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# Cost-effectiveness of screening and correcting refractive errors in school children in Africa, Asia, America and Europe

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**Abstract**

*Objective:* To estimate the costs and effects of alternative strategies for annual screening of school children for refractive errors, and the provision of spectacles, in different WHO sub-regions in Africa, Asia, America and Europe.
*Methods:* We developed a mathematical simulation model for uncorrected refractive error, using prevailing prevalence and incidence rates. Remission rates reflected the absence or presence of screening strategies for school children. All screening strategies were implemented for a period of 10 years and were compared to a situation were no screening was implemented. Outcome measures were life years adjusted for disability (DALYs), costs of screening and provision of spectacles and follow-up for six different screening strategies, and cost-effectiveness in international dollars per DALY averted. Epidemiological information was derived from the burden of disease study from the World Health Organization (WHO). Cost data were derived from large databases from the WHO. Both univariate and multivariate sensitivity analyses were performed on key parameters to determine the robustness of the model results.
*Results:* In all regions, screening of 5–15 years old children yields most health effects, followed by screening of 11–15 years old, 5–10 years old, and screening of 8 and 13 years old. Screening of broad-age intervals is always more costly than screening of single-age intervals, and there are important economies of scale for simultaneous screening of both 5–10 and 11–15-year-old children. In all regions, screening of 11–15 years old is the most cost-effective intervention, with the cost per DALY averted ranging from I$67 per DALY averted in the Asian sub-region to I$458 per DALY averted in the European sub-region. The incremental cost per DALY averted of screening 5–15 years old ranges between I$111 in the Asian sub-region to I$672 in the European sub-region.
*Conclusions:* Considering the conservative study assumptions and the robustness of study conclusions towards changes in these assumptions, screening of school children for refractive error is economically attractive in all regions in the world.


*Keywords:* Refractive error; Costs; Cost-effectiveness; Economic evaluation; Modeling

## 1. Introduction

Uncorrected refractive errors (URE) are the main cause of severely impaired vision in the world, and are responsible for a major disease burden [1–11]. Yet,

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diagnosis and treatment of refractive errors is one of the easiest ways to reduce impaired vision or even blindness. Clearly, access to eye care services, public awareness of the need for them, and availability of spectacles have not yet reached adequate levels.

There are three population groups that require spectacles: children with refractive error, the middle age with presbyopia, and, to a lesser extent, the older group with pseudo(aphakia) [12]. This paper focuses on refractive errors in school children. The lack of refraction and spectacle provision in underserved communities is believed to have important negative effects in terms of lost education and future lost employment opportunities, which might influence the quality of life of the individual, the family and the community [12].

Active screening to identify children with URE and treating them through the provision of spectacles is used in many countries. However, the costs and effects of such programs are largely unknown, and it is not clear what the best screening strategy is. A number of countries have experience with active screening of school children [13,14], and this study builds on that experience by performing a cost-effectiveness analysis.

In this paper, we evaluate through mathematical modelling the costs and effects of various screening strategies of schoolchildren. We do this for four major global regions using a generic measure of effectiveness and a standardized analytical approach. This analysis is designed to provide a broad assessment of the cost-effectiveness of screening for uncorrected refractive errors that covers various strategies in different settings, and that allows comparisons with recent cost-effectiveness analyses for other health care interventions – in blindness control but also in other areas – that follow the same analytical approach [15–18].

## 2. Methods

### 2.1. Overview of cost-effectiveness analysis (CEA)

CEA in health aims to inform policymakers on the economic attractiveness (or returns on investment) of interventions to reduce disease-related mortality and morbidity. By assessing costs and effectiveness of an intervention, a 'value for money' estimate is provided. The cost-effectiveness of a given intervention is typically expressed as costs per unit of effectiveness, with costs measured in monetary terms and effectiveness measured in health metrics terms. Health metrics measure the impact of an intervention on the quality of life (morbidity) and length of life (mortality) of a population and express this as a single number such as a Quality Adjusted Life Year (QALY) or Disability Adjusted Life Year (DALY) [19]. Interventions with a favorable cost-effectiveness ratio (e.g. low cost per DALY) are said to be eligible for implementation, at least in economic terms.

CEA can be undertaken in many ways, and there have been several attempts to develop methodological guidelines to make results more comparable. WHO has developed a standardized set of methods and tools that can be used to analyze the societal costs and effectiveness of current and possible new interventions simultaneously [19], named WHO-CHOICE. The program is designed to provide regularly updated databases on the costs and effects of a full range of promotive, preventive, curative and rehabilitative health interventions [20].

### 2.2. Regions analyzed

Most countries do not have the capacity to evaluate all potential interventions aimed at improving given health indicators at the national and sub-national level, and global estimates are too general and of little use to any specific country. Countries may however benefit from regional evaluations of data, where data of neighboring countries with similar settings are pooled. The present analysis drew on a comprehensive examination of 14 world sub-regions defined by geographic proximity and epidemiology according to WHO classification. This paper only presents results for four regions selected on the basis of their diverse epidemiological patterns. The four sub-regions are the African sub-region with high rates of adult and child mortality (Afr-D), the South American sub-region with low adult and child mortality (Amr-B), the European sub-region with very low adult and child mortality (Eur-A) and the South-East Asian sub-region with high rates of adult and child mortality (Sear-D). A full list of sub-regions and included countries is available in Annex Table A.1. Full results for all regions are available in Annex Table A.2.

Table 1
The prevalence and incidence of uncorrected refractive error (per 1000)[a]

| Age | Afr-D | | Amr-B | | Eur-A | | Sear-D | |
|---|---|---|---|---|---|---|---|---|
| | Prevalence | Incidence | Prevalence | Incidence | Prevalence | Incidence | Prevalence | Incidence |
| 0 | 0.025 | 0.049 | 0.009 | 0.019 | 0.007 | 0.013 | 0.010 | 0.021 |
| 1 | 0.074 | 0.049 | 0.028 | 0.019 | 0.020 | 0.013 | 0.031 | 0.021 |
| 2 | 0.133 | 0.069 | 0.080 | 0.085 | 0.082 | 0.110 | 0.082 | 0.083 |
| 3 | 0.234 | 0.133 | 0.275 | 0.304 | 0.351 | 0.429 | 0.267 | 0.287 |
| 4 | 0.394 | 0.189 | 0.675 | 0.495 | 0.918 | 0.706 | 0.643 | 0.465 |
| 5 | 0.617 | 0.258 | 1.288 | 0.733 | 1.795 | 1.052 | 1.218 | 0.687 |
| 6 | 0.917 | 0.342 | 2.162 | 1.019 | 3.052 | 1.468 | 2.037 | 0.954 |
| 7 | 1.292 | 0.410 | 3.296 | 1.256 | 4.686 | 1.814 | 3.099 | 1.176 |
| 8 | 1.722 | 0.450 | 4.618 | 1.399 | 6.592 | 2.021 | 4.336 | 1.308 |
| 9 | 2.176 | 0.460 | 6.033 | 1.445 | 8.632 | 2.090 | 5.660 | 1.352 |
| 10 | 2.626 | 0.442 | 7.444 | 1.396 | 10.667 | 2.020 | 6.980 | 1.306 |
| 11 | 3.043 | 0.395 | 8.757 | 1.252 | 12.560 | 1.811 | 8.208 | 1.170 |
| 12 | 3.399 | 0.319 | 9.878 | 1.012 | 14.175 | 1.464 | 9.257 | 0.946 |
| 13 | 3.672 | 0.229 | 10.737 | 0.724 | 15.412 | 1.047 | 10.061 | 0.677 |
| 14 | 3.863 | 0.154 | 11.335 | 0.484 | 16.272 | 0.700 | 10.621 | 0.453 |
| 15 | 3.987 | 0.094 | 11.719 | 0.293 | 16.823 | 0.422 | 10.980 | 0.274 |

[a] Source: own estimates based on Resnikoff et al. 2008 [11].

### 2.3. Epidemiology of refractive error

WHO has recently estimated the burden of disease of uncorrected refractive error (URE), i.e. the number of people who present with visual impairment but could achieve normal vision with appropriate correction [11], for four broad age-categories. On the basis of the data for children 5–15 years old, we estimated the prevalence of uncorrected refractive error by 1-year age categories, and the corresponding incidence rates (Table 1) using DISMOD software [21]. The case fatality and remission rates are considered zero, because refractive error is assumed not to result in excess mortality or remit to normal refraction without intervention.

### 2.4. Interventions

The analyses differentiate between screening of school children at primary school (5–10 years old) and secondary school (11–15 years old): although the prevalence of URE among the latter age group is known to be higher, school enrolment in this group is lower in many regions, and it is therefore not clear where the highest reduction of URE can be achieved. The analyses also differentiate between screening of school children of all ages in schools (5–10 years and 11–15 years), and of those of a certain age only (arbitrarily chosen here as 8 years, representing age at middle of primary school, and 13 years, representing age at middle of secondary school): although the use of broad target groups improves identification of URE, it also increases costs, and it is therefore not clear which strategy is most cost-effective. This leads to the identification of six alternative screening strategies:

(1) Annual screening of all school children of age 5–10 years.
(2) Annual screening of all school children of age 11–15 years.
(3) Annual screening of all school children of age 5–15 years.
(4) Annual screening of all school children of age 8 years.
(5) Annual screening of all school children of age 13 years.
(6) Annual screening of all school children of age 8 and 13 years.

All screening strategies are combined with the provision of spectacles for eligible school children.

Table 2
School enrolment rates[a]

| Region | Primary school (%) | Secondary school (%) |
|---|---|---|
| Afr-D | 62 | 30 |
| Amr-B | 95 | 72 |
| Eur-A | 96 | 94 |
| Sear-D | 77 | 42 |

[a] Weighted averages of country-specific rates, for most recent available years. Source: UNICEF database [35].

### 2.5. Estimating population health effects

We used the population model PopMod [22] to estimate the effects of the above interventions on population health in the regions considered. Population health is expressed as the number of healthy years lived (HYL), and differences in HYL as DALYs averted as a result of the intervention. The model divides the population of interest – i.e. children between 5 and 15 years – into three health states: uncorrected refractive error, corrected refractive error, and dead, on the basis of the epidemiological patterns described above. Population health is dependent upon the proportion of children in each health state, as well as the health state valuation that is associated with the health state (the health state valuation for visual impairment is 0.755 [23]).

The proportion of individuals in the different states is dependent on parameters such as prevalence, incidence, remission, and is similarly modelled for both the 'no-screening' scenario and the screening scenarios. The 'no-screening' scenario describes the current situation and assumes a URE remission rate of zero. The screening scenarios show the impact of the screening strategies on the target group, i.e. on the prevalence and incidence of URE among school children (based on primary and secondary school enrolment rates (Table 2)). In these scenarios, the impact of screening is modelled through the remission rate. Estimates of population health in the screening scenarios were subsequently adjusted for non-compliance to wearing the provided spectacles. Compliance has been estimated to be as high as 99% among primary school children in India, but much lower in other settings [14], e.g. among adults [24]. Our base case analysis assumes a conservative estimate of compliance of 70% (in the sensitivity analysis, we assumed compliance levels of respectively, 27 and 82%). Differences in population health estimates between the baseline and intervention scenario were considered a measure of intervention effectiveness, expressed in DALYs.

Following standardized WHO-CHOICE cost-effectiveness analysis, all interventions were evaluated for a period of 10 years, and benefits (i.e. restored eyesight following the use of spectacles) were included to the extent they took place within this period. Following this standardized approach, it was assumed that interventions were performed optimally, i.e. no under- or over-treatment at the highest efficiency level [19].

### 2.6. Estimating costs

Costs covered in this analysis include programme-level costs associated with running the intervention, such as administration and training, and patient-level costs such as primary care visits. These costs were based on a standard ingredients approach developed by WHO-CHOICE to facilitate costing of interventions [19]. The following components were thus included:

Firstly, programme-level costs relate to the resource inputs used in the production of an intervention at a level above that of the patient or providing facility, such as central planning and administration functions, supervision, and training. Estimated quantities of resources required for central planning and administration at national, provincial and district levels were based on a series of evaluations made by WHO-CHOICE costing experts in the different sub-regions and validated against the literature (categories of resource input included personnel, training, materials and supplies, media, transport, maintenance, utilities and capital [19]. We assumed supervision, monitoring and evaluation activities of schools to be conducted by the national and province level. Training costs are an important component of the screening program, and we assumed to train one teacher for 165 school children in the regions under study (following Limburg et al. [13]) (in the sensitivity analysis, we assumed one teacher per 245 children). Training lasts 1 day, and is assumed to be repeated every 5 years. Details are provided in Table 3.

Secondly, patient-level costs relate to resource inputs used in the provision of a given health care intervention. We assumed, that once a child is screened positive, (s)he is referred to a secondary hospital for examination. Following Limburg et al. [13], we assume

Table 3
Program costs of screening of school children in Afr-D (I$)

| | Primary school | | Secondary school | |
|---|---|---|---|---|
| | 5–10 years | 8 years | 11–15 years | 13 years |
| (A) Training costs | | | | |
| Number of children (*A*)[a] | 50,783,503 | 8,333,406 | 36,613,294 | 7,325,180 |
| School enrolment rate (*B*)[b] | 0.62 | 0.62 | 0.30 | 0.30 |
| Number of school children (*C*) = (*A*)[a] × (*B*) | 31,299,379 | 5,136,125 | 22,565,859 | 4,514,726 |
| Teacher to train per number of school children (both primary and secondary) (*D*)[c] | 165 | 50 | 165 | 100 |
| Number of teachers to train (*E*) = (*C*)/(*D*) | 189,693 | 102,723 | 136,763 | 45,147 |
| Cost per teacher to train (I$) (*F*)[d] | 45 | 45 | 45 | 45 |
| Variable training costs in 2000 (*G*) = (*E*) × (*F*) | 8,545,822 | 4,627,726 | 6,161,266 | 7,449,297 |
| Annualised costs (useful life 5 years, 3% discount rate) | 1,866,019 | 1,010,485 | 1,345,341 | 293,761 |
| Training costs over 10-year period | 16,395,049 | 8,878,233 | 11,820,310 | 2,581,019 |
| (B) Other costs (*H*)[d] | | | | |
| Central planning, administration and supervision (*either* primary or secondary school) (*I*) | 26,078,793 | 26,078,793 | 26,078,793 | 26,078,793 |
| Central planning, administration and supervision (*both* primary or secondary school) (*J*) = (*H*) + (*I*)[e] | 37,655,416 | 37,655,416 | 37,655,416 | 37,655,416 |
| Total costs | 42,473,842 | 34,957,026 | 37,899,103 | 28,659,812 |

[a] Sources: WHO-CHOICE website [28].
[b] Source: UNICEF [35].
[c] Source: Limburg et al. [14].
[d] Source: WHO programme costs database [26,28].
[e] In case screening at primary and secondary school is combined, supervision costs double but costs of central planning and administration remain at the same level.

3.6 false-positive children for each true-positive child (in the sensitivity analysis, we assumed a false-positive rate of 2). Limburg et al. used VA < 6/9 as screening criteria, while at present VA < 6/12 is recommended. Costs involved are those of the outpatient visit, the ophthalmic assistant, ophthalmic equipment, of spectacles, and of one follow-up visit. We assumed that the spectacles have a useful life of 4 years, after which the child goes through the same procedure to fit the next spectacles (in the sensitivity analysis, we assumed a useful life of, respectively, 2 and 6 years) (Table 4).

Thirdly, unit costs relate to the prices of programme-level and patient-level resource inputs, such as the salaries of central administrators, the capital costs of offices and furniture, the cost per in- and outpatient visit, or the cost of spectacles (in the sensitivity analysis, we varied costs of spectacles). Data were obtained from a review of literature and supplemented by primary data from several countries, or based on international catalogue prices for, e.g. operation supplies and equipment [19]. For a full overview of all unit costs, see the WHO-CHOICE website [28].

Costs are reported in International Dollars to facilitate more meaningful comparisons across regions (WHO-CHOICE book). The base year is 2000. More details on health facility unit cost estimates are reported in Adam et al. [25] whereas a description on the programme cost estimates, including the costing of various coverage levels as well as the scaling-up of costs to the level of WHO sub-regions, can be found in Johns et al. [26].

### 2.7. Estimating cost-effectiveness

Average cost-effectiveness ratios are calculated for each screening strategy by combining the information

Table 4
Patient costs of screening of school children in Afr-D (I$)

| | |
|---|---|
| Screening at schools | |
| Material costs (tape, cards, etc.)[a] | 10 |
| Treatment at health clinic | |
| (I) Cost of ophthalmic assistant | |
| FTE of ophthalmic assistant per patient (15 min) (*A*) | 0.00016 |
| Annual salary per ophthalmic assistant (*B*)[b] | 7,968 |
| Cost per examined child (*C*) = (*A*)[a] × (*B*) | 1.24 |
| (II) Costs of ophthalmic equipment | |
| Costs of set (*D*)[a] | 4,000 |
| Useful life (years)[a] | 10 |
| Average annual patient load (*E*)[a] | 6,400 |
| Annualisation factor (*F*) | 8.5302 |
| Annualised costs (*G*) = (*D*)/(*E*)/(*F*) | 0.07 |
| (III) Costs of spectacles | |
| Purchase price (*H*)[a] | 5 |
| Useful life of spectacles (years)[a] | 4 |
| Annualisation factor (*I*) | 3.72 |
| Annualised costs (*J*) = (*H*)/(*I*) | 1.35 |
| (IV) Costs of outpatient visits | |
| Ratio of false-positive URE to positive URE[c] | 3.6 |
| Number of visits | 4.6 |
| Costs of visits at secondary hospital level[b] | 4.45 |
| Total costs of outpatient visit (*K*) | 20.45 |
| Annualisation factor (*L*) | 3.72 |
| Annualised costs (*M*) = (*K*)/(*L*) | 5.50 |
| Average annual costs of spectacles, per client (I + II + III + IV) | 8.17 |

[a] Assumptions, based on personal communication with S. Mariotti (WHO), and H. Limburg (author).
[b] WHO-CHOICE prices database [25,28].
[c] Based on Limburg et al. [14].

on the total costs with information on the total health effects in terms of DALYs averted. All costs and effects are discounted at 3%, following standardized WHO-CHOICE analysis [19]. Using a standard approach, we identified the set of interventions a region should purchase to maximize health gain for different budget levels. The order in which interventions would be purchased is called an expansion path and is based on the incremental costs and benefits of each intervention compared to the last intervention purchased.

The Commission on Macroeconomics and Health (CMH) defined interventions that have a cost-effectiveness ratio of less than three times the Gross Domestic Product (GDP) per capita as cost-effective [27]. Based on this, three broad categories are defined here. Interventions that gain each year of healthy life (e.g. DALY averted) at a cost less than the GDP per capita are defined as very cost-effective. Those averting each DALY at a cost between one and three times GDP per capita are cost-effective, and the remainder are not cost-effective. Both univariate and multivariate sensitivity analysis were performed on key parameters to determine the robustness of model results.

## 3. Results

Table 5 shows the number of children treated, costs, effects, and cost-effectiveness of the different screening strategies in the regions considered. The number of children treated varies between regions and screening strategies, and depends on population size, prevalence of URE and the school enrolment rate. In all regions, screening of 11–15 years old leads to the treatment of a higher number of children compared to screening of 5–10 years old, e.g. 0.30 million vs. 0.26 million children in Afr-D. In all regions, screening of schoolchildren at single age-intervals leads to the treatment of fewer children compared to screening at broader age-intervals (e.g. 0.10 and 0.09 million children for 8 and 13 years old, respectively, in Afr-D). Most children are treated when screening takes place at broad age-intervals ad simultaneously at both primary and secondary schools (e.g. 0.43 million in Afr-D).

Screening costs vary between regions and screening strategies, and depend on the number of children screened, the number of children treated, and regional price levels. Screening of broad age-intervals is always more costly than screening of single-age intervals, and simultaneous screening at both primary and secondary school is costing more than screening at either of the schools, but less than the sum of the two individual screening strategies. Costs per child treated range between strategies, e.g. in Afr-D between I$204 (screening of 11–15 years old) and I$450 (screening of 13–years old) (not in table).

Table 5
Costs, effects and cost-effectiveness of screening strategies

| Region | Screening strategy (age-group in years) | Number treated (millions) | Total cost (millions) | DALYs averted (millions) | Cost-effectiveness ratio | Incremental cost-effectiveness |
|---|---|---|---|---|---|---|
| Afr-D | 5–10 | 0.26 | 55.6 | 0.26 | 214 | NA |
| | 11–15 | 0.30 | 52.0 | 0.31 | 165 | 165 |
| | 5–15 | 0.43 | 88.8 | 0.48 | 184 | 219 |
| | 8 | 0.10 | 39.5 | 0.09 | 443 | NA |
| | 13 | 0.09 | 32.8 | 0.09 | 354 | NA |
| | 8 and 13 | 0.24 | 57.5 | 0.17 | 329 | NA |
| Amr-B | 5–10 | 0.86 | 196.7 | 0.90 | 218 | NA |
| | 11–15 | 1.36 | 292.5 | 1.64 | 178 | 178 |
| | 5–15 | 1.62 | 392.8 | 2.05 | 192 | 247 |
| | 8 | 0.43 | 99.5 | 0.39 | 258 | NA |
| | 13 | 0.72 | 140.5 | 0.73 | 193 | NA |
| | 8 and 13 | 1.23 | 213.7 | 1.04 | 206 | NA |
| Eur-A | 5–10 | 0.63 | 395.1 | 0.69 | 576 | NA |
| | 11–15 | 1.09 | 642.8 | 1.40 | 458 | 458 |
| | 5–15 | 1.25 | 823.3 | 1.67 | 492 | 672 |
| | 8 | 0.31 | 213.6 | 0.29 | 734 | NA |
| | 13 | 0.71 | 374.3 | 0.74 | 503 | NA |
| | 8 and 13 | 1.04 | 516.0 | 0.96 | 540 | NA |
| Sear-D | 5–10 | 2.39 | 228.4 | 2.50 | 91 | NA |
| | 11–15 | 3.36 | 256.2 | 3.82 | 67 | 67 |
| | 5–15 | 4.30 | 410.8 | 5.21 | 79 | 111 |
| | 8 | 1.04 | 121.6 | 0.94 | 130 | NA |
| | 13 | 1.26 | 104.4 | 1.28 | 82 | NA |
| | 8 and 13 | 2.65 | 197.9 | 2.11 | 94 | NA |

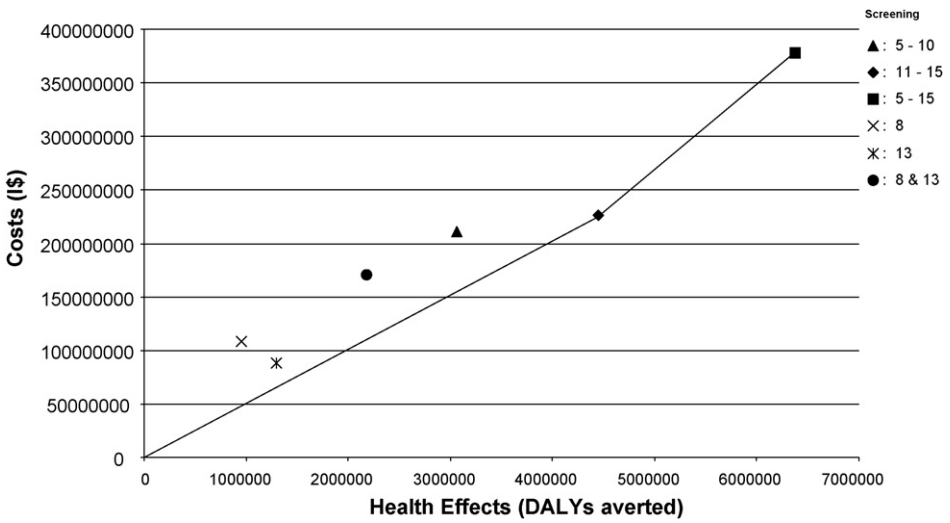


Fig. 1. Expansion path in Sear-D.

Table 6
One-way and multi-way sensitivity analysis of the cost-effectiveness of screening strategies in Afr-D

| Parameter (compared to base-case) | Screening strategy (age group in years) | Total cost (millions) | DALYs averted (thousands) | Cost-effectiveness ratio | Incremental cost-effectiveness |
|---|---|---|---|---|---|
| Primary enrolment 52% (10% decrease) | 5–10 | 59.2 | 239.8 | 247 | NA |
| | 11–15 | 54.0 | 314.6 | 172 | – |
| | 5–15 | 94.1 | 469.5 | 200 | 259 |
| | 8 | 41.7 | 75.9 | 550 | NA |
| | 13 | 33.3 | 92.7 | 359 | NA |
| | 8 and 13 | 60.1 | 162.3 | 370 | NA |
| Primary enrolment 72% (10% increase) | 5–10 | 124.2 | 275.9 | 450 | NA |
| | 11–15 | 119.1 | 314.6 | 379 | – |
| | 5–15 | 188.5 | 493.9 | 382 | 387 |
| | 8 | 96.4 | 103.2 | 934 | NA |
| | 13 | 86.7 | 92.7 | 935 | NA |
| | 8 and 13 | 137.4 | 187.6 | 732 | NA |
| Secondary school enrolment 20 % (10% decrease) | 5–10 | 55.7 | 259.8 | 214 | NA |
| | 11–15 | 48.7 | 238.3 | 204 | 199 |
| | 5–15 | 86.6 | 428.8 | 202 | – |
| | 8 | 39.6 | 89.6 | 442 | NA |
| | 13 | 39.6 | 62.6 | 503 | NA |
| | 8 and 13 | 56.3 | 147.4 | 382 | NA |
| Secondary school enrolment 40% (10% increase) | 5–10 | 55.6 | 259.1 | 214 | NA |
| | 11–15 | 54.5 | 371.1 | 147 | – |
| | 5–15 | 90.5 | 522.7 | 173 | 237 |
| | 8 | 39.5 | 89.1 | 443 | NA |
| | 13 | 34.1 | 122.0 | 280 | NA |
| | 8 and 13 | 58.7 | 201.4 | 291 | NA |
| Spectacles cost I$10 (I$5 increase) | 5–10 | 57.7 | 259.1 | 223 | NA |
| | 11–15 | 54.3 | 314.6 | 173 | – |
| | 5–15 | 92.5 | 482.5 | 192 | 228 |
| | 8 | 40.2 | 89.1 | 451 | NA |
| | 13 | 33.5 | 92.7 | 362 | NA |
| | 8 and 13 | 58.8 | 174.5 | 337 | NA |
| Spectacles cost I$20 (I$15 increase) | 5–10 | 62.1 | 259.1 | 239 | NA |
| | 11–15 | 59.0 | 314.6 | 187 | – |
| | 5–15 | 100.1 | 482.5 | 207 | 245 |
| | 8 | 41.7 | 89.1 | 468 | NA |
| | 13 | 34.9 | 92.7 | 376 | NA |
| | 8 and 13 | 61.6 | 174.5 | 353 | NA |
| Useful life of spectacles 2 years (2 years decrease) | 5–10 | 65.9 | 259.1 | 254 | NA |
| | 11–15 | 63.1 | 314.6 | 201 | – |
| | 5–15 | 106.8 | 482.5 | 221 | 260 |
| | 8 | 43.1 | 89.1 | 483 | NA |
| | 13 | 36.1 | 92.7 | 390 | NA |
| | 8 and 13 | 64.0 | 174.5 | 367 | NA |
| Useful life of spectacles 6 years (2 years increase) | 5–10 | 52.1 | 259.1 | 201 | NA |
| | 11–15 | 48.3 | 314.6 | 153 | – |
| | 5–15 | 82.7 | 482.5 | 171 | 205 |
| | 8 | 38.3 | 89.1 | 430 | NA |
| | 13 | 31.7 | 92.7 | 342 | NA |
| | 8 and 13 | 55.3 | 174.5 | 317 | NA |

Table 6 (*Continued*)

| Parameter (compared to base-case) | Screening strategy (age group in years) | Total cost (millions) | DALYs averted (thousands) | Cost-effectiveness ratio | Incremental cost-effectiveness |
|---|---|---|---|---|---|
| One teacher per 85 children (80 children decrease) | 5–10 | 71.0 | 259.1 | 274 | NA |
| | 11–15 | 63.1 | 314.6 | 201 | – |
| | 5–15 | 115.3 | 482.5 | 239 | 311 |
| | 8 | 39.5 | 89.1 | 443 | NA |
| | 13 | 35.3 | 92.7 | 380 | NA |
| | 8 and 13 | 59.9 | 174.5 | 343 | NA |
| One teacher per 245 children (80 children increase) | 5–10 | 50.2 | 259.1 | 194 | NA |
| | 11–15 | 48.1 | 314.6 | 153 | – |
| | 5–15 | 79.5 | 482.5 | 165 | 187 |
| | 8 | 39.5 | 89.1 | 443 | NA |
| | 13 | 32.0 | 92.7 | 345 | NA |
| | 8 and 13 | 56.6 | 174.5 | 324 | NA |
| Worst case scenario[a] | 5–10 | 91.2 | 239.8 | 380 | NA |
| | 11–15 | 78.4 | 238.3 | 329 | – |
| | 5–15 | 146.8 | 413.8 | 355 | 390 |
| | 8 | 45.5 | 75.9 | 600 | NA |
| | 13 | 38.8 | 62.6 | 620 | NA |
| | 8 and 13 | 69.3 | 134.3 | 516 | NA |

[a] The worst case scenario is simulated with following conditions: primary enrolment of 52% and secondary enrolment of 20%; spectacles cost I$20; useful life of spectacles 2 years; 1 teacher per 85 children.

Health effects also vary between regions and screening strategies, primarily depending on the number of children treated, and therefore follow the same pattern as described above. In all regions, screening of 5–15 years old yields most health effects, followed by screening of 11–15 years old, 5–10 years old, and screening of 1-year age-intervals.

The expansion path shows the order in which interventions should be introduced according to their cost-effectiveness. In all regions, screening of 11–15 years old is the most cost-effective intervention, with the cost per DALY averted ranging from I$67 per DALY averted in Sear-D to I$458 per DALY averted in Eur-A. If more resources are available, policy makers may wish to spend these on extending the screening program to also include 5–10 years old. The incremental cost per DALY averted of screening 5–15 years old ranges between I$111 in Sear-D to I$672 in Eur-A. The above is illustrated in the expansion path for Sear-D (Fig. 1). The expansion path is similar in all regions. The results for all 14 WHO epidemiological sub-regions are presented in Annex Table A.2.

In more absolute terms, both screening of 10–15 years old and 5–15 years old are very cost-effective strategies according to CMH classification, in all regions concerned. For example, Afr-D has a GDP per capita of I$1381 [28], and the cost-effectiveness of both screening strategies is thus well below the one-time GDP per capita level.

Table 6 shows the one-way and multi-way sensitivity analysis for Afr-D for the variables that are either uncertain and/or have a relative large impact on study results. Table 6 shows the estimates of costs, effects and cost-effectiveness of screening strategies following alternative assumptions for (i) compliance in terms of children wearing spectacles; (ii) school enrolment rates; (iii) costs of spectacles; (iv) useful life of spectacles; (v) number of children per teacher trained; (vi) age-patterns of incidence and prevalence rates (the latter not in table). Alternative assumptions did affect absolute levels costs, effects and cost-effectiveness estimates, but all strategies remained very cost-effective according to the CMH classification. The relative cost-effectiveness levels did not change, and the study findings therefore appeared robust to alternative study assumptions (with the exception of assuming a 10% reduction in secondary school enrolment rate which would render screening at secondary schools less cost-effective than screening at primary schools).

## 4. Discussion

Uncorrected refractive error causes a major disease burden among children around the world, and this study has shown that annual screening of school children is an economically attractive intervention to reduce this disease burden. All screening strategies can be labelled as very cost-effective according to the CMH classification [27].

Our results indicate that screening of children of 11–15 years old is more cost-effective than screening of children of 5–10 years old. The higher health effects of screening of children of 11–15 years old, compared to children of 5–10 years old, are mainly due to their higher prevalence of disease. This is not offset by the lower school enrolment rate of secondary schools compared to primary schools. However, cost-effectiveness differences between the two screening strategies are only marginal, and the results are not robust regarding alternative assumptions on school enrolment rate. Hence, our study does not allow us to draw strong conclusions on the economic attractiveness of screening of children at primary vs. secondary school.

Our results also indicate that screening of children at broad age-intervals is always more cost-effective than screening at single-age intervals. However, differences are small. In our analysis, we estimated similar programme costs for both screening strategies, and findings are not robust towards alternative assumptions. Hence, we cannot draw strong conclusions on the economic attractiveness of screening of children at broad-age versus single-age intervals.

This study has presented results in terms of International dollars (I$), to make results comparable within a certain region for countries with different purchasing power. International dollars can be expressed in US dollars (US$), by multiplying them by the factor (1/(official exchange rate/purchasing power parity exchange rate)). For Ghana, this factor equals 0.21 [28] for the year 2000, and the cost-effectiveness of screening of 11–15 years old can hence be considered as either I$165 per DALY averted, or US$35 per DALY averted [28].

The study has a number of limitations. Firstly, the analysis is based on the WHO burden of disease analysis of URE [11], and therefore assesses the cost and effects of screening in addition to current treatment of refractive error in the regions concerned. This also implies that the health effects of screening children who have already been corrected – in terms of re-examination and possibly a more accurate prescription of spectacles – are not included in this analysis. The effects of this are difficult to assess but may be large: more than one-third of children wearing eyeglasses have been found to be under corrected in Malaysia, India and China [29–31]. In addition, the rate in which myopia progresses in selected Asian populations will be such that a large number of children will be under corrected [32–34]. We chose to base our analysis on the epidemiology of URE as only a few studies report on corrected refractive error, i.e. people whose eyes have already been corrected [1–11]. Secondly, in the absence of evidence on the association between refractive error and excess mortality, we assumed no case-fatality related to refractive error. This may have underestimated the resulting health effects. Thirdly, we considered children of 5–10 years to attend primary school and children of 11–15 years to attend secondary schools, but the age of primary and secondary school enrolment may differ in some countries, and results should be interpreted in that respect.

Fourthly, the evaluation of costs of the screening program was limited to health system costs, following WHO-CHOICE standardized methods [19]. On the one hand, this means that costs falling on the education sector, such as the time investments of teachers in the screening program, were not included. It should however not be ignored that any well-functional screening program is dependent on successful intersectoral collaboration between the health and education sector [13,14]. On the other hand, this means that cost savings outside the health system, such as productivity losses and averting reductions in learning capacities have not been included in the analysis. Fifthly, our analysis did not fully comply with WHO-CHOICE standardized methods, that benefits should be followed for the lifetime of the beneficiaries. We included the benefits of wearing spectacles during the time they last, but not the mere knowledge that a child is diagnosed with URE and spectacles may be useful. The latter brings (lasting) benefits to the program that are not fully captured in our analysis, and we may have therefore underestimated its cost-effectiveness. Finally, we used a relative large number of parameter estimates from two studies from Limburg et al. in India [13,14], and it is not sure whether these can readily be extrapolated to other

settings. Sensitivity analyses was performed to reduce this uncertainty.

This paper only presents results for the evaluation of annual screening of school children, and not of, e.g. biannual screening. Although biannual screening will identify the same number of incident cases in comparison to annual screening over a period of 2 years, many of these cases will be identified in a somewhat later stage. Since program costs – in terms of training teachers – remain similar, our analysis indicates that biannual screening will never be as cost-effective as annual screening, and is therefore not an option to consider for policy makers. One should be aware though, that these findings are to a certain extent dependent on the analytical framework. As noted above, the WHO-CHOICE standardized methods excludes costs falling on the education sector. If these costs would be included, it would improve the cost-effectiveness of programs that would screen children, e.g. biannually in comparison to those that screen children annually.

This study has made available crude estimates of costs and effects of screening of school children for refractive error at the world sub-regional level: more detailed estimates can only be made when analyses are contextualised at the country level, taking into account the local socio-economic, epidemiologic and behavioural situation [20]. However, considering the conservative study assumptions and the robustness of study conclusions towards changes in these assumptions, we believe that screening of school children for refractive error remains economically attractive in all regions in the world.

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## Appendix A. Appendix A

See Tables A.1 and A.2 .

Table A.1
Regions used in this study

| Region | Mortality stratum[a] | Countries included |
|---|---|---|
| Africa | D | Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea–Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome And Principe, Senegal, Seychelles, Sierra Leone, Togo |
| Africa | E | Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic Of The Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, Zimbabwe |
| Region of the Americas | A | Canada, United States Of America, Cuba |
| Region of the Americas | B | Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela |
| Region of the Americas | D | Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru |
| Eastern Mediterranean Region | B | Bahrain, Cyprus, the Islamic Republic of Iran, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates |
| Eastern Mediterranean Region | D | Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen |
| European Region | A | Andorra, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom |

Table A.1 (*Continued*)

| Region | Mortality stratum[a] | Countries included |
|---|---|---|
| European Region | B | Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Slovakia, Tajikistan, the Former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Uzbekistan, Yugoslavia |
| European Region | C | Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine |
| South–East Asia Region | B | Indonesia, Sri Lanka, Thailand |
| South–East Asia Region | D | Bangladesh, Bhutan, Democratic People's Republic Of Korea, India, Maldives, Myanmar, Nepal |
| Western Pacific Region | A | Australia, Japan, Brunei Darussalam, New Zealand, Singapore |
| Western Pacific Region | B | Cambodia, China, Lao People's Democratic Republic, Malaysia, Mongolia, Philippines, Republic of Korea, Viet Nam Cook Islands, Fiji, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu |

[a] A = regions with very low adult mortality and child mortality; B = Low adult mortality and low child mortality; C = High adult mortality and low child mortality; D = High adult mortality and high child mortality; E = Very high adult mortality and high child mortality.

Table A.2
Cost-effectiveness of screening strategies, all regions

| Region | Intervention (yearly screened age group) | Number treated (millions) | Total cost (millions) | DALYs averted (millions) | Cost-effectiveness ratio | Incremental cost-effectiveness |
|---|---|---|---|---|---|---|
| Afr-D | 5–10 | 0.26 | 55.6 | 0.26 | 214 | NA |
| | 11–15 | 0.30 | 52.0 | 0.31 | 165 | – |
| | 5–15 | 0.43 | 88.8 | 0.48 | 184 | 219 |
| | 8 | 0.10 | 39.5 | 0.09 | 443 | NA |
| | 13 | 0.09 | 32.8 | 0.09 | 354 | NA |
| | 8 and 13 | 0.24 | 57.5 | 0.17 | 329 | NA |
| Afr-E | 5–10 | 0.31 | 59.1 | 0.31 | 194 | NA |
| | 11–15 | 0.33 | 53.9 | 0.34 | 156 | - |
| | 5–15 | 0.49 | 95.1 | 0.55 | 173 | 201 |
| | 8 | 0.12 | 39.1 | 0.11 | 369 | NA |
| | 13 | 0.10 | 30.5 | 0.10 | 311 | NA |
| | 8 and 13 | 0.27 | 56.5 | 0.20 | 288 | NA |
| Amr-A | 5–10 | 0.63 | 434.5 | 0.69 | 634 | NA |
| | 11–15 | 1.07 | 727.4 | 1.34 | 542 | – |
| | 5–15 | 1.23 | 924.5 | 1.62 | 571 | 711 |
| | 8 | 0.31 | 199.0 | 0.29 | 695 | NA |
| | 13 | 0.68 | 383.5 | 0.69 | 558 | NA |
| | 8 and 13 | 1.01 | 528.4 | 0.90 | 587 | NA |
| Amr-B | 5–10 | 0.86 | 196.7 | 0.90 | 218 | NA |
| | 11–15 | 1.36 | 292.5 | 1.64 | 178 | – |
| | 5–15 | 1.62 | 392.8 | 2.05 | 192 | 247 |
| | 8 | 0.43 | 99.5 | 0.39 | 258 | NA |
| | 13 | 0.72 | 140.5 | 0.73 | 193 | NA |
| | 8 and 13 | 1.23 | 213.7 | 1.04 | 206 | NA |

Table A.2 (*Continued*)

| Region | Intervention (yearly screened age group) | Number treated (millions) | Total cost (millions) | DALYs averted (millions) | Cost-effectiveness ratio | Incremental cost-effectiveness |
|---|---|---|---|---|---|---|
| Amr-D | 5–10 | 0.17 | 31.9 | 0.17 | 184 | NA |
| | 11–15 | 0.25 | 29.1 | 0.29 | 135 | – |
| | 5–15 | 0.31 | 56.8 | 0.37 | 152 | 207 |
| | 8 | 0.08 | 19.4 | 0.07 | 273 | NA |
| | 13 | 0.11 | 20.5 | 0.11 | 180 | NA |
| | 8 and 13 | 0.21 | 32.3 | 0.17 | 190 | NA |
| Emr-B | 5–10 | 0.22 | 66.0 | 0.25 | 267 | NA |
| | 11–15 | 0.39 | 87.0 | 0.49 | 177 | – |
| | 5–15 | 0.45 | 122.6 | 0.60 | 205 | 334 |
| | 8 | 0.10 | 44.5 | 0.10 | 460 | NA |
| | 13 | 0.21 | 53.0 | 0.22 | 241 | NA |
| | 8 and 13 | 0.33 | 80.1 | 0.29 | 272 | NA |
| Emr-D | 5–10 | 0.61 | 81.7 | 0.61 | 134 | NA |
| | 11–15 | 0.84 | 97.0 | 0.94 | 103 | – |
| | 5–15 | 1.10 | 145.9 | 1.29 | 113 | 141 |
| | 8 | 0.24 | 48.5 | 0.21 | 231 | NA |
| | 13 | 0.31 | 49.8 | 0.31 | 161 | NA |
| | 8 and 13 | 0.63 | 81.9 | 0.49 | 166 | NA |
| Eur-A | 5–10 | 0.63 | 395.1 | 0.69 | 576 | NA |
| | 11–15 | 1.09 | 642.8 | 1.40 | 458 | – |
| | 5–15 | 1.25 | 823.3 | 1.67 | 492 | 672 |
| | 8 | 0.31 | 213.6 | 0.29 | 734 | NA |
| | 13 | 0.71 | 374.3 | 0.74 | 503 | NA |
| | 8 and 13 | 1.04 | 516.0 | 0.96 | 540 | NA |
| Eur-B | 5–10 | 0.51 | 108.6 | 0.55 | 196 | NA |
| | 11–15 | 0.89 | 167.3 | 1.13 | 148 | – |
| | 5–15 | 1.03 | 222.3 | 1.36 | 163 | 237 |
| | 8 | 0.24 | 60.1 | 0.22 | 268 | NA |
| | 13 | 0.51 | 88.8 | 0.53 | 167 | NA |
| | 8 and 13 | 0.78 | 129.4 | 0.70 | 184 | NA |
| Eur-C | 5–10 | 0.35 | 96.0 | 0.40 | 238 | NA |
| | 11–15 | 0.73 | 173.7 | 1.01 | 172 | - |
| | 5–15 | 0.82 | 216.3 | 1.16 | 186 | 277 |
| | 8 | 0.16 | 53.5 | 0.15 | 357 | NA |
| | 13 | 0.44 | 96.0 | 0.49 | 195 | NA |
| | 8 and 13 | 0.61 | 127.2 | 0.60 | 211 | NA |
| Sear-B | 5–10 | 0.60 | 88.3 | 0.64 | 137 | NA |
| | 11–15 | 0.93 | 121.2 | 1.13 | 107 | – |
| | 5–15 | 1.13 | 173.9 | 1.44 | 121 | 168 |
| | 8 | 0.30 | 43.6 | 0.27 | 162 | NA |
| | 13 | 0.42 | 49.3 | 0.44 | 112 | NA |
| | 8 and 13 | 0.79 | 84.4 | 0.66 | 127 | NA |
| Sear-D | 5–10 | 2.39 | 228.4 | 2.50 | 91 | NA |
| | 11–15 | 3.36 | 256.2 | 3.82 | 67 | – |
| | 5–15 | 4.30 | 410.8 | 5.21 | 79 | 111 |
| | 8 | 1.04 | 121.6 | 0.94 | 130 | NA |
| | 13 | 1.26 | 104.4 | 1.28 | 82 | NA |
| | 8 and 13 | 2.65 | 197.9 | 2.11 | 94 | NA |

Table A.2 (*Continued*)

| Region | Intervention (yearly screened age group) | Number treated (millions) | Total cost (millions) | DALYs averted (millions) | Cost-effectiveness ratio | Incremental cost-effectiveness |
|---|---|---|---|---|---|---|
| Wpr-A | 5–10 | 0.05 | 53.4 | 0.05 | 1003 | NA |
| | 11–15 | 0.08 | 71.3 | 0.10 | 697 | – |
| | 5–15 | 0.09 | 97.8 | 0.12 | 790 | 1232 |
| | 8 | 0.03 | 36.3 | 0.02 | 1502 | NA |
| | 13 | 0.05 | 47.1 | 0.06 | 847 | NA |
| | 8 and 13 | 0.08 | 68.4 | 0.07 | 937 | NA |
| Wpr-B | 5–10 | 7.74 | 1043.7 | 8.44 | 124 | NA |
| | 11–15 | 12.72 | 1644.9 | 16.15 | 102 | – |
| | 5–15 | 15.02 | 2183.9 | 19.94 | 110 | 142 |
| | 8 | 3.88 | 501.7 | 3.55 | 141 | NA |
| | 13 | 6.53 | 745.7 | 7.01 | 106 | NA |
| | 8 and 13 | 11.19 | 1134.8 | 9.89 | 115 | NA |

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