Global return on investment and cost-effectiveness of WHO's HEAR interventions for hearing loss: a modelling study

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Summary

Background To address the growing prevalence of hearing loss, WHO has identified a compendium of key evidence-based ear and hearing care interventions to be included within countries' universal health coverage packages. To assess the cost-effectiveness of these interventions and their budgetary effect for countries, we aimed to analyse the investment required to scale up services from baseline to recommended levels, and the return to society for every US$1 invested in the compendium.

Methods We did a modelling study using the proposed set of WHO interventions (summarised under the acronym HEAR: hearing screening and intervention for newborn babies and infants, pre-school and school-age children, older adults, and adults at higher risk of hearing loss; ear disease prevention and management; access to technologies such as hearing aids, cochlear implants, or hearing assistive technologies; and rehabilitation service provision), which span the life course and include screening and management of hearing loss and related ear diseases, costs and benefits for the national population cohorts of 172 countries. The return on investment was analysed for the period between 2020 and 2030 using three scenarios: a business-as-usual scenario, a progress scenario with a scale-up to 50% of recommended coverage, and an ambitious scenario with scale-up to 90% of recommended coverage. Using data for hearing loss burden from the Global Burden of Disease Study 2019, a transition model with three states (general population, diagnosed, and those who have died) was developed to model the national populations in countries. For the return-on-investment analysis, the monetary value of disability-adjusted life-years (DALYs) averted in addition to productivity gains were compared against the investment required in each scenario.

Findings Scaling up ear and hearing care interventions to 90% requires an overall global investment of US$238·8 billion over 10 years. Over a 10-year period, this investment promises substantial health gains with more than 130 million DALYs averted. These gains translate to a monetary value of more than US$1·3 trillion. In addition, investment in hearing care will result in productivity benefits of more than US$2 trillion at the global level by 2030. Together, these benefits correspond to a return of nearly US$15 for every US$1 invested.

Interpretation This is the first-ever global investment case for integrating ear and hearing care interventions in countries' universal health coverage services. The findings show the economic benefits of investing in this compendium and provide the basis for facilitating the increase of country's health budget for strengthening ear and hearing care services.

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Introduction

Hearing loss is a global public health challenge. Latest estimates reveal that hearing loss currently affects 1·59 billion people worldwide—ie, 20·3% of the global population—of whom 430 million (5·5%) have moderate or higher severity of hearing loss.[1] By 2050, the number of people with hearing loss is anticipated to reach nearly 2·5 billion, of whom 700 million will require interventions.[2] When unaddressed, hearing loss has a huge negative effect at individual and societal levels. Hearing loss is the third leading cause for years lived with disability worldwide,[3] affecting one's quality of life, communication, cognition, education, employment, and social participation.[4–9] At a societal level, unaddressed

Research in context

Evidence before this study

The only global economic study on hearing loss to our knowledge was undertaken by WHO in 2017 to estimate the societal economic burden of unaddressed hearing loss, which equalled US$750 billion annually. This analysis differed substantially from the present work in terms of scope and the methodology (eg, productivity costs were considered only in countries with full employment, unlike in this study). The current study provides the first-ever global investment case for a recommended set of ear and hearing care interventions that countries can integrate in their universal health coverage service package.

Added value of this study

Our study analysed three different scenarios for upscaling the HEAR compendium of evidence-based interventions: business-as-usual scenario, progress scenario, and ambitious scenario. The ambitious scenario estimates that US$239 billion would be needed to improve the coverage of HEAR to 90% over the next 10 years. Even though this number might seem staggering, the

ambitious scenario requires less than US$45 per person over 10 years in high-income countries and less than US$20 per person in low-income countries. Over a 10-year period, such investment is expected to provide a return of nearly US$15 for every US$1 invested and result in health gains that translate to monetary values of more than US$1·3 trillion and productivity gains of more than US$2 trillion.

Implications of all the available evidence

The HEAR interventions are the first comprehensive compendium of evidence-based interventions promoted by WHO at the global level. This package includes interventions for prevention, identification, management, and rehabilitation of hearing loss and related ear diseases that span the life course and can be directly delivered through the health system in every country. On the basis of health and societal gains, the HEAR package represents an attractive opportunity for policy makers to invest in ear and hearing care.

hearing loss poses a huge economic burden, previously estimated as more than US$750 billion per year globally.[10]

Most people who have hearing loss can successfully benefit from existing and effective interventions. WHO has identified a compendium of key evidence-based interventions required for prevention, screening, diagnosis, and treatment, including rehabilitation of hearing loss and related ear diseases, which can be directly delivered through the health system and are essential to ensure that people have access to ear and hearing care.[1] These interventions cover the whole life course and are summarised under the acronym HEAR, which refers to hearing screening and intervention for newborn babies and infants, preschool and school-age children, older adults, and adults at higher risk of hearing loss; ear disease prevention and management; access to technologies such as hearing aids, cochlear implants, or hearing assistive technologies; and rehabilitation service provision. The effective delivery of these interventions can only be possible through their inclusion within countries' universal health coverage packages.

To integrate the HEAR interventions into their health systems, countries need to first assess the health benefits of such a package for universal health coverage. This assessment will include consideration of the cost-effectiveness of interventions (representing the interventions' value for money), and their budgetary effect. An economic case for HEAR can be used to show the economic benefits of investing in this particular package as part of universal health coverage. It can also facilitate the increase of a country's health budget for strengthening ear and hearing care services, and for a more efficient use of government resources.

We therefore aimed to provide the first-ever global investment case for integrating ear and hearing care interventions in countries as part of their universal health coverage package. More specifically, we aimed to explore the financial investment required between 2020 and 2030 to scale up services from baseline to recommended levels, and the return to society for every US$1 invested in HEAR, including the health effect in disability-adjusted life-years (DALYs) and productivity gains resulting from improved employment opportunities.

Methods

Study design

We did a modelling study in collaboration with the teams at WHO working on the World Report on Hearing,[11] which recommends the implementation of the HEAR interventions by its member states. Inputs were sought from and oversight provided by a group of technical experts representing different WHO regions and income levels. Using the proposed set of interventions, which span the life course and include screening and management of hearing loss and related ear diseases, costs and benefits for the national population cohorts of 172 countries were modelled. These countries and those for which data gaps resulted in exclusion are listed in the appendix (pp 46–56). Country income groups were based on the World Bank country classification.[12]

Perspective, time horizon, and scenarios

Costs and benefits were determined from the health-care perspective and societal perspective separately. The health-care perspective included direct costs to the health system of screening and treatment commodities and human resources. The societal perspective additionally included

See **Online** for appendix

productivity benefits. The timeframe for estimating the return on investment was the 11-year period between 2020 and 2030, corresponding to the Sustainable Development Goals period. The analysis was run for three scenarios: a business-as-usual scenario, representing a continuation of current levels of activity; a progress scenario, in which scale-up reaches 50% of recommended coverage (or remains at baseline coverage if already above 50%); and an ambitious scenario, in which scale-up reaches 90% of the recommended coverage. In most health interventions, a 90% coverage achievement is what can be expected through sustained investment and strict policy implementation. Many countries have achieved 90% coverage for newborn hearing screening,[13] but not for hearing screening and intervention in later life. Hence, achieving 90% coverage is an ambitious goal. The goal of 50% coverage was arrived at through consensus during discussions with experts. This goal was based on trends observed in countries such as the UK where planning for newborn hearing screening started in 1997 and took more than 15 years (between 2001 and 2017) to achieve a coverage of more than 90%. Hence, a target of 50% was considered to be achievable with the political commitment and sustained investment that this Article and the World Report on hearing calls for. This target is also consistent with WHO's approach in other fields, such as the resource requirements and cost-effectiveness estimates for scaling up hepatitis management.

Model structure

A transition model with three states (general population, diagnosed, and those who have passed away) was developed to model the national populations. Individuals transitioned from the general population to the diagnosed population on account of screening activity. Total populations by 1-year age groups and by severity of hearing loss were represented in the model (figure 1). For any country and any year in the model time horizon, the model quantified the number of individuals at different levels of hearing loss, for each age, as well as the number of individuals already screened for or diagnosed with hearing loss. Transition probabilities are a function of national screening rate, national burden of hearing loss, and national background mortality statistics, and are therefore not annotated on figure 1.

Transitions between states of the model were governed by the rate of screening, which is a function of the baseline screening rate and scale-up; the remaining number of unidentified individuals with hearing loss at each age and severity level relative to the size of the screened group; and the background mortality at each age, which defined transitions from all compartments to the dead compartment. National populations by age were sourced directly from the World Population Prospects, and mortality data by 5-year age groups from the same source were rescaled to estimate 1-year mortality rates.[14] Central parameters, their ranges, and data sources for the
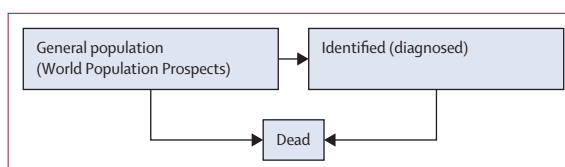

Figure 1: Model structure

model are outlined in table 1. Central equations are provided in the appendix (pp 60–61). The model was coded in R (version 3.6.1).

Interventions and coverage

As the analysis considers HEAR in the context of universal health coverage, the model considers all population segments who might benefit from the HEAR interventions. To determine resource use and outcomes, individuals in the model were screened and managed according to age-specific protocols. WHO screening protocols corresponding to 100% coverage are outlined in the appendix (p 1), and coverage of these screening services were scaled according to the current coverage level. The full protocol consists of screening of all newborns, biannual screening of school age children (5–14 years), annual screening of occupational risk groups in the 15–49-year age group, biannual screening of adults aged 50–69 years, and annual screening of adults aged 70 years or more. Screened individuals were either diagnosed with hearing loss or returned to the population eligible for screening. Additionally, children not covered by screening are managed on a presenting case basis, which could miss out those who develop hearing loss in this age group, but who fail to come into contact with the formal health system. This scenario implies that a small proportion of those in need of care might not be captured by this model. Individuals identified with hearing loss incurred management costs in the year they were diagnosed, and were not considered for further interventions over the time horizon of the model.

The level of baseline coverage of both screening services and interventions, expressed as a proportion of the WHO recommended screening or treatment protocol, was based on expert opinion aligned with WHO coverage assumptions for other non-communicable disease interventions:[15,16] 5% for low-income countries, 10% for lower-middle-income countries, and 15% for upper-middle-income countries across all interventions. Baseline coverage for high-income countries was based on available evidence and expert opinion, and was estimated as 90% for newborn screening,[13] 50% for screening in children aged 5–14 years, 60% for screening in the 15–49-year risk groups, and 20% for remaining interventions (appendix p 57). Correspondingly, the proportion of hearing loss already identified and managed at baseline was assumed to be the same as the baseline screening and treatment coverage, and these individuals were not considered for further screening or interventions.

We did not model specific risk factors for hearing loss within populations, except for the screening of high-risk occupational groups. The occurrence of hearing loss is therefore assumed to be a uniformly distributed random process across the general population, and the efficiency of screening is therefore determined by the ratio of prevalent but unidentified cases of hearing loss to the total screened population. Once an individual is diagnosed with hearing loss, they are no longer screened.

Details about the interventions modelled across the life course along with the commodities and staff time required for these interventions are outlined in the appendix (pp 7–25). Briefly, the compendium of interventions includes the following groups: hearing screening in newborns and infants, pre-school and

	Values	Low estimate	High estimate	Source
Baseline screening and service coverage (all age groups)				Expert opinion[15,16]
Low-income countries	5%	NA	NA	
Lower-middle-income countries	10%	NA	NA	
Upper-middle-income countries	15%	NA	NA	
Baseline screening and service coverage in high-income countries				Expert opinion*
Newborns	90%	NA	NA	
0–1 years	20%	NA	NA	
1–4 years	20%	NA	NA	
5–14 years	50%	NA	NA	
15–49 years	60%	NA	NA	
50–69 years	20%	NA	NA	
≥70 years	20%	NA	NA	
National age-structured populations	Country specific	NA	NA	World Population Prospects[14]
National background mortality by age	Country specific	NA	NA	World Population Prospects[14]
Prevalence of hearing loss by country				GBD 2019[17]
Mild	8·2–24·7%	NA	NA	
Moderate	1·3–7·8%	NA	NA	
Moderately severe	0·4–2·1%	NA	NA	
Severe	0·05–0·3%	NA	NA	
Profound	0·09–0·3%	NA	NA	
Complete	0·06–0·3%	NA	NA	
Disutilities of hearing loss levels				GBD 2019[17]
Mild	–0·01	50% of base case	150% of base case	
Moderate	–0·027	50% of base case	150% of base case	
Moderately severe	–0·092	50% of base case	150% of base case	
Severe	–0·158	50% of base case	150% of base case	
Profound	–0·204	50% of base case	150% of base case	
Complete	–0·215	50% of base case	150% of base case	
Relative reduction in employment rate† for moderately severe to complete hearing loss	25·2%‡	NA	NA	UK Department for Work and Pensions[18]
Adult employment-to-population ratio by age and sex	Country specific	NA	NA	ILO[19]
Unemployment rate by sex and age	Country specific	NA	NA	ILO[20]
Gross domestic product per capita in purchasing power parity	Country specific	NA	NA	World Bank[21]
Duration of treatment benefits	7 years or remaining life expectancy	4 years	10 years	Assumption
Treatment effectiveness				
Hearing aid	Disability level reduced by one level	NA	NA	Expert opinion, aligned with GBD 2019 methodology[22]
Cochlear implants	Complete or profound hearing loss transitions to moderate hearing loss	NA	NA	Expert opinion
Medical management	Mild hearing loss transitions to no hearing loss	NA	NA	Expert opinion
				(Table 1 continues on next page)

	Values	Low estimate	High estimate	Source
(Continued from previous page)				
Unit costs, 2018 US$				
Otoacoustic emissions	0·55	0·55	0·69	Expert opinion*
Auditory brainstem response	1·35	1·35	1·43	Expert opinion*
Hearing aid				
Low power	50	50	306	Expert opinion*
High power	100	100	306	Expert opinion*
Medical management§	0·5	0·25	1	Expert opinion*
Screening otoscope	0	0	0	Expert opinion*
Otoscope	0·01	0·01	0·02	Expert opinion*
Cochlear implant	6011·47	6011·43	6056·75	Expert opinion*
Audiometer	0·05	0·05	0·18	Expert opinion*
Grommet or tympanoplasty	40·18	40·18	90·5	Expert opinion*
Mastoidectomy	11·47	11·43	56·75	Expert opinion*
Tympanometer	0·19	0·19	0·27	Expert opinion*
App screening	0	0	0	Expert opinion*
Screening audiometer	0·03	0·03	0·08	Expert opinion*
Nurse	Level 1	50% of base case	150% of base case	WHO CHOICE[23]
Audiologist	Level 4	50% of base case	150% of base case	WHO CHOICE[23]
Ear, nose, and throat physician	Level 4	50% of base case	150% of base case	WHO CHOICE[23]
Rehabilitation	Level 1	50% of base case	150% of base case	WHO CHOICE[23]
General practitioner	Level 2	50% of base case	150% of base case	WHO CHOICE[23]
Technician	Level 1	50% of base case	150% of base case	WHO CHOICE[23]
Radiologist	Level 3	50% of base case	150% of base case	WHO CHOICE[23]
Radiology technician	Level 1	50% of base case	150% of base case	WHO CHOICE[23]
Anaesthetist	Level 3	50% of base case	150% of base case	WHO CHOICE[23]

Costs of staff types are country-specific and are detailed in the appendix (pp 27–33). Low values of staff costs for the sensitivity analysis are chosen as 50% of the WHO CHOICE value and high values as 150%. GBD 2019=Global Burden of Disease Study 2019. ILO=International Labour Organization. HEAR=hearing screening and intervention; ear disease prevention and management; access to technologies; and rehabilitation service provision. NA=not applicable. *WHO HEAR group, based on country-level expertise and programmatic work. †Percentage of people who are employed. ‡Relative reduction is calculated from employment rate in individuals with difficulty in hearing of 61·1% and employment rate in population without disability of 81·7%;[18] employment rate in population without disability is 81·7%.[18] §Antibiotics for otitis media.

Table 1: Central parameters, unit costs, and low and high estimates for commodities used in HEAR interventions

school-age children, adults at higher risk of hearing loss, and older adults; ear disease identification and management; access to technologies with the objective to improve access to hearing aids, cochlear implants, and related services; and rehabilitation services.

Disease burden

The burden of hearing loss by country was estimated from the Global Burden of Disease Study 2019 (GBD 2019),[3] using the relative prevalence in the GBD 2019 and country populations from the World Population Prospects to estimate the total number of individuals in each category of hearing loss from 2020 to 2030. Categories of hearing loss were mild, moderate, moderately severe, severe, profound, and complete. To account for different burdens and interventions in different age groups, population and burden was modelled in 1-year age groups. Data for disease burden therefore comprised, for each country, the prevalence rate stratified by gender, 5-year age groups (from 0 years to >95 years), and severity level from the GBD 2019.

DALYs and treatment effect

DALYs averted were calculated based on disutilities associated with mild (–0·01), moderate (–0·027), moderately severe (–0·092), severe (–0·158), profound (–0·204), and complete (–0·215) hearing loss.[2] Management of hearing loss results in improvement in disability as detailed in the appendix (pp 2–3). Briefly, individuals receiving hearing aids moved to one lower level of hearing loss disability, those receiving cochlear implants moved from complete or profound to moderate hearing loss disability, and mild hearing loss either remained as mild hearing loss disability if not actively treated, or moved to no disability if treated. Thus, for example, disutility for an individual with moderate hearing loss (–0·027) who receives a hearing aid would improve to one lower level of hearing loss disability, being mild hearing loss (–0·01). This effect would avert 0·017 DALYs per year the individual survives, up to a maximum of 7 years.

We assumed a proportion of mild hearing loss would be due to otitis media or impacted wax; and, of these, a subset of individuals with otitis media would
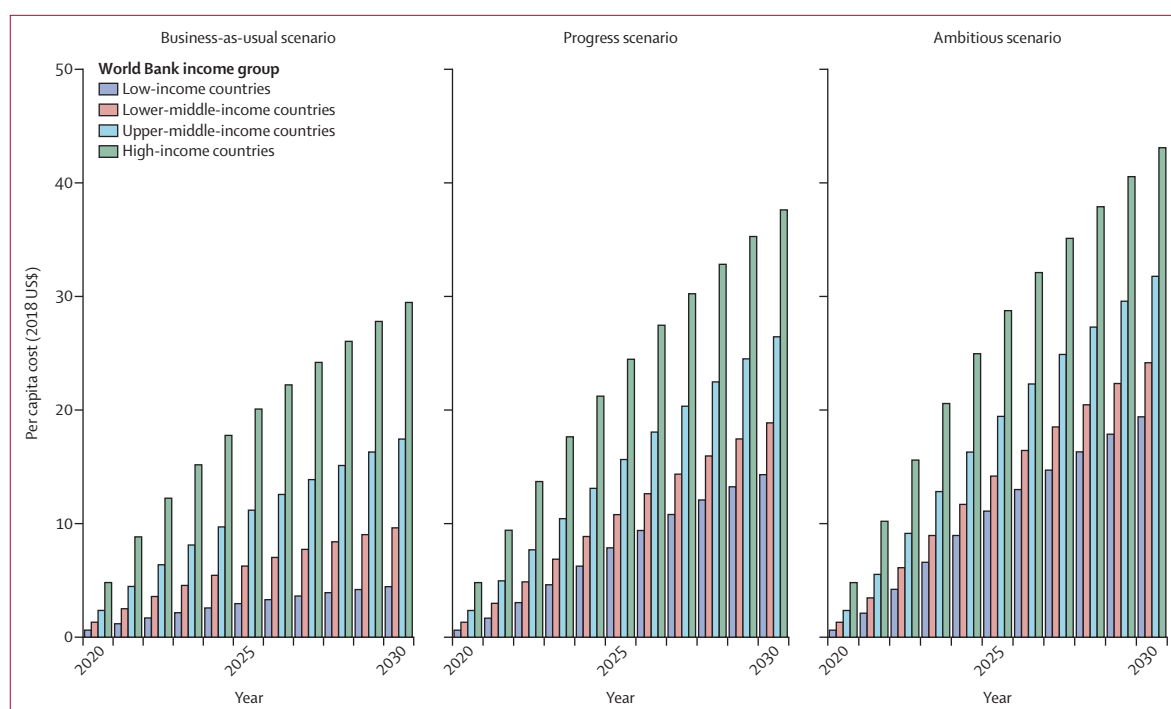
Figure 2: **Cumulative per capita discounted costs of screening and treatment by income level in the business-as-usual scenario, progress scenario, and ambitious scenario**
Progress scenario involves 50% scale-up. Ambitious scenario involves 90% scale-up.

spontaneously recover without treatment. To avoid overestimating a benefit, for the proportion of hearing loss which was treated with medical (non-surgical) management, we therefore estimated 83·5% of cases in children (0–14 years) and 98% of cases in adults (≥15 years) would have a DALY benefit from treatment (appendix pp 2–3). These estimates are based on available evidence[24–26] and expert opinion. All treatments were assumed to yield a benefit for a maximum of 7 years in the base case, except for the 16·5% of mild cases in children and 2% of mild cases in adults, who would recover spontaneously, and individuals who would die before 7 years. 7 years is the approximate useful life of the device in the case of hearing aids and cochlear implants, and considered to be a conservative estimate both for medical management, which averts chronic sequelae of infection, and surgery not requiring implants (eg, mastoidectomy or tympanoplasty).

Treatments for hearing loss confer no survival benefit, so DALYs averted are calculated on the basis of quality of life (disutility) alone. Discounted DALYs averted are calculated for each individual undergoing treatment. DALYs averted are calculated based on the effect of treatment on severity (change in disability level), and duration for which the treatment is effective (7 years). For all treatments initiated, DALY benefits were counted in full regardless of what year treatment was initiated—ie, benefit was not truncated if treatment was initiated near the end of the model time horizon. However, the duration of treatment

effect also took into account mortality, using a life-table approach to avoid over-estimating DALYs for individuals who would die before 7 years. No further DALY benefit is accounted for in individuals who die in the 7 years following a hearing loss intervention. A full illustration of DALY calculations is given in the appendix (p 62).

Direct costs
All costs and benefits are discounted at 3% in the base case in line with the WHO CHOICE approach.[27] All costs are presented in 2018 US$. Gross domestic product (GDP) per capita in purchasing power parity was inflated from the most recently available year to 2018 using the World Bank GDP deflator. The year of most recent GDP data along with details about labour market data is given in the appendix (pp 34–45).

The global unit costs (2018 US$) for interventions included in the analysis are calculated using a bottom-up or ingredients-based approach in line with previous WHO analyses.[16] Unit costs are outlined in table 1, based on detailed commodity costs; useful life of devices and utilisation are further outlined in the appendix (pp 4–6). Staff costs are not included in global unit costs, as individual costs are available for each of the 172 countries modelled. Staff salaries per minute by level were extracted for each country from the WHO CHOICE database to estimate staff costs for each intervention (appendix pp 27–33). Low and high estimates for use in the sensitivity analysis are included.
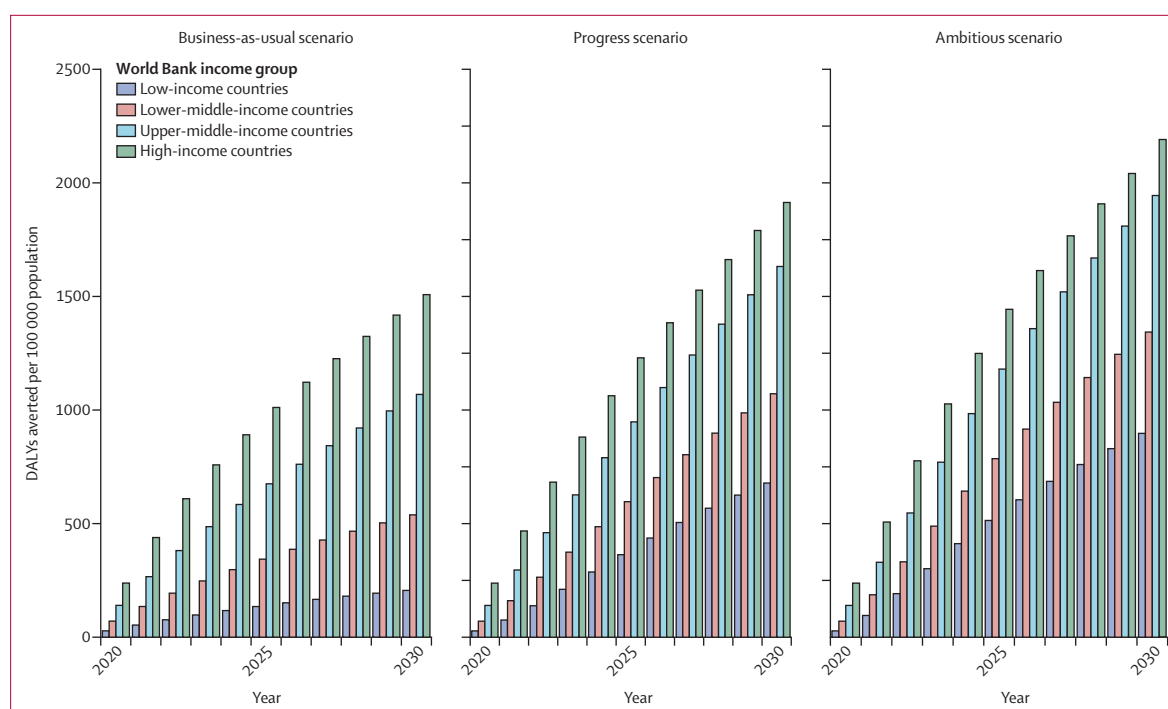
Figure 3: Cumulative DALYs averted per 100 000 population by income level in the business-as-usual scenario, progress scenario, and ambitious scenario
Progress scenario involves 50% scale-up. Ambitious scenario involves 90% scale-up. DALYs=disability-adjusted life-years.

Total cost per intervention is calculated for each intervention using the proportion of the target group receiving the intervention (coverage), unit cost of equipment, and the type, number, and duration of consultations by staff type. Full details are enumerated in the appendix (pp 7–25).

Return on investment was defined as the ratio of the discounted net benefit to costs (total monetised benefits minus total costs, divided by total costs).

Sensitivity analysis
A series of univariate sensitivity analyses were done (rationale and results are shown in the appendix p 58). The analyses examined the relative return-on-investment effect of changes to the level of unemployment above which productivity benefits were quantified (6% cutoff), the WHO CHOICE salary data (50–150% variation), the time horizon for benefits (4–10 years), discount rate (0–5%), disutilities used for DALY calculations (50–150% variation), and costs of commodities (ranges shown in table 1).

Model validation
The model was validated in a three-step process. First, unit tests of the code were done to check the results of central script functions. Second, the logic of the code was independently reviewed by one author (NG) during the coding process. Third, two authors (NG and DT) independently calculated the total avoidable burden of

hearing loss and costs for a sample of countries and compared the results with the model output (appendix pp 63–73).

Results
The cumulative discounted cost of screening and treatment in the three scenarios, expressed as US$ per capita by income group, is shown in figure 2. Overall, the total cumulative cost of the package of hearing loss increases by scenario and by country income group. At current levels of screening and intervention coverage (ie, business as usual), total costs over the model time horizon range from US$4·44 per capita in low-income countries to US$29·47 per capita in high-income countries. In the progress scenario, total costs over the time horizon reach US$14·30 per capita in low-income countries and US$37·62 per capita in high-income countries. In the ambitious scenario, representing 90% coverage of hearing loss services, total costs over the model time horizon are US$19·39 per capita in low-income countries and US$43·10 per capita in high-income countries. The gradient in costs between income levels is driven by higher consultation costs in higher-income countries than in lower-income countries (appendix pp 27–33).

Figure 3 shows the cumulative discounted DALY gains in the three scenarios. At current levels of screening and intervention coverage, DALYs increase over time because of individuals with hearing loss continuously being identified and treated in countries at all income levels.

Higher DALY gains in higher-income countries than in lower-income countries are due to greater levels of service coverage at baseline (appendix p 57). However, DALY gains increase more rapidly in the progress and ambitious scenarios, as a greater proportion of prevalent cases of hearing loss are identified and managed. Over the time horizon of the model, at current levels of screening and intervention, total DALYs averted per 100 000 population range from 206 in low-income countries to 1508 in high-income countries. In the progress scenario, the range is from 679 in low-income countries to 1914 in high-income countries. In the ambitious scenario, scale-up to 90% service coverage results in 898 DALYs averted per 100 000 population in low-income countries, ranging up to 2170 DALYs averted per 100 000 population in high-income countries.

Total cost and total DALYs averted for the progress and ambitious scenarios are shown for comparison in table 2. The effect of the ambitious scenario is approximately twice the amount of DALYs averted in the business-as-usual scenario, although costs of the HEAR interventions are also greater by a similar magnitude. Productivity benefits are almost US$1 trillion higher in

the ambitious scenario than in the business-as-usual scenario.

The return-on-investment results for the ambitious scenario are grouped by the World Bank income groups and are shown in table 3. The total costs of the interventions increase with income level, explained by higher salaries of health-care workers. Similarly, the productivity and monetised health benefits increase by income level, explained by increasing GDP per capita. The return on investment ranges from –0·07 in low-income countries, signifying an estimated cost of implementation that is marginally higher than total benefits, to 36·59 in high-income countries. At a global level, the return on investment of screening and managing hearing loss as outlined in the ambitious scenario is 14·81. From a health system perspective, the average incremental cost-effectiveness ratio (ACER) ranges from US$1633 per DALY averted in upper-middle income countries, to US$2161 per DALY averted in low-income countries in the ambitious scenario. From a societal perspective, which includes productivity benefits, the interventions are dominant in all income groups, except for low-income countries where the societal ACER is US$1159 per DALY averted in the ambitious scenario.

Comparing the costs and outcomes of the ambitious scenario with the business-as-usual scenario, the incremental cost-effectiveness ratios of screening and management of hearing loss are shown in table 4. The additional DALYs gained in the ambitious scenario ranged from over 6 million in low-income countries to more than 28 million in lower-middle income countries. Gains in productivity benefit ranged from more than US$6 billion in low-income countries to more than US$419 billion in high-income countries.

	Total DALYs averted	Total costs of HEAR (US$ million)	Productivity benefits (US$ million)	Monetised DALY benefits (US$ million)
Ambitious scenario	132 981 877	$238 759	$2 425 997	$1 347 913
Progress scenario	110 122 200	$194 942	$2 104 034	$1 152 233
Business-as-usual scenario	67 451 499	$120 058	$1 498 645	$810 395

Costs are given in 2018 US$. DALYs=disability-adjusted life-years. HEAR=hearing screening and intervention; ear disease prevention and management; access to technologies; and rehabilitation service provision.

Table 2: Total costs and benefits across scenarios

	DALYs averted	Costs of HEAR (US$ million)	Productivity benefits (US$ million)	Monetised DALY benefits (US$ million)	ACER (health perspective)*	ACER (societal perspective)†	Return on investment‡
Progress scenario							
Low-income countries	6 116 611	$12 898	$6345	$6119	$2109	$1071	–0·03
Lower-middle-income countries	37 319 524	$65 705	$182 868	$147 043	$1761	–$3139	4·02
Upper-middle-income countries	42 746 278	$69 275	$720 277	$404 064	$1621	–$15 229	15·23
High-income countries	23 939 788	$47 064	$1 194 544	$595 006	$1966	–$47 932	37·02
Total	110 122 200	$194 942	$2 104 034	$1 152 233	$1770	–$17 336	15·70
Ambitious scenario							
Low-income countries	8 090 085	$17 486	$8108	$8078	$2161	$1159	–0·07
Lower-middle-income countries	46 790 337	$84 142	$222 393	$183 835	$1798	–$2955	3·83
Upper-middle-income countries	50 949 302	$83 219	$843 739	$481 285	$1633	–$14 927	14·92
High-income countries	27 152 154	$53 912	$1 351 757	$674 715	$1986	–$47 799	36·59
Total	132 981 877	$238 759	$2 425 997	$1 347 913	$1795	–$16 448	14·81

Costs are given in 2018 US$. ACER=average incremental cost-effectiveness ratio. DALYs=disability-adjusted life-years. HEAR=hearing screening and intervention; ear disease prevention and management; access to technologies; and rehabilitation service provision. *Total costs divided by total DALYs averted. †Total costs minus total productivity benefits, divided by total DALYs averted. In cases where there was a positive DALY gain, and productivity benefits are greater than total costs, the intervention is dominant from a societal perspective. ‡Return on investment was calculated as total monetised benefits (productivity plus monetised DALYs) minus total costs, divided by total costs.

Table 3: Return on investment by World Bank income groups for the progress and ambitious scenarios

	Incremental DALYs	Incremental costs (US$ million)	Incremental productivity benefit (US$ million)	Incremental monetised DALY benefit (US$ million)	Health perspective ICER	Societal perspective ICER
Low-income countries	6 235 396	$13 471	$6227	$6183	$2160	$1162
Lower-middle-income countries	28 045 395	$50 628	$130 548	$109 733	$1805	–$2850*
Upper-middle-income countries	22 960 664	$37 519	$370 980	$216 490	$1634	–$14 523*
High-income countries	8 288 922	$17 047	$419 597	$205 112	$2057	–$48 565*
Total	65 530 378	$118 666	$927 352	$537 518	$1811	–$12 341*

Costs are given in 2018 US$. DALYs=disability-adjusted life-years. ICER=Incremental cost-effectiveness ratio. *Dominant.

Table 4: ICER of the ambitious scenario compared with the business-as-usual scenario

In the sensitivity analysis, except for using a global value for monetising DALYs, none of the analyses resulted in a change in return on investment of more than 50%, except in low-income countries where all parameters except salary multiplier caused the return on investment to change by more than 50%. We note that the return on investment for low-income countries is numerically small (–0·07; table 3), which causes even minor changes to appear relatively large. None of the parameter ranges explored caused the return on investment to become negative, except for the group of low-income countries; however, the lowest return on investment observed in this group was –0·42, signifying that in the worst case, total benefits are 42% lower than total costs. Full details of the sensitivity analysis are provided in the appendix (p 58).

Discussion

In this study, we estimated the total resource requirements for implementing WHO's recommended HEAR interventions across the life course,[11] and we quantified the benefits in terms of DALYs averted and productivity gained from higher participation in the labour market. We estimated that scaling up the provision of HEAR requires a per capita total investment between years 2020 and 2030 of less than US$20 in low-income countries and less than US$44 in high-income countries. This investment would achieve 90% coverage of hearing loss screening and interventions, and avoid almost 133 million DALYs at a global return on investment of 14·81, or US$14·81 of benefit for each US$1 invested. Our estimates for intervention costs in lower-middle-income countries—ie, less than US$20 over 10 years—are proportional to the US$58 per capita annual investment required to finance universal health coverage in this income group,[16] particularly as we do not take into account the integration of HEAR screening and service delivery with broader health system activities, which would yield cost-savings.

The investment case for hearing loss is favourable compared with other interventions. In the case of cancer, a recent economic analysis revealed that every US$1 invested in cancer care in lower-middle-income countries is equivalent to a direct productivity return of US$2·30 and a social return based on both direct productivity and societal gains of US$9·50.[17] A much bigger investment case for prevention and control interventions for non-communicable diseases, known as best buys, showed that for every US$1 invested in scaling up interventions in lower-middle-income countries, a return to society of at least US$7 is to be expected.[18]

Previous analysis has estimated the societal economic burden of unaddressed hearing loss as more than US$750 billion annually. The analysis considered costs to the health-care and education systems resulting from unaddressed hearing loss, estimated globally by using data for the proportion of direct health-care costs attributable to hearing loss. The analysis also considered productivity costs, but only in countries with full employment, and conservatively valued each DALY gained at one-times GDP per capita net of productivity costs.[10] Our approach differs, in that we value productivity benefits in all countries regardless of full employment, and adhere to the most recent recommendations for the valuation of DALYs, which is 1·5-times GDP per capita.[19,20] To avoid double-counting productivity benefits, we subtracted the intrinsic value proportion, valuing each DALY at 0·5-times GDP per capita. Results from our model suggest an even greater avoidable economic burden of hearing loss than previously estimated, with a 90% reduction of the burden of currently unmanaged hearing loss leading to productivity benefits of US$2·4 trillion and monetised DALY benefits of US$1·3 trillion.

Unaddressed hearing loss poses a substantial cost to countries because of its diverse effect on various sectors. The health-care sector bears the burden of high health-care costs for children and adults because of failing to address hearing loss on time. Failing to diagnose and treat hearing loss from a very early age also poses a burden on the education sector due to costs of providing support to children with unaddressed hearing loss at school. Similarly, loss of productivity associated with unemployment and premature retirement among people with hearing loss substantially affects the labour sector. At a societal level, WHO estimates that the result of social isolation, communication difficulties, and stigma associated with unaddressed hearing loss costs societies US$573 billion each year.[10]

When considered separately, the effectiveness and cost-effectiveness of the different components of HEAR have been studied and reported in the literature. For instance, studies from different income settings have shown that implementing a newborn hearing screening followed by early intervention brings substantial advantages in terms of improved developmental outcomes in those receiving the required care.[21–23,28,29] An analysis from China showed that newborn hearing screening and intervention resulted in a long-term cost-benefit ratio of 1 to 7·52 in China,[30] and a study from India estimated life-time savings of more than US$500 000 per child identified with hearing loss.[31] Otitis media, which is a common childhood condition either acute or chronic in nature, as well as impacted wax, can be identified through ear and hearing screening undertaken at the school level so that children can be directed into the health system to receive the care they require.[32] HEAR interventions also refer to risk-based screening for adults followed by diagnosis, provision of hearing technology where needed, and rehabilitation. Typically, this risk-based screening includes adults exposed to occupational noise and those older than 50 years. Identifying and addressing such hearing loss in a prompt manner can potentially reduce the productivity losses related to hearing loss and bring economic gains, as shown by our current analysis.

Screening for hearing loss, however, is most relevant for adults older than 50 years, as hearing loss increases exponentially with age, rising from 24% among those in their early 50s to more than 44% in those aged 70 years.[1] Active screening followed by interventions are relevant in this age group since people, even those living in well resourced settings, commonly wait for years before going for a hearing test or seeking care.[33,34] The 2017 WHO guidelines for the integrated care of older people recommends that screening of hearing loss followed by provision of hearing aids should be offered to older people for timely identification and management.[35] The financial implications and gains of such a service were studied in the UK through a modelling exercise, which showed that although this service increased the overall investment required, it had favourable incremental cost-effectiveness ratio values of around £1000–2000 per quality-adjusted life-year. This UK study reached a conclusion that screening of people older than 55 years could result in a substantial public health gain and is a cost-effective means of improving participation and quality of life for older adults.[36]

An estimated US$239 billion would be needed to improve the coverage to 90% over the next 10 years. Although the numbers might seem staggering, the ambitious scenario requires less than US$45 per person over 10 years in high-income countries and less than US$20 per person in low-income countries. Given the potential health and societal gains, this investment is worth being considered by health policy makers. In addition to financial commitments, provision of the

HEAR interventions can only be achieved when all pillars of the health system are strengthened. This goal includes establishing appropriate, evidence-based policies that address the priorities within each country in a manner most suitable for its health system; ensuring training, availability, and equitable distribution of the relevant health workforce; promoting access to hearing technologies through their inclusion in the country's list of essential assistive products; and integrating appropriate indicators for ear and hearing care within health information systems.

Our study, however, has limitations. Firstly, we account only for staff and commodity costs, but not for programme costs associated with screening interventions (eg, training, logistics, monitoring, and evaluation). Secondly, we do not take into account any reduction in future resource use from intervening early in hearing loss. Thirdly, we assume a limited time horizon for benefits of hearing loss interventions, whereas in reality, several of the interventions modelled here would have lifetime benefits. Fourthly, we assume that individuals identified with hearing loss are treated according to that level of hearing loss only, and do not receive further interventions over the time horizon of the model. Individuals with moderate or higher levels of hearing loss would generally receive management and rehabilitation once, whereas individuals with mild hearing loss due to wax or otitis media could have recurring issues. Returning people with mild hearing loss to the population eligible for screening would marginally decrease the efficiency of screening. By contrast, continued management of individuals with identified hearing loss would lead to an improvement in the overall return on investment for HEAR, as the ratio of benefits to costs would be improved by a relative reduction in the cost of screening. Finally, although we explored the effect of central parameters in a one-way deterministic sensitivity analysis, our analysis does not incorporate the combined parameter uncertainty. Parameters specifically relating to the efficacy of hearing loss interventions in terms of disability level improvement, and the baseline service coverage levels for the 172 study countries, are based on expert opinion from within the WHO HEAR working group in lieu of granular evidence on all 172 countries individually.

In conclusion, investment over a 10-year period is expected to provide a return of nearly US$15 for every US$1 invested and result in health gains that translate to monetary values of more than US$1·3 trillion and productivity gains of more than US$2 trillion. On the basis of health and societal gains, the HEAR package represents an attractive opportunity for policy makers to invest in ear and hearing care.

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