

Global and regional hearing impairment prevalence: an analysis of 42 studies in 29 countries

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Background: Hearing impairment is a leading cause of disease burden, yet population-based studies that measure hearing impairment are rare. We estimate regional and global hearing impairment prevalence from sparse data and calculate corresponding uncertainty intervals. **Methods:** We accessed papers from a published literature review and obtained additional detailed data tabulations from investigators. We estimated the prevalence of hearing impairment by region, sex, age and hearing level using a Bayesian hierarchical model, a method that is effective for sparse data. As the primary objective of modelling was to produce regional and global prevalence estimates, including for those regions with scarce to no data, models were evaluated using cross-validation. **Results:** We used data from 42 studies, carried out between 1973 and 2010 in 29 countries. Hearing impairment was positively related to age, male sex and middle- and low-income regions. We estimated that the global prevalence of hearing impairment (defined as an average hearing level of 35 decibels or more in the better ear) in 2008 was 1.4% (95% uncertainty interval 1.0–2.2%) for children aged 5–14 years, 9.8% (7.7–13.2%) for females >15 years of age and 12.2% (9.7–16.2%) for males >15 years of age. The model exhibited good external validity in the cross-validation analysis, with 87% of survey estimates falling within our final model's 95% uncertainty intervals. **Conclusion:** Our results suggest that the prevalence of child and adult hearing impairment is substantially higher in middle- and low-income countries than in high-income countries, demonstrating the global need for attention to hearing impairment.

Introduction

The Global Burden of Disease (GBD) project aims to produce cause-specific estimates of global mortality, disease burden and risk factors for fatal and non-fatal conditions such as hearing impairment. A key principle of the GBD framework is to make the best possible estimates for every condition and population, producing estimates and corresponding uncertainty intervals even when data are sparse.¹ Hearing impairment data are particularly sparse. This is due to the significant logistic hurdles involved in collection of hearing impairment data, such as the need for a quiet setting for the testing (preferably a soundproof booth).

Despite limited data, it is clear that hearing impairment deserves considerable attention. Using 26 population-based studies of adults worldwide and 12 studies of children, the most recent GBD study estimated that adult onset hearing impairment was the third leading cause of disability.² Childhood hearing impairment can result in reduced ability to communicate, poor language acquisition leading to inability to interpret speech sounds, economic and educational disadvantage and social isolation. While childhood hearing impairment has more serious implications due to its potential for interfering with language acquisition, it is far less common than adult onset hearing impairment.

The analysis described in this article is the result of our efforts to synthesize available data from hearing impairment surveys to

generate new estimates of total hearing impairment for the GBD 2010 study.¹ These estimates were carried out under the guidance of an international Expert Group on Hearing Loss convened for the GBD project. In this study, we first aim to employ appropriate methods for making estimates of hearing impairment prevalence given scarce data; and secondly, to accurately reflect the uncertainty associated with these estimates. We fit a Bayesian hierarchical model to fulfill these goals.

Methods

We estimated hearing impairment prevalence in 2008, in children aged ≥ 5 years and in adults, in 21 GBD subregions (see Supplementary File 2: table S1). We define hearing level as the better ear hearing threshold in decibels averaged over frequencies 0.5, 1, 2 and 4 kHz (dBHL). We estimate the prevalence of six categories of hearing impairment proposed by the GBD Expert Group (table 1) and highlight the prevalence at ≥ 35 dBHL (moderate or worse hearing impairment), the level at which intervention is definitively beneficial.³ Our analysis was carried out in two steps: (i) collection of hearing impairment data, and (ii) use of a statistical model to estimate hearing impairment levels by country, age, sex and hearing threshold.

Table 1 Hearing impairment categories

Hearing impairment category	Better ear hearing level (dBHL)	Hearing in a quiet environment	Hearing in a noisy environment
Unilateral	<20 in the better ear; ≥35 in the worse ear	Does not have problems unless sound is near poorer hearing ear	May have real difficulty following/taking part in a conversation
Mild	20–34	Does not have problems hearing what is said	May have real difficulty following/taking part in a conversation
Moderate	35–49	May have difficulty hearing a normal voice	Has difficulty hearing and taking part in conversation
Moderately Severe	50–64	Can hear loud speech	Has great difficulty hearing and taking part in conversation
Severe	65–79	Can hear loud speech directly in one's ear	Has very great difficulty hearing and taking part in conversation
Profound	80–94	Has great difficult hearing	Cannot hear any speech

Hearing impairment categories used in this analysis are defined using the better ear hearing threshold in decibels averaged over frequencies 0.5, 1, 2 and 4 kHz (dBHL)

Data sources

We considered measured hearing loss data from epidemiological studies identified in a previously published systematic review.⁴ Pascolini and Smith reviewed both the published literature and data that were communicated to the World Health Organization (WHO). They included studies if the sampling strategy, testing methods and definitions were described. Studies were excluded if they had a small sample size, a response rate <80% or were not representative of the population sampled. In addition, the authors excluded studies that did not report the thresholds and frequencies measured, location of the testing, background noise levels or descriptions of the audiometric testing and otological examinations. Pascolini and Smith identified 50 studies carried out in 31 countries, of which we excluded 12 for methodological reasons: three studies did not measure hearing in a random sample, for example by using a screening questionnaire to select participants for measurement; two presented data only on ethnic minorities; six did not report hearing loss for the better ear; and one did not sufficiently describe sampling methods.

In order to obtain detailed data for specific age, sex and hearing thresholds, we sent requests to investigators identified in Pascolini and Smith's review for tabulations of the study data. We also asked these investigators to provide information on hearing aid use by hearing level, and to refer us to other unpublished data sources. Detailed tabulations were collected from 11 studies, representing 10 countries. In addition, 12 new studies, representing 7 countries, were personally communicated to us.

We extracted information on prevalence of hearing impairment in the better ear, disaggregated by age, sex, hearing level, as well as the proportion of individuals using a hearing aid, by hearing level, age and sex. Since hearing loss is highly age dependent, strong assumptions about the age groups that comprise the sample are necessary to include prevalences measured in wide age groups (e.g., adults >40 years of age). We therefore excluded survey data from the analysis for which age ranges were >15 years. This excluded 41 of 1874 data points, eliminating 6 surveys. Finally, measuring low levels of hearing impairment accurately is difficult in settings with background noise. For studies that collected data without using a soundproof room, we excluded prevalence data measuring hearing impairment <25 dBHL. We additionally eliminated data from school-based studies that measured hearing impairment <40 dBHL, as schools are a particularly noisy environment.⁵ As a result, two additional studies on schoolchildren were excluded.

Analysis framework and model selection criteria

We used Bayesian hierarchical logistic regression to estimate hearing impairment prevalence for each country–age–severity unit.^{6,7} Prevalence data are geographically nested: a single survey is conducted in a specific subregion; subregions are part of a wider

geographical region; and several regions make up the globe. We used statistical hierarchy to reflect this nesting: a hierarchical model allows regional estimates to be informed both by survey data from that region and by survey data from other regions. The relative weight given to the data from the same region vs. from other regions is informed by the availability and consistency of the within-region data compared with the availability and consistency of data from other regions.

In estimating health parameters, there are a large number of potential covariates, and a combinatorial number of potential interactions. We aimed to follow a principled procedure for choosing among these candidate models to specify a predictive model that makes valid estimates using sparse data, including for those areas with limited survey data. For the purposes of model selection, we defined the best model to be the one with the highest predictive validity, that is the one giving the most accurate estimates for areas without data while accurately reflecting the estimates' large uncertainty. We used cross-validation to evaluate candidate models' predictive validity. For each of 10 non-overlapping 'validation sets' comprising 10% of countries with data, we fitted each candidate model to the remaining 'training set' and used the resulting model to predict prevalences for each country–age–sex–severity group in the validation set. The differences between these predicted prevalences and the known-but-held-out prevalences were used to calculate the average median relative error and validation data that fall within their 95% prediction interval.

For some regions, particularly in sub-Saharan Africa, we had very little survey data. Some models that we evaluated predicted unusual prevalences (compared with available survey data) in regions with little data. Since data were so sparse in these regions, the unusual prevalences were not penalized in the cross-validation analysis. Therefore, we excluded from consideration those models that yielded predicted prevalences >20% higher or lower than the highest or lowest observed prevalence, respectively.

We evaluated the following model specifications: (i) all two-way interactions among hearing threshold, sex and age; (ii) specifying the age effect using a three-knot linear spline, a two-knot linear spline or using higher order terms; (iii) including higher order threshold terms; (iv) using the natural logarithm of GNI per capita, mean years of education, and percent of national population living in urban areas as country-level covariates; and (v) specifying a linear time trend.

Final model

Using the above method to select among models, we selected a model with the following characteristics (see Supplementary File 1):

- a subregion-specific offset parameter for each of the 21 GBD subregions, modelled hierarchically to be nested in eight world

regions (shown in Supplementary File 2: table S1), which in turn shared a global prior;

- a two-knot linear age spline to capture non-linear age patterns;
- linear and quadratic terms for hearing impairment level (dBHL), allowing for modelling of hearing impairment at any threshold;
- a continuous sex variable, modeled as the percent of the sample population that was female.

We fit our model with a Markov chain Monte Carlo (MCMC) algorithm, as implemented in Python with the PyMC statistical package.⁸ Samples from the posterior distribution of model parameters were used to calculate hearing impairment prevalence predictions and their uncertainty intervals, estimated as the 2.5–97.5 percentiles of the posterior distribution of prevalence.

Although our model could be used to predict hearing impairment in children <5 years of age, we did not consider these predictions reliable as hearing impairment in pre-lingual children is typically not assessed in school-based or household surveys. Therefore, we present results for children aged 5–14 years and for adults age ≥ 15 years. The prevalence of adult hearing impairment may vary due to differences in a region's age structure (that is, a higher proportion of older adults in Europe vs. in developing regions) or due to differences in age-specific hearing impairment prevalence. For presentation, we age-standardized prevalences using the WHO reference population.⁹ We also calculate unstandardized prevalences, which reflect the proportion of each region's population with a hearing impairment in 2008.

Hearing aid coverage

We modelled data on current hearing aid use, by hearing impairment level, from high-income countries using a logistic regression. Our final model accounted for improvements in coverage over time (see Supplementary File 1). Calculations were carried out using Stata version 10.1.

Results

In our final analysis data set, we included 42 studies carried out between 1973 and 2010 in 29 countries (see Supplementary File 2: table S2). Eighteen studies were in high-income countries and 24 in low- or middle-income countries. Thirteen studies only considered

children and adolescents <20 years of age, while 12 tested only adults and 17 reported data for subjects of all ages. Age-specific data on adults in low- and middle- income countries were particularly sparse: only 12 studies reported this type of information. These studies were carried out in Brazil (two studies), China, Ecuador, India, Indonesia, Madagascar, Myanmar, Nigeria, Oman, Sri Lanka and Vietnam; study years ranged from 1995 to 2010. No data were located from the Central and Eastern Europe and Central Asia region. We identified more than one data source from few countries: two studies on child hearing impairment were available for one high-income (USA) and three developing countries (Brazil, Nigeria and Tanzania), while for adults, more than one data source was available for seven countries (Australia, Brazil, Finland, Norway, Sweden, the UK and the USA). When more than one data source was available from a country, they were often not comparable because of differences in geographic coverage. We additionally obtained data from eight studies that recorded hearing aid coverage by hearing level, of which one was from Brazil and the remainder were from high-income countries.

In cross-validation analyses, most country-level covariates tested performed worse than a simpler model excluding covariates. The exceptions were log of GNI per capita and mean adult years of education. However, using these covariates resulted in predictions of hearing impairment prevalences 2–3 times higher than the highest observed study values in some sub-Saharan African countries, which we considered implausible. Therefore, we selected a model that did not use country-level covariates to make predictions. Our final model exhibited good external validity, with 87% of measured estimates falling within our final model's 95% uncertainty intervals. The median relative error was 85%.

Hearing impairment prevalence increased with age (figure 1) and was higher among males than females. The global prevalence of hearing impairment ≥ 35 dBHL among children 5–14 years of age was 1.4% (95% uncertainty interval 1.0–2.2%). Hearing impairment was greater for males than females; globally, the prevalence of hearing impairment ≥ 35 dBHL for males aged ≥ 15 years was 12.2% (9.7–16.2%), whereas for females aged ≥ 15 years it was 9.8% (7.7–13.2%).

The prevalence of mild hearing impairment was 22.7% (19.8–25.7%) for adult males and 19.0% (16.4–21.8%) for adult females (table 2).

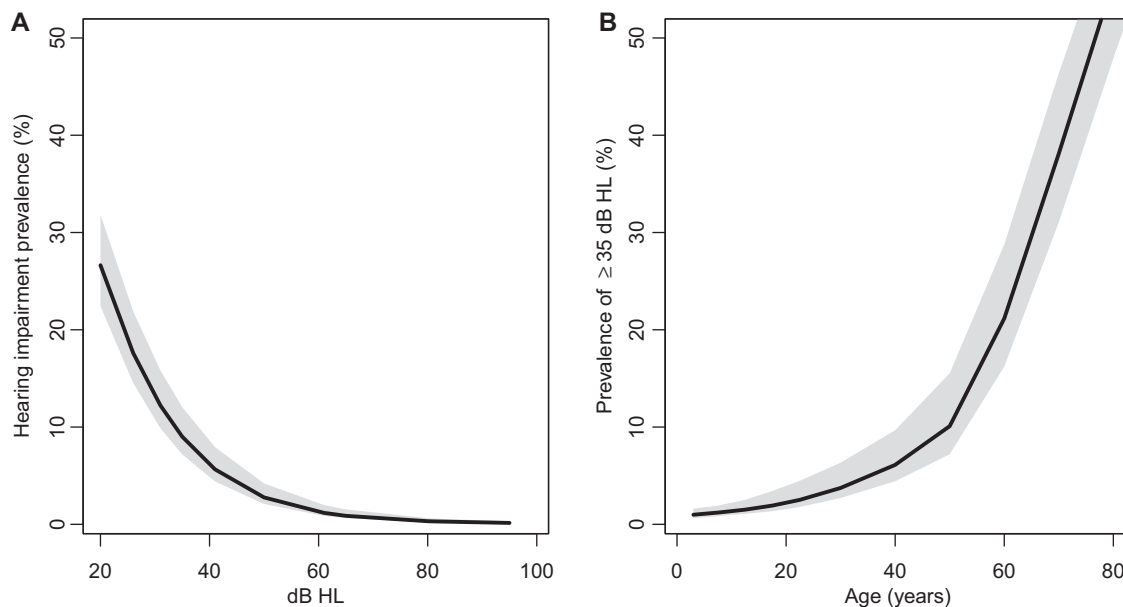


Figure 1 Global pattern of hearing impairment (A) by hearing threshold and (B) by age. Panel (A) shows age-standardized cumulative prevalence, that is, prevalence of hearing impairment at each threshold and at higher thresholds. Solid lines show central estimates and shaded areas show 95% uncertainty intervals

Table 2 Prevalence of hearing impairment by region and impairment category, 2008

Region	Population (1000s)	Mild (20–34 dBHL)	Moderate (35–49 dBHL)	Moderately severe (50–64 dBHL)	Severe (65–79 dBHL)	Profound (80–94 dBHL)	Complete (≥ 95 dBHL)
Males, ≥ 15 years (%)							
High-income region	387 609	16.8 (14.9–19.3)	5.8 (4.9–7.2)	1.6 (1.3–2.2)	0.4 (0.3–0.6)	0.1 (0.1–0.2)	0.1 (0.1–0.2)
Central/Eastern Europe and Central Asia region	155 901	23.8 (8.7–33.5)	9.6 (2.2–26.6)	3.1 (0.5–14.3)	0.9 (0.1–6.4)	0.3 (0.0–2.7)	0.2 (0.0–2.8)
Sub-Saharan Africa region	232 208	24.1 (19.3–28.8)	8.3 (6.0–10.9)	2.5 (1.7–3.5)	0.7 (0.5–1.1)	0.2 (0.1–0.3)	0.2 (0.1–0.3)
Middle East and North Africa region	154 985	16.4 (10.1–25.3)	4.9 (2.6–9.0)	1.3 (0.6–2.8)	0.4 (0.2–0.8)	0.1 (0.0–0.3)	0.1 (0.0–0.2)
South Asia region	543 896	26.9 (20.1–33.4)	10.2 (6.6–15.6)	3.2 (1.8–5.5)	1.0 (0.5–1.9)	0.3 (0.2–0.6)	0.3 (0.1–0.6)
Asia Pacific region	212 693	25.5 (20.8–30.1)	9.4 (7.0–12.6)	2.9 (2.0–4.3)	0.9 (0.6–1.4)	0.3 (0.2–0.4)	0.2 (0.1–0.4)
Latin America and Caribbean region	200 837	22.5 (16.9–28.1)	8.2 (5.6–11.8)	2.6 (1.6–4.1)	0.8 (0.4–1.4)	0.2 (0.1–0.5)	0.2 (0.1–0.4)
East Asia region	556 140	22.7 (14.9–30)	8.2 (4.4–13.5)	2.5 (1.1–4.8)	0.7 (0.3–1.6)	0.2 (0.1–0.5)	0.2 (0.1–0.4)
World	2 444 268	22.7 (19.8–25.7)	8.4 (6.8–10.6)	2.6 (2.0–3.7)	0.8 (0.6–1.2)	0.2 (0.2–0.4)	0.2 (0.1–0.4)
Females, ≥ 15 years (%)							
High-income region	408 794	15 (13.3–17.2)	5.3 (4.4–6.6)	1.4 (1.1–2.0)	0.4 (0.3–0.5)	0.1 (0.1–0.2)	0.1 (0.1–0.1)
Central/Eastern Europe and Central Asia region	178 626	21.6 (8.7–31.4)	9.2 (2.2–23.7)	3.0 (0.5–13.2)	0.9 (0.1–6.1)	0.3 (0.0–2.6)	0.2 (0.0–2.8)
Sub-Saharan Africa region	238 564	19.6 (15.3–23.9)	6.4 (4.6–8.5)	1.8 (1.2–2.6)	0.5 (0.3–0.8)	0.2 (0.1–0.2)	0.1 (0.1–0.2)
Middle East and North Africa region	148 927	12.8 (7.7–20.4)	3.7 (1.9–6.9)	0.9 (0.4–2.0)	0.2 (0.1–0.6)	0.1 (0.0–0.2)	0.1 (0.0–0.1)
South Asia region	515 635	22.3 (16.2–29.4)	7.8 (5.0–12.2)	2.4 (1.3–4.2)	0.7 (0.4–1.3)	0.2 (0.1–0.4)	0.2 (0.1–0.4)
Asia Pacific region	219 241	21.2 (16.9–25.8)	7.5 (5.5–10.2)	2.3 (1.5–3.3)	0.7 (0.4–1.0)	0.2 (0.1–0.3)	0.2 (0.1–0.3)
Latin America and Caribbean region	210 768	18.5 (13.7–24.1)	6.6 (4.4–9.6)	2.0 (1.2–3.3)	0.6 (0.3–1.1)	0.2 (0.1–0.4)	0.2 (0.1–0.3)
East Asia region	531 769	18.6 (12.1–26.1)	6.4 (3.4–10.7)	1.9 (0.8–3.7)	0.5 (0.2–1.2)	0.2 (0.1–0.4)	0.1 (0.1–0.3)
World	2 452 325	19.0 (16.4–21.8)	6.8 (5.5–8.6)	2.0 (1.5–3.0)	0.6 (0.4–1.0)	0.2 (0.1–0.4)	0.2 (0.1–0.3)
Children, 5–14 years (per 1000)							
High-income region	111 951	17 (12.4–25)	2.7 (2.0–4.0)	0.5 (0.4–0.8)	0.1 (0.1–0.2)	0.0 (0.0–0.1)	0.0 (0.0–0.0)
Central/Eastern Europe and Central Asia region	46 745	51.8 (6.8–319.1)	8.6 (1.1–97)	1.7 (0.2–21.8)	0.4 (0.0–5.4)	0.1 (0.0–1.6)	0.1 (0.0–1.3)
Sub-Saharan Africa region	216 405	70.9 (46.4–103.5)	12.2 (7.6–18.9)	2.4 (1.5–3.7)	0.6 (0.4–0.9)	0.2 (0.1–0.3)	0.1 (0.1–0.2)
Middle East and North Africa region	87 037	32.3 (14.5–76.1)	5.2 (2.3–13)	1.0 (0.4–2.6)	0.2 (0.1–0.6)	0.1 (0.0–0.2)	0.1 (0.0–0.1)
South Asia region	339 896	82.5 (45–151.4)	14.3 (7.4–29.7)	2.8 (1.4–6.0)	0.7 (0.3–1.4)	0.2 (0.1–0.4)	0.2 (0.1–0.3)
Asia Pacific region	112 290	69.4 (45–106.6)	11.8 (7.3–19.1)	2.3 (1.4–3.8)	0.6 (0.3–0.9)	0.2 (0.1–0.3)	0.1 (0.1–0.2)
Latin America and Caribbean region	110 179	53.9 (29.7–96.3)	8.9 (4.7–17.1)	1.7 (0.9–3.4)	0.4 (0.2–0.8)	0.1 (0.1–0.2)	0.1 (0.1–0.2)
East Asia region	192 131	45.7 (19.3–98.3)	7.5 (3.0–17.4)	1.5 (0.6–3.4)	0.3 (0.1–0.8)	0.1 (0.0–0.2)	0.1 (0.0–0.2)
World	1 216 633	62.2 (46.1–88.1)	10.7 (7.7–16.9)	2.1 (1.5–3.4)	0.5 (0.4–0.8)	0.1 (0.1–0.2)	0.1 (0.1–0.2)

Prevalence of hearing impairment in 2008 by region, impairment category and demographic group, with 95% uncertainty intervals in parentheses

Values are not age-standardized (age-specific prevalences are reported in Supplementary File 2: table S3). Percentages are reported for adult males and females; rates per 1000 are reported for children.

The corresponding prevalences of moderate hearing impairment were 8.4% for adult males (6.8–10.6%) and 6.8% for females (5.5–8.6%), and of moderately severe hearing impairment were 2.6% (2.0%–3.7%) for males and 2.0% (1.5–3.0%) for females. The prevalence of severe hearing impairment was 0.8% (0.6–1.2%) for adult males and 0.6% (0.4–1.0%) for females. Profound and complete hearing impairment have a combined global prevalence of 0.5% (0.3–0.8%) for adult males and 0.3% (0.2–0.7%) for females. Globally, we estimate that 92.4% (89.1–94.4%) of children and 68.1% (62.0–73.1%) of adults have unilateral or no hearing impairment.

After adjusting for differences in age structure, the prevalence of adult hearing impairment was highest in developing regions and lowest in high-income regions (figure 2). Age-standardized hearing impairment ≥ 35 dBHL for adults aged ≥ 15 years ranged from 4.9% in high-income countries (4.0–6.4%) to 15.7% in sub-Saharan Africa region (11.5–20.3%) and 17.0% in the South Asian region (11.0–26.2%). Adult males in South Asia had the highest prevalence of impairment: 19.2% (12.7–29.6%). Mild, moderate, severe, profound and complete hearing impairment were modeled to have the same geographic pattern.

The posterior probability that the high-income region's age-standardized prevalence was lower at all hearing loss thresholds than the sub-Saharan African, South Asian, Asia Pacific and Latin American and Caribbean regions was >0.99 ; the probability that it was the lowest of all regions was 0.82. We estimated that the age-standardized prevalence of hearing impairment ≥ 35 dBHL was 4 (2.3–6.6) times higher in South Asia than in high-income regions.

We estimate 299 million men (237–397 million), and 239 million women (189–325 million) have hearing impairment ≥ 35 dBHL. Calculating prevalence as the number impaired over the total population, the lowest prevalence of hearing impairment ≥ 35 dBHL among adults ≥ 15 years was in the Middle East and North Africa region (5.9%, 3.0–11.5%) and the high-income regions (7.7%, 6.4–9.8%). The greatest percentage of adults with hearing impairment ≥ 35 dBHL was in the South Asian region (13.2%, 8.1–21.4%) and Central/Eastern Europe and Central Asian region (13.9%, 2.9–51.0%).

Prevalence of hearing impairment ≥ 35 dBHL among children aged 5–14 years was highest in South Asia (2.2%, 1.1–4.7%), sub-Saharan Africa (1.9%, 1.2–3.0%) and in the Asia Pacific region (1.8%, 1.2–3.0%). Child hearing impairment was lowest in the high-income regions, at 0.4% (0.3–0.6%). We estimate 16 million (12–26 million) children have a hearing impairment ≥ 35 dBHL.

In high-income countries, use of a hearing aid was most common among those with profound hearing loss and increased over time (see Supplementary File 2: table S4). Coverage was estimated to increase from 6% (5–7%) among those with mild hearing impairment to 89% (83–93%) among those with profound hearing impairment. Among those with complete hearing impairment, for whom a hearing aid is unlikely to be effective, 62% (49–74%) had a hearing aid. In the high-income region, 40 million (35–47 million) adults use a hearing aid, of whom 26 million have hearing impairment ≥ 35 dBHL (22–34 million, corresponding to 43% of those with hearing impairment ≥ 35 dBHL).

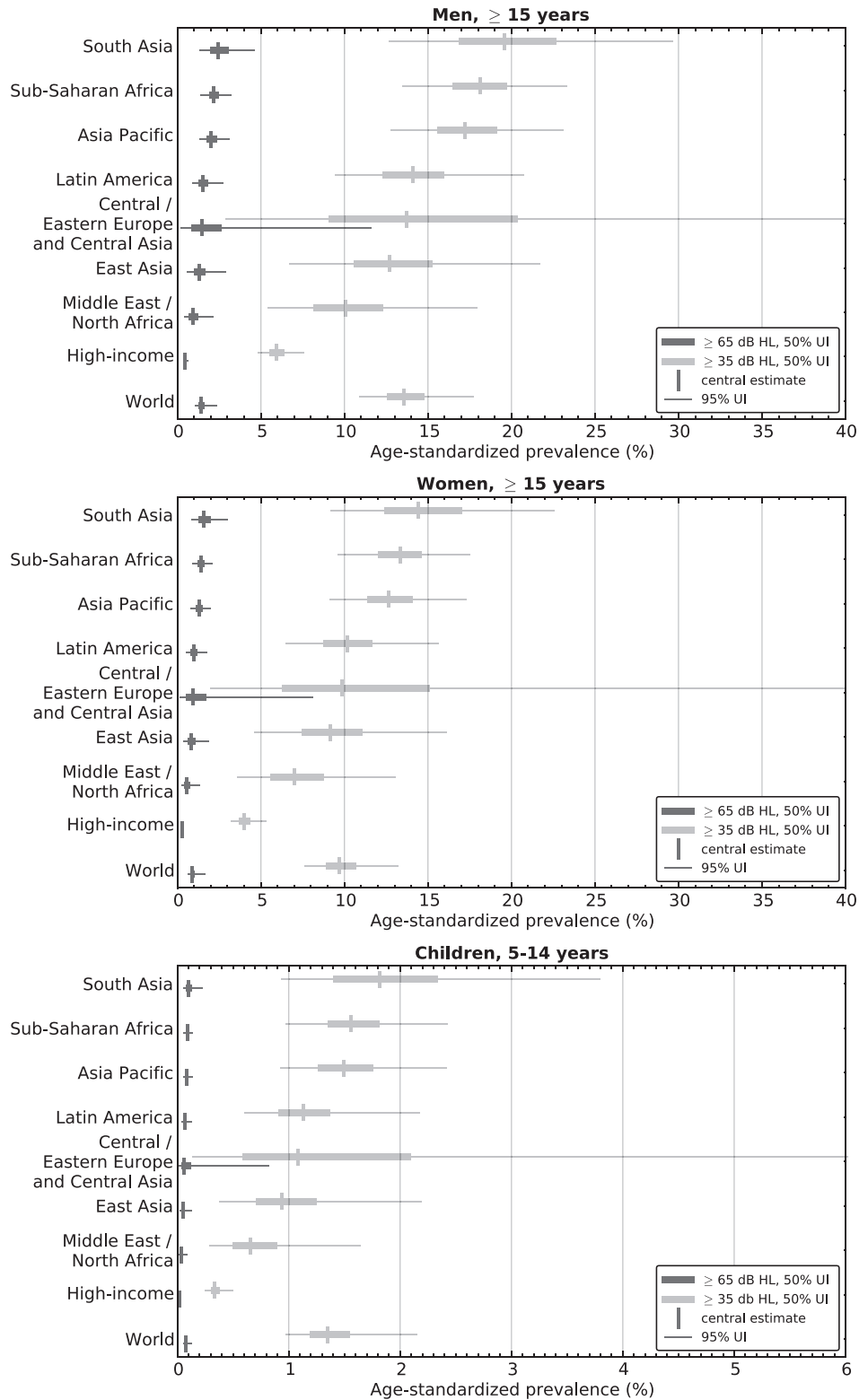


Figure 2 Age-standardized prevalence of hearing impairment, 2008. Age-standardized prevalence of hearing impairment by region, men ≥15 years, women ≥15 years and children 5–14 years of age. UI, uncertainty interval

Discussion

We found very high prevalences of adult hearing impairment in low-income regions, especially in sub-Saharan Africa and in South and Southeast Asia; childhood onset of hearing impairment was also higher in these regions than other regions. Our estimates of adult hearing impairment were consistent with the survey data from India, Indonesia, Madagascar, Myanmar, Nepal, Sri Lanka and Vietnam

(however, we estimated higher hearing impairment prevalences than were reported in Nigeria). Some studies have indicated that the higher rates of moderate and moderately severe hearing impairment in developing countries may be partially explained by impacted wax and otitis media and its sequelae (Mackenzie I, unpublished report).^{10,11} Excess severe hearing impairment among children and adults in developing countries may have been caused by higher rates of pre- and post-natal childhood infections such as

rubella, measles and meningitis and from the use of ototoxic drugs.¹² Further research is needed to confirm the causes of moderate and severe adult hearing impairment in low-income regions.

We also estimated hearing aid use in high-income countries. We did not have sufficient data to estimate hearing aid use in developing countries, but suspect that coverage is small to negligible: one study in Brazil did not identify anyone who used a hearing aid, and combining our data with data on hearing aid production indicates that, relative to need, few hearing aids are sold in developing countries.^{13,14} A primary obstacle to hearing aid provision in developing countries is their cost.¹⁴ There is likely a large unmet need for innovative interventions including low-cost hearing aids in developing countries.

Strengths of this study include the use of population-based studies of measured hearing impairment, and the use of a Bayesian hierarchical model to estimate the prevalence of hearing impairment, including its uncertainty, from studies reporting hearing impairment defined with a variety of hearing thresholds. Hierarchical modeling compromises between using only data from one region vs. combining data from all regions, to make estimates for that region. This feature is particularly helpful in modeling hearing impairment prevalence where the data is extremely sparse. Further, our use of a Bayesian model leads to a natural representation of uncertainty, which allows for coherent inference on a variety of quantities of interest, including formal calculation of uncertainty. Finally, the formal incorporation of level of hearing impairment into our model allowed us to fit our model using hearing impairment data, regardless of reporting category, and to predict the prevalence of hearing impairment for a range of categories.

The main limitation of our model was the sparse data that we obtained. As a result of this scarcity, we did not estimate time trends in hearing impairment prevalence. Data on adults were available for high-income regions from 1973 to 2005, including several countries with more than one data source, but for other regions data were only available from 1995 or later. When included in our model, our estimates of time trends were unstable, and the cross-validation performance deteriorated. While we suspect that age-standardized hearing impairment prevalences may have changed over time due to secular health improvements and/or changes in occupational exposures, our data were not sufficient to quantify those changes for all world regions.

We initially aimed to use cross-validation as the sole model selection criteria. However, we found that generating plausible out-of-sample predictions was challenging. We attempted to use a variety of development-related covariates, but found that the covariates either worsened cross-validation performance, or resulted in implausible predicted levels of hearing impairment in the countries with covariate values corresponding to low developmental levels. We hypothesize that worse cross-validation performance may be due to difficulties in specifying the correct functional form of the covariate relationships while the unlikely out-of-sample predictions may suggest cross-regional variability in these relationships. Cross-validation did not penalize models with unlikely out-of-sample predictions due to the lack of data in these countries. This demonstrated the limits of sophisticated modeling and model selection techniques when data are extremely sparse, and specifically, the need for additional population-based surveys measuring adult hearing impairment in sub-Saharan Africa and other developing regions.

We estimated the global and regional prevalence of hearing impairment, including its uncertainty. Hearing impairment prevalence is positively related to age, male sex, and middle- and low-income regions; our estimates are quite uncertain in many regions due to sparse data. Our estimates represent a first effort to quantify requirements for interventions that reduce the disability associated with hearing impairments. We found that repeated studies of hearing impairment prevalence are needed, particularly in the regions where this disabling condition is highly prevalent, in

order to generate more accurate estimates of trends in hearing impairment.

Supplementary data

Supplementary data are available at *EURPUB* online.

Global Burden of Disease Hearing Loss Expert Group

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Key points

- Hearing impairment is a leading cause of disability.
- Hearing impairment prevalence is highest in low- and middle-income regions, demonstrating a need for interventions like low-cost hearing aids.
- Our estimates of hearing impairment were uncertain because few population-based surveys measure hearing impairment. Repeated cross-sectional studies are needed to determine trends in hearing impairment, particularly in the regions with the highest prevalence.

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A selective follow-up study on a public health survey

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Background: The non-response rates in surveys are increasing which is problematic as it means that a progressively smaller proportion of the population represents the majority, and it is uncertain how health survey results are affected. This follow-up was performed on the non-responders to the postal questionnaire in the public health survey Life and Health, conducted in Örebro County Council, Sweden, where large differences in response rates had been found between different socio-demographic groups and geographical areas. The main objective was to analyse non-response bias regarding self-rated health. **Methods:** This follow-up study was conducted as a census to all non-responders in the area that had the lowest response rate and, in one other geographical area used as a control. It was carried out by telephone interviews, 49.3% (580 individuals) answered the follow-up. The outcome variable was self-rated health, a main variable in public health surveys. Differences in response patterns between responders and initial non-responders were approximated by prevalences with confidence intervals and adjusted odds ratios. **Results:** Poor health was more common in the initial non-response group than among the responders, even with consideration given to sex, age, country of birth and education. However, good health was equally common among responders and initial non-responders. **Conclusions:** Public health surveys can be biased due to certain groups being under-represented or not represented at all. For this reason, in repeated public health surveys, we recommend selective follow-ups of such groups at regular intervals.

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Introduction

In order to be able to say anything about public health and its determinants, national and regional surveys are carried out and these are then used as the basis for planning and research. For a number of years, however, the number of people who participate in these surveys has diminished which is both a national and international trend in developed countries.¹ This is problematic as it means that a progressively smaller proportion of the population represents the majority, and it is uncertain how survey results are affected. In the Swedish national public health survey 'Health on Equal Terms', which is a postal questionnaire, the non-response level increased from 39% in 2004 to 48% in 2009.² Another postal public health survey 'Life and Health' carried out since 2000 in five Swedish counties had a non-response level of 35% in that year.³ In 2004, it had increased to 36%⁴ and to 41% in 2008.⁵ In Sweden, the non-response in The Labour Force Surveys has increased from <2% in the year 1970 to >18% in 2008, which means a non-response

increase of ~0.44 percentage points annually.⁶ Internationally, Morton et al. have calculated that in cross-sectional surveys, there has been an average reduction of 0.67 percentage points per year in response rate during the period 1970–2003.⁷

The non-responders which are the focus here consist of people who for various reasons do not participate in the survey. The problem is that one does not know if those who do respond are representative of the groups being investigated as the non-responders can be deviating in one or several respects. The main reasons for non-response are that the selected people refuse to participate or that they are not reached. These people represent two different groups whose non-participation can have different consequences for the survey results.^{8,9}

We know from the Life and Health surveys that women respond to a higher degree than men, the middle-aged more than the young, individuals with a higher level of education more than those with a lower level, Swedish-born more than foreign-born and those living in residential areas more than those in blocks of flats.¹⁰ This