance of the regression model, where

Third, the 95% CIs of the VI associated with MMD were entered into our calculations.¹⁰ Finally, we applied the 95% CI estimate for vision loss in the 2015 WHO disability weights, i.e., 33.3% average uncertainty calculated as: 0.5 (upper bound – lower bound) / median value.¹³

Results

We estimated that there were 201 million people (95% CI, 148–538 million) with myopia of –0.75 D or less but more than –1.00 D, 857 million (95% CI, 638–1105 million) with myopia of –1.00 D or less but more than –2.50 D, 463 million (95% CI, 337–617 million) with myopia of –2.50 D or less but more than –4.00 D, and 515 million (95% CI, 381–686 million) with myopia of –4.00 D or less globally in 2015. The following equation was found to explain best the variance of spectacle coverage between countries (R^2 , 78%):

$$\text{Distance spectacle coverage} = 1.698 \times (\text{HDI})^2 - 0.178.$$

This formula was used to estimate spectacle coverage in each country of the world, with 2 country-specific adjustments. First, analysis of distance spectacle coverage in urban and rural areas of the same age groups of the same country suggested the following adjustments:^{21–24,27,30,35} (1) in countries with HDI of less than 0.4, the ratio of urban-to-overall spectacle coverage was 1.35, whereas the ratio of rural-to-overall spectacle coverage was 0.43; (2) in

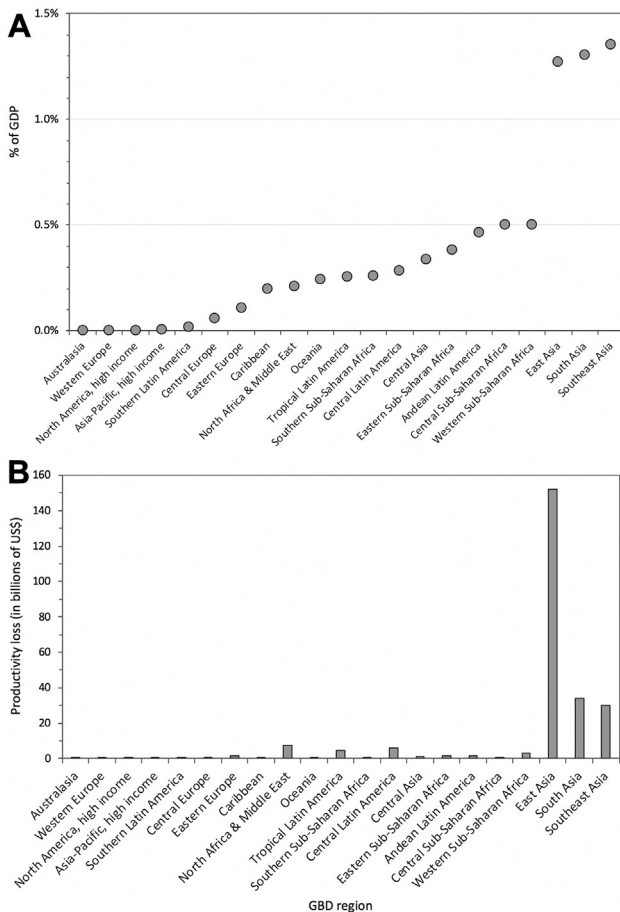


Figure 3. Graphs showing regional productivity loss resulting from myopia in 2015 (A) as a percentage of gross domestic product (% of GDP) and (B) in billions of Unites States dollars (US\$). Regional productivity loss is determined by multiple components, each derived via either meta-analysis or modelling from its own systematically sourced set of primary data via the methodology summarized in Figure S1 (available at www.aojournal.org). GBD = Global Burden of Disease.

countries with HDI of 0.4 or more and 0.744 or less, the ratio of urban-to-overall spectacle coverage was $1.72 - 0.93 \times (\text{HDI})$, whereas the ratio of rural-to-overall spectacle coverage was $1.52 \times (\text{HDI}) - 0.18$; and (3) in countries with HDI of more than 0.744, the ratio of urban-to-overall spectacle coverage was 1.03, whereas the ratio of rural-to-overall spectacle coverage was 0.95. Second, analysis of distance spectacle coverage in different age groups of the same country suggested the following adjustments for age groups from 40 to 80 years of age inclusive:^{23,24,30,36,37,44} (1) in countries with HDI of less than 0.55, the ratio of age-specific spectacle coverage compared with overall coverage was $2.92 - 0.035 \times \text{age}$; (2) in countries with HDI of 0.55 or more and HDI of 0.80 or less, the ratio of age-specific spectacle coverage compared with overall coverage was $1.82 - 0.015 \times \text{age}$; and (3) in countries with HDI of more than 0.80, the ratio of age-specific spectacle coverage compared with overall coverage was $1.18 - 0.003 \times \text{age}$.

In age groups younger than 40 years and older than 80 years, the same equations were used for each development level, but with age as a constant of 40 or 80 years, respectively. It should be noted that most spectacle coverage data have been gathered from participants older than 40 years, so there is less certainty for estimates

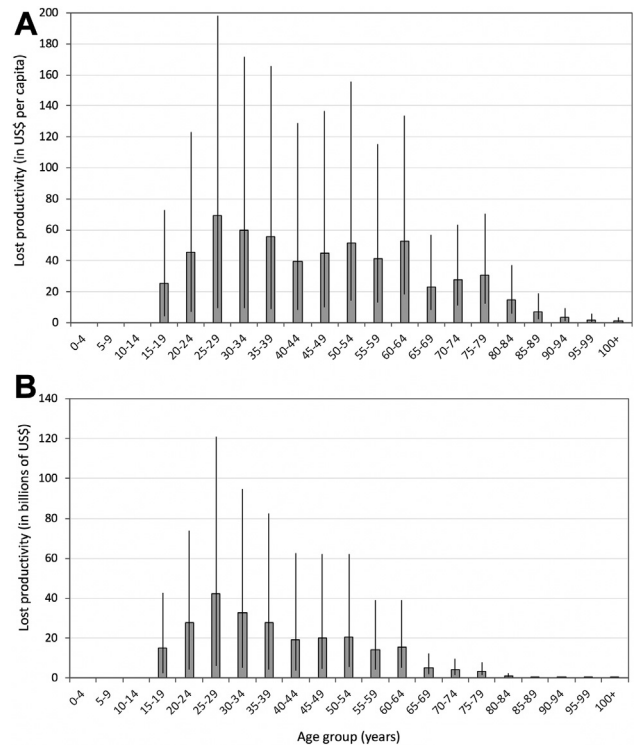


Figure 4. Graphs showing global productivity loss resulting from myopia in each age group in 2015 (A) in Unites States dollars (US\$) per capita and (B) in billions of US\$.

from those younger than 40 years, although the data that do exist do not suggest any major variation other than the equations above. Table 2 shows our estimates of the number of people at each level of VI resulting from uncorrected myopia, the number of people at each level of VI resulting from MMD, and the lost productivity resulting from each cause and/or level of VI.

Figure 3 shows the regional productivity loss owing to VI resulting from myopia. Southeast Asia, South Asia, and East Asia stand out as having well over twice the burden of any other region as a percentage of GDP: 1.35%, 1.30%, and 1.27%, respectively. Differences between regions result from the interplay between country-specific variables: myopia and high myopia prevalence, demographics, HDI, health expenditure, urbanization, labor force participation, employment, GDP, and population. In absolute terms (bottom graph), the same 3 regions show larger burdens than any other region, but East Asia is a particular standout because of its large population and comparatively high GDP per capita.

Figure 4 shows the global productivity loss owing to VI resulting from myopia in each age group. Productivity loss in US\$ peaks in the 25- to 29-year age group and then declines. Differences between age groups result from demographics, myopia and high myopia prevalences, the effect of age on distance spectacle coverage, the effect of age on VI resulting from MMD, and the labor force participation rate. When the effect of population age distribution is negated by considering productivity loss in US\$ per capita terms (Fig 4, top), the burden is distributed more evenly across working-age adults.

Discussion

Results suggest myopia has a global economic impact, with the greatest burden focused in Southeast Asia, South Asia,

and East Asia. Expected increases in myopia prevalence are likely to cause greatly increased public health and economic problems in the future unless action is taken to prevent myopia, to correct and control myopia after it has occurred, and to manage the pathologic complications of high myopia.² Encouraging data suggesting that time outdoors prevents or delays the onset of myopia, or both,^{45,46} together with the ability of optical, pharmacologic, and other interventions to correct VI and slow the progression of myopia,^{47,48} offer an opportunity to lessen future burden.

The HDI provided the best explanation of variance across national spectacle coverage evidence, as well as the effect of urbanization within countries. The HDI is a composite indicator calculated by the United Nations Development Programme that aggregates life expectancy at birth, expected years of schooling, and per-capita gross national income. Countries can achieve a high HDI via extremely good performance in 1 dimension, but generally, high HDI indicates a level of achievement over all 3 dimensions: health, education, and wealth. Our modeling suggests that older people in rural areas of the least developed countries carry the greatest burden of VI resulting from uncorrected refractive error. This does not neatly translate to the regional myopia-related productivity losses illustrated in Figure 3, because myopia prevalence, labor force participation and employment rates, and GDP per capita counteract the effect of spectacle coverage to various extents. Figure 3 shows that the balance of these factors suggests that East Asia shows by far the greatest productivity loss resulting from myopia in total dollar terms, but that South Asia and Southeast Asia carry a similar burden to East Asia as a percentage of GDP.

Eyesight influences the way a person relates to and integrates into society and can impact education, employment, child development, mental health, and functional capacity in older people.⁴⁹ The concentration of VI resulting from uncorrected refractive error in the least developed countries increases the difficulty for these countries to achieve United Nations sustainable development goal 1 (no poverty), goal 4 (quality education), goal 8 (decent work and economic growth), and goal 10 (reduced inequalities).

Previous studies based on 2007 data estimated US\$202 billion annual global productivity loss resulting from distance VI caused by uncorrected refractive error, but that it would cost approximately US\$20 billion to build the infrastructure, train the personnel, and deliver the services needed to correct all VI resulting from uncorrected refractive error over 5 years.^{11,12} These studies differed from the current study in that they (1) combined all types of refractive error, (2) did not include VI resulting from MMD, (3) were based on primary VI data identifying uncorrected refractive error as the cause, rather than myopia studies adjusted for correction rates and effect of MMD, (4) used simpler methods to extrapolate data between regions and over time, (5) used an all-ages figure for labor force participation rate, (6) used different disability weights,⁵⁰ and (7) were based on 2007 and earlier data.

One of the strengths of the current study is the modeling, described in “Methods” and illustrated in Figure S1 (available

at www.aaojournal.org), which permits evidence-based estimations in countries lacking primary data, facilitates temporal changes to be accounted for, and enables more realistic age and urbanization adjustments. Accounting for changes over time is particularly important when estimating spectacle correction rates, VI resulting from uncorrected refractive error, or both because it seems that significant gains have been made over the past 20 years.^{51,52} Including VI resulting from MMD is another strength in terms of attempting to estimate the cost of myopia as a whole rather than just the refractive component.

Our study design has some potential limitations. The first is that the nature of our sequential methodology—estimating myopia at specific cutoffs, then determining each level of VI by adjusting by the location- and age-specific rate of uncorrected refractive error—means that errors can be cumulative. Second, because of lack of evidence to the contrary, we assumed that spectacle coverage was independent of refractive error type and magnitude, as long as it caused some level of VI. Third, our estimate of care-related productivity loss was based on assumptions previous authors have made, rather than primary evidence.^{12,43} We consider their assumptions conservative, which is appropriate given the lack of primary evidence. Fourth, because the care-associated productivity loss was a percentage of the potential productivity loss in individuals with VI and international labor laws mean that labor force participation is 0 in those younger than 15 years, our models returned no care-related impact for any individual younger than 15 years. Although it could be argued that this is overly conservative, we note that it is based on the precedence of previous authors who cited a lack of evidence^{12,43} and that children already require some level of care, meaning that it is more difficult to judge how much in additional resources may be required for a child with VI. Fifth, we assumed that people with any level of myopia, with vision correction and normal visual acuity when wearing their correction, are of equal employability and earning potential as nonmyopic people of the same age, country, and urbanization. Sixth, we believe that we have underestimated the productivity impact of pathologic conditions associated with myopia and high myopia. We limited our estimate of myopia-related pathologic features to MMD because of the availability of disaggregated evidence, which means that the increased risks of VI resulting from retinal detachment, glaucoma, and cataract are not included and that our estimate is likely to be conservative.^{40,41} Seventh, published disability weights, employment rates, labor force participation rates, and per-capita GDP aggregate urban and rural samples. The aggregations may affect the accuracy of our estimates if the ratio of urban to rural people affected by myopia-related VI in a country differs significantly from that country’s overall ratio of urban to rural people. There are factors pushing this ratio in both directions (e.g., higher myopia prevalence in urban areas, but lower spectacle correction rate in rural areas). Overall, these effects are minimal and we consider our estimates accurate within stated 95% CIs. We also note that the potential lost productivity resulting from myopia-related VI estimated in this study is only one part of the overall burden of myopia. Further studies are required to quantify

other components of the overall burden, such as the cost of eye examinations, the cost of refractive corrections, the cost of managing pathologic consequences of myopia such as MMD, and related opportunity costs.

The value of any investment to prevent myopia, slow progression of myopia, improve spectacle correction rates, and improve outcomes in MMD depends on a comparison of lost productivity owing to VI resulting from myopia with the cost of prevention and management interventions. It has been estimated that the global cost of educating the additional personnel and establishing and operating the additional eye care facilities required to deal with VI resulting from uncorrected refractive error in 2007 was US\$20 billion over 5 years.¹¹ The current estimate of potential global productivity loss associated with myopia is more than an order of magnitude larger than this cost of addressing uncorrected refractive error, highlighting an economic case for prioritizing the management of myopia. Even without aiming for myopia prevention or control or dealing with MMD, simply improving spectacle correction rates for people with myopia is estimated potentially to gain US\$244 billion in productivity annually for a US\$20 billion investment. Although our CIs cover a wide range, our lower 95% confidence limit is still 2.5 times the estimated cost of comprehensively addressing uncorrected refractive error. Additionally, the cost of addressing uncorrected refractive error may have increased since 2007. Although the number of people with myopia has increased,² this has been counterbalanced in part by improvements in spectacle correction rates,^{51,52} almost certainly retaining an overall net positive return under even the most conservative assumptions. Although policy makers in health and financial areas of both government and the private sector need to consider the estimated productivity effects associated with myopia in a broader framework of individual and societal costs, our results highlight the potential economic value of intervention.

References

1. Modjtahedi BS, Ferris III FL, Hunter DG, Fong DS. Public health burden and potential interventions for myopia. *Ophthalmology*. 2018;125(5):628–630.
2. Holden BA, Fricke TR, Wilson DA, et al. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology*. 2016;123(5):1036–1042.
3. World Health Organization, Brien Holden Vision Institute. *The impact of myopia and high myopia. Report of the Joint World Health Organization—Brien Holden Vision Institute (WHO-BHVI) Global Scientific Meeting on Myopia held at the University of New South Wales in Sydney, Australia, 16–18 March 2015*. Geneva: World Health Organization; 2016.
4. Morgan IG, Ohno-Matsui K, Saw SM. Myopia. *Lancet*. 2012;379(9827):1739–1748.
5. Wong TY, Ferreira A, Hughes R, et al. Epidemiology and disease burden of pathologic myopia and myopic choroidal neovascularization: an evidence-based systematic review. *Am J Ophthalmol*. 2014;157(1):9–25.e12.
6. The Eye Disease Case-Control Study Group. Risk factors for idiopathic rhegmatogenous retinal detachment. *Am J Epidemiol*. 1993;137(7):749–757.
7. Kim YW, Lee EJ, Kim TW, et al. Microstructure of beta-zone parapapillary atrophy and rate of retinal nerve fiber layer thinning in primary open-angle glaucoma. *Ophthalmology*. 2014;121(7):1341–1349.
8. Verkicharla PK, Ohno-Matsui K, Saw SM. Current and predicted demographics of high myopia and an update of its associated pathological changes. *Ophthalmic Physiol Optics*. 2015;35(5):465–475.
9. Contreras AB, Ackland P. *Spectacle coverage report*. London, UK: International Agency for the Prevention of Blindness; 2017.
10. Fricke TR, Jong M, Naidoo KS, et al. Global prevalence of visual impairment associated with myopic macular degeneration and temporal trends from 2000 through 2050: systematic review, meta-analysis and modelling. *Br J Ophthalmol*. 2018;102(7):855–862.
11. Fricke TR, Holden BA, Wilson DA, et al. Global cost of correcting vision impairment from uncorrected refractive error. *Bull World Health Organ*. 2012;90:728–738.
12. Smith TS, Frick KD, Holden BA, et al. Potential lost productivity resulting from the global burden of uncorrected refractive error. *Bull World Health Organ*. 2009;87(6):431–437.
13. Mathers C, Ho J. *Global Health Estimates Technical Paper—WHO methods and data sources for global burden of disease estimates 2000–2015*. Geneva: Department of Information Evidence and Research, World Health Organization; 2017.
14. World Health Organization. International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10)—WHO version for 2016. <http://apps.who.int/classifications/icd10/browse/2016/en#/H53-H54>. Accessed 12.11.17.
15. Sloan LL. Measurement of visual acuity: a critical review. *AMA Arch Ophthalmol*. 1951;45(6):704–725.
16. United Nations Population Division, Department of Economic and Social Affairs. *World Population Prospects: the 2015 Revision*. United Nations; 2015. <https://esa.un.org/unpd/wpp/>. Accessed 19.02.16.
17. United States Census Bureau. International programs: international data base 2013. <http://www.census.gov/population/international/data/idb/informationGateway.php>. Accessed 8.04.16.
18. Central Intelligence Agency. The World Factbook. <https://www.cia.gov/library/publications/the-world-factbook/rank-order/2129rank.html>. Accessed 25.05.16.
19. Bourne RR, Stevens GA, White RA, et al. Causes of vision loss worldwide, 1990–2010: a systematic analysis. *Lancet Glob Health*. 2013;1(6):e339–e349.
20. Bourne R, Dineen B, Ali S, et al. Prevalence of refractive error in Bangladeshi adults: results of the National Blindness and Low Vision Survey of Bangladesh. *Ophthalmology*. 2004;111(6):1150–1160.
21. Bourne R, Dineen B, Noorul Huq D, et al. Correction of refractive error in the adult population of Bangladesh: meeting the unmet need. *Invest Ophthalmol Vis Sci*. 2004;45:410–417.
22. Chan VF, Mebrahtu G, Ramson P, et al. Prevalence of refractive error and spectacle coverage in Zoba Ma'ekel Eritrea: a rapid assessment of refractive error. *Ophthalmic Epidemiol*. 2013;20(3):131–137.
23. Brian G, Pearce MG, Ramke J. Refractive error and presbyopia among adults in Fiji. *Ophthalmic Epidemiol*. 2011;18(2):75–82.

24. Marmamula S, Khanna RC, Narsaiah S, et al. Prevalence of spectacles use in Andhra Pradesh, India: rapid assessment of visual impairment project. *Clin Exp Ophthalmol*. 2014;42(3):227–234.
25. Bastawrous A, Mathenge W, Foster A, Kuper H. Prevalence and predictors of refractive error and spectacle coverage in Nakuru, Kenya: a cross-sectional, population-based study. *Int Ophthalmol*. 2013;33(5):541–548.
26. Ezelum C, Razavi H, Sivasubramaniam S, et al. Refractive error in Nigerian adults: prevalence, type, and spectacle coverage. *Invest Ophthalmol Vis Sci*. 2011;52(8):5449–5456.
27. Shah SP, Jadoon MZ, Dineen B, et al. Refractive errors in the adult Pakistani population: the National Blindness and Visual Impairment Survey. *Ophthalmic Epidemiol*. 2008;15(3):183–190.
28. Naidoo KS, Chinanayi FS, Ramson P, Mashige KP. Rapid assessment of refractive error in the eThekweni Municipality of KwaZulu-Natal, Durban, South Africa. *Clin Exp Optom*. 2016;99(4):360–365.
29. Mashayo ER, Chan VF, Ramson P, et al. Prevalence of refractive error, presbyopia and spectacle coverage in Kahama District, Tanzania: a rapid assessment of refractive error. *Clin Exp Optom*. 2015;98(1):58–64.
30. Ramke J, du Toit R, Palagyi A, et al. Correction of refractive error and presbyopia in Timor-Leste. *Br J Ophthalmol*. 2007;91:860–866.
31. RAAB Repository. Repository of results from Rapid Assessment of Avoidable Blindness (RAAB) studies. <http://raabdata.info/repository>. Accessed 8.08.17.
32. World Bank. World Development Indicators. <http://data.worldbank.org/products/wdi>. Accessed 23.03.17.
33. United Nations Development Programme. Human Development Index and its components. <http://hdr.undp.org/en/2016-report>. Accessed 27.04.16.
34. Institute for Health Metrics and Evaluation. Global Health Data Exchange. <http://ghdx.healthdata.org/gbd-2015>. Accessed 26.05.17.
35. Prema R, George R, Sathyamangalam Ve R, et al. Comparison of refractive errors and factors associated with spectacle use in a rural and urban South Indian population. *Indian J Ophthalmol*. 2008;56(2):139–144.
36. Fotouhi A, Hashemi H, Raissi B, Mohammad K. Uncorrected refractive errors and spectacle utilization in Tehran: the unmet need. *Br J Ophthalmol*. 2006;90(5):534–537.
37. Varma R, Wang MY, Ying-Lai M, et al. The prevalence and risk indicators of uncorrected refractive error and unmet refractive need in Latinos: the Los Angeles Latino Eye Study. *Invest Ophthalmol Vis Sci*. 2008;49(12):5264–5273.
38. Zhu M, Tong X, Zhao R, et al. Visual impairment and spectacle coverage rate in Baoshan district, China: population-based study. *BMC Public Health*. 2013;13:311.
39. Ohno-Matsui K, Lai TY, Lai CC, Cheung CM. Updates of pathologic myopia. *Prog Retinal Eye Res*. 2016;52:156–187.
40. Tideman JW, Snabel MC, Tedja MS, et al. Association of axial length with risk of uncorrectable visual impairment for Europeans with myopia. *JAMA Ophthalmol*. 2016;134(12):1355–1363.
41. Verhoeven VJ, Wong KT, Buitendijk GH, et al. Visual consequences of refractive errors in the general population. *Ophthalmology*. 2015;122(1):101–109.
42. United Nations. UNdata—a world of information. <http://data.un.org/>. Accessed 25.05.16.
43. Shamanna B, Dandona L, Rao G. Economic burden of blindness in India. *Indian J Ophthalmol*. 1998;46(3):169–172.
44. Ramke J, Brian G, Naduvilath T. Refractive error and presbyopia in Timor-Leste: the impact of 5 years of a national spectacle program. *Invest Ophthalmol Vis Sci*. 2012;53(1):434–439.
45. He M, Xiang F, Zeng Y, et al. Effect of time spent outdoors at school on the development of myopia among children in China: a randomized clinical trial. *JAMA*. 2015;314(11):1142–1148.
46. Wu PC, Tsai CL, Wu HL, et al. Outdoor activity during class recess reduces myopia onset and progression in school children. *Ophthalmology*. 2013;120(5):1080–1085.
47. Sankaridurg PR, Holden BA. Practical applications to modify and control the development of ametropia. *Eye*. 2014;28(2):134–141.
48. Chia A, Lu QS, Tan D. Five-year clinical trial on Atropine for the Treatment of Myopia 2: myopia control with atropine 0.01% eyedrops. *Ophthalmology*. 2016;123(2):391–399.
49. Cieza A, Kocur I, Mariotti S, McCoy M. The future of eye care in a changing world. *Bull World Health Organ*. 2017;95:667.
50. Mathers C, Bernard C, Iburg K, et al. *Global burden of disease in 2002: data sources, methods and results. Global Programme on Evidence for Health Policy Discussion paper no. 54*. Geneva: World Health Organization; 2003.
51. Bourne RRA, Flaxman SR, Braithwaite T, et al. Magnitude, temporal trends, and projections of the global prevalence of blindness and distance and near vision impairment: a systematic review and meta-analysis. *Lancet Glob Health*. 2017;5(9):e888–e897.
52. Flaxman SR, Bourne RRA, Resnikoff S, et al. Global causes of blindness and distance vision impairment 1990–2020: a systematic review and meta-analysis. *Lancet Glob Health*. 2017;5(12):e1221–e1234.

Footnotes and Financial Disclosures

Originally received: April 27, 2018.

Final revision: October 10, 2018.

Accepted: October 10, 2018.

Available online: October 17, 2018.

Manuscript no. 2018-983.

¹ Brien Holden Vision Institute, Sydney, Australia.

² School of Optometry and Vision Science, University of New South Wales, Sydney, Australia.

³ African Vision Research Institute, University of KwaZulu Natal, Durban, South Africa.

⁴ Carey Business School, Johns Hopkins University, Baltimore, Maryland.

Financial Disclosure(s):

The author(s) have no proprietary or commercial interest in any materials discussed in this article.

Supported by the Brien Holden Vision Institute, Sydney, Australia, and the Vision Impact Institute.

HUMAN SUBJECTS: No human subjects were included in this study.

No animal subjects were included in this study.

Author Contributions:

Conception and design: Naidoo, T.R.Fricke, K.D.Frick, Naduvilath, Sankaridurg

Analysis and interpretation: Naidoo, T.R.Fricke, K.D.Frick, Naduvilath, Resnikoff

Data collection: T.R.Fricke, Jong

Obtained funding: Study was performed as part of regular employment (Naidoo, Jong, Naduvilath, Sankaridurg) or contracted consultancy (T.R. Fricke, K.D. Frick, Resnikoff) duties at Brien Holden Vision Institute. No additional funding was provided.

Overall responsibility: Naidoo, T.R.Fricke, K.D.Frick, Resnikoff, Sankaridurg

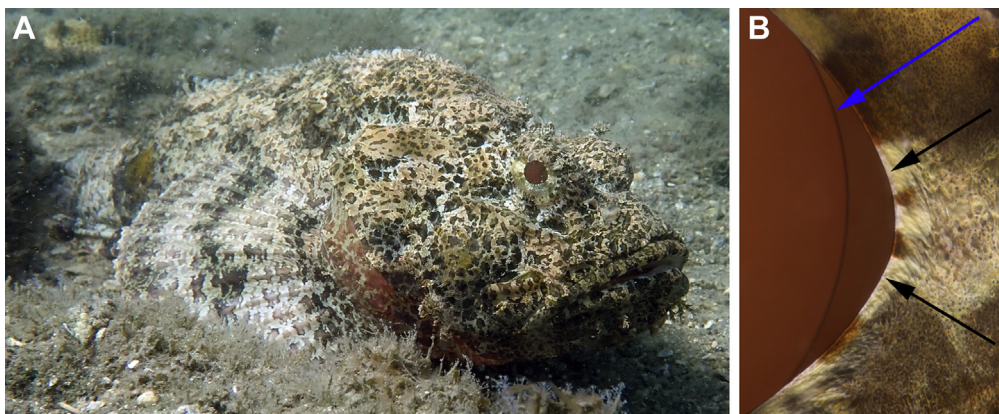
Abbreviations and Acronyms:

CI = confidence interval; **D** = diopter; **GBD** = Global Burden of Disease; **GDP** = gross domestic product; **HDI** = Human Development Index; **MMD** = myopic macular degeneration; **US\$** = United States dollars; **VI** = vision impairment; **WHO** = World Health Organization.

Correspondence:

Timothy R. Fricke, MSc, Brien Holden Vision Institute, University of New South Wales, Gate 14 Barker Street, Rupert Myers Building, 4th Floor, Kensington, NSW 2052, Australia. E-mail: t.fricke@brienholdenvision.org.

Pictures & Phylogeny



The Piscine Lens and the Aphakic Space: Scorpionfish (*Scorpaena plumieri*)

Most piscine lenses are nearly spherical providing crisp focus. These lenses protrude through the pupil and nearly touch the cornea. Predatory fish (Fig A, *Scorpaena plumieri*) have a pyriform-shaped pupil with the pupillary apex directed anteriorly. This pupil permits the lens to be moved forward during accommodation. The “notch” of the pupil then permits an image to traverse a more peripheral portion of the lens striking a peripheral fovea. This odd pupil also reveals the anterior equatorial edge of the lens showing the capsule and lenticular epithelium (Fig B, lens capsule and epithelium, *blue arrow*; pupillary notch adjacent to aphakic space, *black arrows*). This epithelium is highly regular and has flattened cuboidal cells, responsible for the production of the lenticular fibers. This perspective reveals the remarkable evolutionary diversity in the eyes of different animals even in lens and pupillary size and shape. (Magnified version of Fig A-B is available online at www.aaojournal.org).

IVAN R. SCHWAB, MD, FACS¹

DAVID G. HEIDEMANN, MD (PHOTOGRAPHER)²

¹University of California, Davis, California; ²Michigan Cornea Consultants, Southfield, Michigan

Footnotes and Financial Disclosures

Editor's Note: We will occasionally run Pictures & Phylogeny images. The journal welcomes submission of high-quality photographs, photomicrographs, radiologic or other imaging studies, or procedural illustrations that depict novel features of clinically important entities.
