



# Prevalence of Childhood Hearing Loss and Secular Trends: A Systematic Review and Meta-Analysis

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## ABSTRACT

**BACKGROUND:** Better epidemiologic information on childhood hearing loss would inform research priorities and efforts to prevent its progression.

**OBJECTIVES:** To estimate prevalence and secular trends in children's hearing loss.

**DATA SOURCES:** We searched MEDLINE and Embase from January 1996 to August 2017.

**STUDY ELIGIBILITY CRITERIA:** We included epidemiologic studies in English reporting hearing loss prevalence.

**STUDY APPRAISAL AND SYNTHESIS METHODS:** The modified Leboeuf-Yde and Lauritsen tool was used to assess methodological quality. Meta-analyses combined study-specific estimates using random-effects models.

**PARTICIPANTS:** Children 0 to 18 years of age.

**RESULTS:** Among 88 eligible studies, 43.2% included audiometric measurement of speech frequencies. In meta-analyses, pooled prevalence estimates of slight or worse bilateral speech frequency losses >15 decibels hearing level (dB HL) were 13.1% (95% confidence interval [CI], 10.0–17.0). Using progressively more stringent cutpoints, pooled prevalence estimates were 8.1% (95% CI, 1.3–19.8) with >20 dB HL, 2.2% (95% CI, 1.4–3.0) with >25 dB HL, 1.8% (95% CI, 0.4–4.1)

with >30 dB HL, and 0.9% (95% CI, 0.1–2.6) with >40 dB HL. Also, 8.9% (95% CI, 6.4–12.3) had likely sensorineural losses >15 dB HL in 1 or both ears, and 1.2% (95% CI, 0.5–2.1) had self-reported hearing loss. From 1990 to 2010, the prevalence of losses >15 dB HL in 1 or both ears rose substantially (all *P* for trend <.001).

**LIMITATIONS:** The studies had high heterogeneity and offered limited information for hearing loss types and secular trend.

**CONCLUSIONS AND IMPLICATIONS:** Childhood slight or worse hearing loss is prevalent and may be increasing. Advances in understanding hearing loss trajectories, causes, and prevention would require international repositories and longitudinal studies with audiometric data beginning in childhood.

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**KEYWORDS:** adolescent; child; child, preschool; epidemiology; hearing loss; meta-analysis; prevalence

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## WHAT THIS SYSTEMATIC REVIEW ADDS

- Hearing loss is prevalent in children, with 13.1% having bilateral hearing loss of at least 15 dB HL within the speech frequencies.
- The prevalence of self-reported hearing loss for children was 1.2%.
- Prevalence rose significantly from 1990 to 2010 for losses that were >15 dB HL in 1 or both ears.

## HOW TO USE This Systematic Review

- The high and possibly increasing prevalence of hearing loss in children could compound its growing burden in aging populations.
- Better understanding of hearing loss trajectories, causes, and prevention would require international repositories and longitudinal studies with audiometric data from childhood.

In 2015, HEARING loss was estimated to cause 46.2 million years lived with disability (YLDs) globally,<sup>1</sup> revealing a higher disease burden than obesity (28.6 million YLDs).<sup>2</sup> The World Health Organization (WHO) recently estimated that approximately 32 million children have disabling hearing loss, defined as hearing threshold greater than 30 decibels hearing level (dB HL) in the better ear.<sup>3</sup> This rises to one third of adults by the age of 65 and virtually all adults by the age of 80 years.<sup>3</sup> It appears increasingly likely that, like other noncommunicable diseases, hearing loss is a life course problem whose prevalence most likely increases slowly across the whole life span.<sup>4,5</sup> Thus, early prevention could yield great benefit. However, although research into conditions such as childhood obesity and atopy have exploded in recent years, much less is known about children's hearing loss—despite its costs and links to a broad range of emotional, cognitive, and social problems in later life.<sup>6–8</sup>

Finer-grained knowledge of the prevalence of and secular trends in children's hearing loss is needed for several reasons. First, universal newborn hearing screening is now commonplace in much of the developed world and is usually designed to detect moderate or greater congenital hearing loss. Second, the epidemiology of many childhood conditions, including asthma,<sup>9</sup> food allergy,<sup>10</sup> and autism,<sup>11</sup> has changed rapidly over the last 2 decades. This may also be the case for hearing loss. Some key putative risk factors of hearing loss are also increasing over time. For example, in the US National Health and Nutrition Examination Survey, 34.8% of 12- to 19-year-olds were exposed to music through headphones and earphones from 2005 to 2006 compared to 19.8% from 1988 to 1994,<sup>12</sup> and listening to music through headphones and earphones carries a 70% increased risk of slight to mild sensorineural hearing loss.<sup>13</sup> Childhood obesity, which has risen dramatically over the last 3 decades,<sup>14</sup> has been cross-sectionally associated with hearing loss.<sup>15</sup> Finally, while clinical hearing loss requiring hearing aids and cochlear implantation has received a great deal of attention, milder degrees of hearing loss have been largely ignored.

Understanding the epidemiology of childhood hearing loss and its possible evolution requires consistent and high-quality population research over time. Unfortunately, across studies there is wide variation in hearing loss definitions and, because all cutpoints are essentially arbitrary, future universally agreed-upon definitions seem unlikely. Test frequencies (full, speech, lower, and higher frequencies), availability of information on conductive losses, and participant characteristics also vary among studies. To our knowledge, only 2 previous systematic reviews have attempted to determine prevalence of hearing loss.<sup>16,17</sup> Both reported major challenges in dealing with non-comparable data. To overcome this difficulty, Mehra et al<sup>16</sup> restricted their analyses to lower frequency (across 0.5, 1, and 2 kHz) hearing loss >25 dB HL and considered studies from the United States only. The other review, conducted by WHO, included only bilateral hearing loss >30 dB HL across the speech frequencies

(0.5, 1, 2, and 4kHz) and estimated prevalence using a Bayesian hierarchical model.<sup>17</sup> However, there are drawbacks to both approaches. First, by using a single definition, the authors excluded much useful data. The full range of human audibility ranges from approximately 0.25 to 8 kHz. Within this, the speech frequencies (across 1, 2, and 4 kHz) reflect speech perception. The higher frequencies (across 3, 4, 6, and 8 kHz) are believed to be most affected by noise exposure, and the lower frequencies (across 0.5, 1, and 2 kHz) might indicate microcirculation dysfunction in the cochlea.<sup>18</sup> Laterality and severity are important determinants of impacts and can indicate the causes and management of hearing loss. Second, choices about single definitions that differ across studies limit future comparisons. Third, because few studies met their restricted criteria, these 2 reviews could not estimate secular trends in hearing loss prevalence.

In the current systematic review and meta-analysis, we searched for all studies published between 1996 and 2017 describing prevalence of hearing loss in the general population of children 0 to 18 years old. For this age group, we aimed to: 1) measure the pooled prevalence of hearing loss by classification (full frequency, speech frequency, lower frequency, and higher frequency), laterality (bilateral or unilateral, bilateral, or unilateral), and severity; and 2) determine secular trends in hearing loss prevalence over the last 20 years.

## METHODS

### PROTOCOL AND REGISTRATION

Methods for this systematic review and meta-analysis are specified in the protocol registered on February 9, 2016, with PROSPERO, the International Prospective Register of Systematic Reviews.

### SEARCH STRATEGY

We systematically searched articles published between January 1, 1996, and August 13, 2017, in the electronic databases MEDLINE (Ovid) and Excerpta Medica Database (Embase Ovid). Medical Subject Headings and free text words were used to interrogate each database, including the following search terms: “hearing loss,” “hearing impairment,” “deafness,” “prevalence,” and “epidemiology.” The full search strategies are listed in [Supplementary Table 1](#).

### ELIGIBILITY CRITERIA

Studies were included if they met all of the following criteria: 1) participants were between 0 and 18 years old; 2) data were available to calculate the prevalence of hearing loss; 3) the study was observational, including cross-sectional, case-control, and cohort study designs; and 4) the manuscript was published in English. Studies were excluded if they 1) were duplicate (where the same study generated multiple publications, we drew on the paper with the largest sample size); 2) reported results only for “number of ears”; 3) contained no definition of hearing

loss; 4) involved children with or likely to have other primary diseases (eg, aboriginal children, who have extremely high rates of suppurative ear disease); and 5) had fewer than 100 participants.

### STUDY SELECTION

Publications were catalogued using EndNote X7 (Clarivate Analytics; Philadelphia, Penn). Two reviewers (child public health researchers J.W. and A.A.) independently screened the retrieved records including titles, abstracts, and full texts according to eligibility criteria. A third audiologist researcher (P.C.) resolved any disagreement through discussions.

### DATA EXTRACTION

An extraction form was predesigned with EpiData 3.1 (EpiData Association; Odense, Denmark) and then modified following a pilot test. The extraction form included study characteristics (study design, country, years of data collection, sample size, participants' age range), hearing loss definition (eg, testing frequencies, cutoff points, reported ear, inclusion or exclusion of conductive hearing loss, self-reported hearing loss), and reported prevalence estimates. Data were independently extracted for each paper twice, once by J.W. and once by Y.W. or M.L. Inconsistencies were resolved by discussions.

### ASSESSMENT OF RISK OF BIAS

The same 3 reviewers (J.W., Y.W., and M.L.) assessed each included study for methodological quality using a modified Leboeuf-Yde and Lauritsen tool developed by Hoy et al,<sup>19</sup> which is comprised of 10 items addressing 2 study domains (external and internal validity). Each item can be judged as "yes" (low risk of bias) or "no" (high risk of bias). One point was awarded if an item was judged as low risk of bias, with a maximum score of 10 points indicating the lowest possible risk of bias. Studies were judged to be at low ( $\geq 8$  points), moderate (6 to 7 points), or high ( $\leq 5$  points) risk of bias. Inconsistencies were resolved by discussions. A summary of the risks of bias was graphed using RevMan 5.3 (Cochrane; London, UK).

### ADDRESSING DIFFERENCES IN DEFINITIONS OF AUDIOMETRIC HEARING LOSS AMONG STUDIES

In order to compare and draw inferences from studies that defined hearing loss differently, studies were grouped using the following approaches (Supplementary Fig. 1). First, studies were grouped by the frequencies tested. Speech frequency hearing loss (across 0.5, 1, 2, 3, and 4 kHz) was the primary definition of hearing loss, because it is most commonly used in population studies and is likely to have the greatest functional relevance for oral communication.<sup>20</sup> Additional classifications were applied to enable inclusion of useful data (see earlier text) and maximize cross-study comparability: full frequency (across 0.5 to 8 kHz), lower frequency (0.5, 1, and 2 kHz), and higher frequency (3, 4, 6, and 8 kHz). Second,

studies were further grouped by the reported ear (laterality): bilateral or unilateral (1 or both ears), bilateral (both ears), or unilateral (1 ear). Third, within each classification and laterality, we grouped studies using the following severity cutoff points, each used in more than 1 study:  $>15$  dB HL (slight or worse),  $>20$  dB HL,  $>25$  dB HL,  $>30$  dB HL, and  $>40$  dB HL (moderate or worse). We used the same approaches to group studies reporting sensorineural hearing loss (defined as hearing loss with air-bone conduction gaps less than 15 dB HL).

### DEALING WITH MISSING DATA

When information regarding the variables for analysis was missing from publications, we e-mailed the corresponding authors requesting the data. If the authors did not reply after a second contact attempt, we excluded these publications from the relevant analyses.

### STATISTICAL ANALYSIS

Statistical analyses were performed using Stata 14.0 (StataCorp; College Station, Tex).

#### CALCULATION OF PREVALENCE

Prevalence of hearing loss was calculated using the following formula for each included study:

Prevalence of hearing loss

$$= \frac{\text{Number of hearing loss cases indentified}}{\text{Number of all participants}} \times 100\%$$

#### POOLED PREVALENCE ESTIMATES AND SENSITIVITY ANALYSIS (AIM 1)

We conducted meta-analyses to calculate the overall pooled prevalence of hearing loss with 95% confidence intervals (CIs) by classification, laterality, and severity using the Metaprop module in Stata.<sup>21</sup> We computed the study-specific confidence intervals using exact method.<sup>21</sup> Considering likely between-study heterogeneity, a random-effects model was applied to all meta-analyses using the DerSimonian and Laird method.<sup>22</sup> As recommended for meta-analyses of prevalence and to prevent the overweighting of studies reporting extremely low prevalence (eg, a prevalence approaching 0),<sup>23</sup> we used the Freeman-Tukey double arcsine transformed prevalence in meta-analyses in line with previous studies.<sup>24,25</sup> We used the  $I^2$  statistic (percentage variability in prevalence estimates likely to reflect heterogeneity rather than sampling error or chance) to examine and quantify between-study heterogeneity.  $I^2 \geq 75\%$  was regarded as substantial heterogeneity. The same approach was used for sensorineural hearing loss and self-reported hearing loss. In sensitivity analyses, the above was repeated in the studies deemed at low risk of bias to examine effects of methodological quality on prevalence estimates. Risk of publication bias across studies was examined by the test of Egger et al<sup>26</sup> when  $>10$  estimates were included in a single analysis, and  $P < .10$  was regarded as significant.

### SECULAR TRENDS IN HEARING LOSS PREVALENCE (AIM 2)

We selected population studies that reported prevalence of audiometric hearing loss and year(s) of data collection. We plotted secular trend lines summarizing prevalence of hearing loss by mid-year of data collection. As there were limited studies in each classification, meta-regression was not applied. We calculated the *P* value for an overall trend using logistic regression. This statistical method fits a logistic regression model of a dependent variable (hearing loss) on an independent continuous variable (mid-year of data collection). To investigate whether these time trends might be nonlinear, we added time-squared and time-cubed terms to the model. As neither was predictive of prevalence of hearing loss (eg, their odds ratios did not differ significantly from 1.0; data available from authors on request), we presented the linear values only.

## RESULTS

### CHARACTERISTICS OF ALL INCLUDED STUDIES

Figure 1 outlines the process of study selection. The systematic search of electronic databases identified 5164 articles. After removal of duplicates and initial title/abstract screening, we reviewed 263 articles in full. Eighty-eight studies involving a total of 3,360,850 individuals in 39 countries were eligible for inclusion (see Supplementary References). Supplementary Table 2 details the general information of all the included studies. The median number of participants per study was 2535 (range 209 to 790,200). Ten studies reported self-reported hearing loss for children, and 78 studies reported audiometric hearing loss, among which 35 studies reported the prevalence of sensorineural hearing loss. The methodological quality for all 88 individual studies is illustrated in Supplementary Table 3 and Supplementary Figure 2. Low risk of bias was found in 54 (61.4%) studies, moderate risk of bias in 31 (35.2%) studies, and high risk of bias in only 3 (3.4%) studies.

### POOLED PREVALENCE OF HEARING LOSS (AIM 1)

Table 1 shows the pooled prevalence of audiometric hearing loss by classification, laterality, and severity. As expected, the pooled prevalence decreased as the severity of hearing loss (the threshold cutoff) increased. Prevalence ranged widely, from as low as 0.1% (95% CI, 0.1–0.2) when hearing loss was defined using a lower frequency average (0.5, 1, and 2 kHz) with a 40-dB HL threshold in both ears to as high as 17.9% (95% CI, 15.9–20.0) when using a full frequency average (0.5 to 8 kHz) with a 15-dB HL threshold in 1 or both ears. A total of 43.2% of the studies focused on speech frequency hearing loss (our primary outcome), with pooled prevalence estimates of bilateral losses as follows: 13.1% (95% CI, 10.0–17.0) >15 dB HL (slight or worse); 8.1% (95% CI, 1.3–19.8) >20 dB HL; 2.2% (95% CI, 1.4–3.0) >25 dB HL; 1.8% (95% CI, 0.4–4.1) >30 dB HL; and 0.9% (95% CI, 0.1–2.6) > 40 dB HL (moderate or

worse). Regarding unilateral losses across speech frequency, the pooled prevalence estimates were 6.9% (95% CI, 6.3–7.5) >15 dB HL (slight or worse); 4.6% (95% CI, 3.8–5.4) > 20 dB HL; 1.9% (95% CI, 1.0–3.3) >25 dB HL; 1.9% (95% CI, 1.1–3.3) >30 dB HL; and 1.4% (95% CI, 1.1–1.7) >40 dB HL (moderate or worse). Publication bias was assessed for the prevalence of bilateral hearing loss >25 dB HL (*n* = 11), and the Egger test for regression asymmetry did not suggest the presence of publication bias (*P* = 0.141).

Among the 35 studies restricted to include sensorineural hearing loss, 25 (71.4%) focused on speech frequency hearing loss. The pooled prevalence estimates also varied widely, from as low as 0.1% (95% CI, 0.0–0.3) with a 40-dB HL threshold in 1 ear to as high as 8.9% (95% CI, 6.4–12.3) with a 15-dB HL threshold in 1 or both ears (Table 1). For self-reported hearing loss for children, the pooled prevalence from 10 studies was 1.2% (95% CI, 0.5–2.1) (Supplementary Fig. 3). In sensitivity analyses, the pooled prevalence of hearing loss from studies with low risk of bias (*n* = 54) was very similar to our main prevalence estimates (Supplementary Table 4).

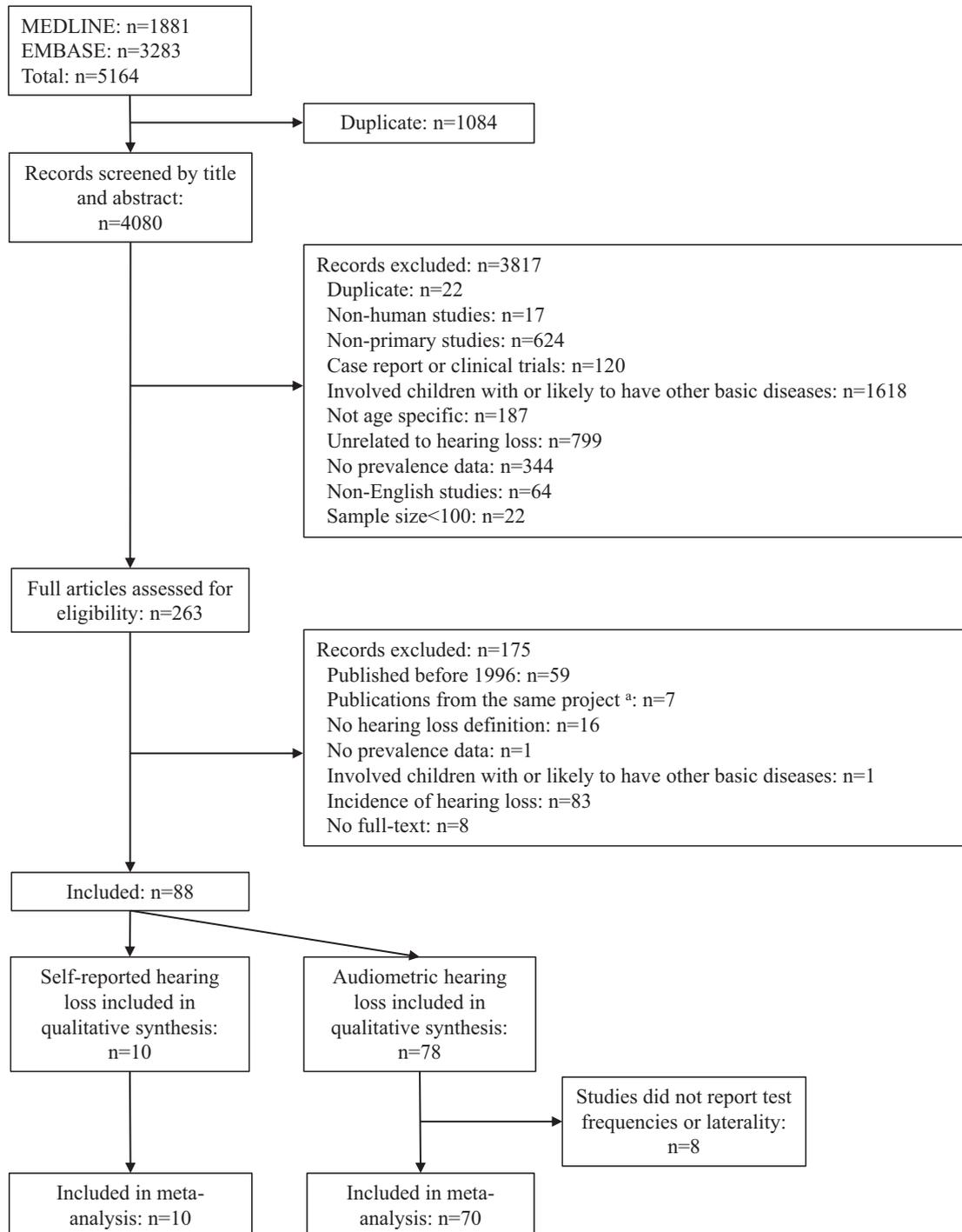
### SECULAR TREND IN POOLED PREVALENCE OF HEARING LOSS (AIM 2)

As few studies reported year of data collection, we could only explore secular trends in the prevalence of hearing loss >15 dB HL. Table 2 summarizes studies reporting the prevalence of hearing loss >15 dB HL and data collection time. In these studies, the year(s) of data collection ranged from 1990 to 2010. We plotted secular trend lines during the 20-year period for full frequency, speech frequency, lower frequency, and higher frequency losses (Fig. 2). Although we only included publications since 1996, these included studies conducted in the earlier 1990s. Although the prevalence of full frequency hearing loss >15 dB HL in 1 or both ears decreased from 22.3% in 2010 to 17.5% in 2013, there was consistent evidence of rising prevalence from 1990 to 2010 using all 4 classifications (all *P* for trend <.001): full frequency hearing loss, from 14.9% to 17.5%; speech frequency hearing loss, from 9.7% to 18.0%; lower frequency hearing loss, from 7.1% to 17.0%; and higher frequency hearing loss, from 12.7% to 14.4%.

## DISCUSSION

### PRINCIPAL FINDINGS

This systematic review and meta-analysis of 88 studies involved a total of 3,360,850 children up to 18 years of age from 39 countries—a much larger number of participants than any previous analysis. Around 1 in 7 children had at least a slight hearing loss (>15 dB HL) within the speech frequencies; 8.9% of children had likely sensorineural speech frequency hearing loss >15 dB HL, and 1.2% had self-reported hearing loss. Prevalence estimates of hearing loss >15 dB HL in 1 or both ears substantively increased from 1990 to 2010.



<sup>a</sup> where the same study generated multiple publications, we drew on the paper with the largest sample size

**Figure 1.** Study selection flowchart.

## STRENGTHS AND LIMITATIONS

Our major strength is the approach to dealing with different definitions of hearing loss between studies, which allowed consideration and analysis of all relevant studies. This will also facilitate future comparisons with a wide range of studies. Most of the included studies (96.2%) are of good quality with low or moderate risk of bias according to our criteria (Supplementary Table 3). This indicates that most of the included studies had attempted

to minimize bias (eg, sampling or measurement bias) in order to avoid under- or overestimating hearing loss prevalence.<sup>27</sup>

Our study also has some limitations. First, substantial heterogeneity was observed across studies. Restricting our analysis to only high-quality studies did not fully explain this heterogeneity, which may result in uncertainty around the pooled estimates. We initially aimed to estimate pooled prevalence of hearing loss by age, sex,

**Table 1.** Pooled Prevalence of Audiometric Hearing Loss

Classification	Hearing Loss Severity (dB HL)	Hearing Loss					Sensorineural Hearing Loss*				
		Studies	Sample Size	Estimate (%) <sup>†</sup>	95% CI (%)	I <sup>2</sup> (%)	Studies	Sample Size	Estimate (%) <sup>†</sup>	95% CI (%)	I <sup>2</sup> (%)
Full frequency (0.5 kHz–8 kHz)											
Bilateral or unilateral	>15	5	14,316	17.9	15.9–20.0	87.2	2	901	13.0	10.9–15.3	0.0
	>20	1	1296	14.9	13.1–16.9	—	0	—	—	—	—
	>25	4	308,471	9.4	4.7–15.6	99.4	0	—	—	—	—
	>40	1	1670	12.9	11.4–14.6	—	0	—	—	—	—
Bilateral	>15	2	4928	5.3	4.6–5.9	0.0	1	6240	0.9 <sup>‡</sup>	0.7–1.1	—
	>20	2	1984	2.4	1.8–3.1	0.0	0	—	—	—	—
	>25	3	509,276	0.9	0.1–2.2	97.5	1	6240	0.3 <sup>§</sup>	0.2–0.4	—
	>40	1	504,348	0.2	0.1–0.2	—	0	—	—	—	—
Unilateral	>15	2	4928	12.1	11.2–13.0	0.0	0	—	—	—	—
	>25	2	4928	2.1	1.7–2.5	0.0	0	—	—	—	—
Speech frequency (0.5, 1, 2, 3, 4 kHz)											
Bilateral or unilateral	>15	3	6966	13.5	8.4–19.6	93.8	1	359	8.9	6.4–12.3	—
	>20	3	3185	11.0	2.8–23.7	98.8	5	42,073	2.4	0.6–5.4	99.2
	>25	8	26,124	5.8	1.6–12.5	99.7	7	53,091	0.5	0.2–1.0	96.5
	>30	6	8623	6.4	3.4–10.3	96.6	2	6167	1.0	0.8–1.3	0.0
	>40	8	10,206	2.5	1.3–3.9	93.9	4	53,451	0.2	0.0–0.6	95.4
Bilateral	>15	1	359	13.1	10.0–17.0	—	0	—	—	—	—
	>20	5	3974	8.1	1.3–19.8	99.0	4	42,875	1.0	0.4–1.8	96.0
	>25	11	85,439	2.2	1.4–3.0	97.9	3	35,169	0.1	0.0–0.2	68.2
	>30	9	18,888	1.8	0.4–4.1	98.5	0	—	—	—	—
	>40	9	81,716	0.9	0.1–2.6	99.5	5	118,041	0.4	0.0–1.4	99.7
Unilateral	>15	1	6101	6.9	6.3–7.5	—	0	—	—	—	—
	>20	2	2850	4.6	3.8–5.4	0.0	2	37,288	0.1	0.1–0.1	0.0
	>25	5	20,101	1.9	1.0–3.3	96.8	4	84,259	0.1	0.1–0.3	95.4
	>30	1	639	1.9	1.1–3.3	—	0	—	—	—	—
	>40	3	4916	1.4	1.1–1.7	0.0	4	102,257	0.1	0.0–0.3	96.9
Lower frequency (0.5, 1, 2 kHz)											
Bilateral or unilateral	>15	4	13,629	8.7	7.1–10.5	89.6	0	—	—	—	—
	>20	3	11,797	13.3	11.3–15.3	80.9	3	9841	1.7	0.1–5.0	98.5
	>25	3	5535	3.2	0.3–8.5	96.7	0	—	—	—	—
	>40	2	10,147	3.2	2.9–3.5	0.0	0	—	—	—	—
Bilateral	>15	2	4928	1.9	1.5–2.3	0.0	0	—	—	—	—
	>20	0	—	—	—	—	3	51,350	1.0	0.0–3.3	99.3
	>25	4	6946	1.2	0.2–2.8	93.5	0	—	—	—	—
	>30	1	7888	0.6	0.4–0.8	—	0	—	—	—	—
	>40	4	1,085,896	0.1	0.1–0.2	95.3	4	904,448	0.2	0.1–0.4	99.0
Unilateral	>15	2	4928	5.5	4.8–6.1	0.0	0	—	—	—	—
	>20	0	—	—	—	—	2	7639	0.5	0.4–0.7	0.0
	>25	3	5535	1.8	0.4–4.3	91.2	0	—	—	—	—
	>40	1	607	1.3	0.7–2.6	—	0	—	—	—	—

(continued on next page)

Table 1 (Continued)

Classification	Hearing Loss Severity (dB HL)	Hearing Loss				Sensorineural Hearing Loss*				
		Studies	Sample Size	Estimate (%) <sup>†</sup>	95% CI (%)	I <sup>2</sup> (%)	Studies	Sample Size	Estimate (%) <sup>†</sup>	95% CI (%)
Higher frequency (3, 4, 6, 8 kHz) Bilateral or unilateral	>15	4	13,629	14.2	12.7–15.7	79.7	0	—	—	—
	>20	1	1534	6.9	5.7–8.3	—	0	—	—	—
	>25	2	4928	3.0	2.5–3.5	0.0	0	—	—	—
Bilateral	>15	2	4928	3.9	3.4–4.5	0.0	0	—	—	—
	>20	1	1534	1.7	1.2–2.5	—	0	—	—	—
	>25	2	4928	0.8	0.6–1.1	0.0	0	—	—	—
Unilateral	>15	2	4928	10.8	10.0–11.7	0.0	0	—	—	—
	>20	1	1534	5.2	4.2–6.4	—	0	—	—	—
	>25	2	4928	2.1	1.7–2.5	0.0	0	—	—	—

dB HL indicates decibels hearing level; CI, confidence interval; bilateral or unilateral, 1 or both ears; bilateral, both ears; and unilateral, 1 ear.

\*Hearing loss with air-bone conduction gaps less than 15 dB HL.

†Random-effects model was used to pool the prevalence of hearing loss.

‡Hearing loss 16 to 40 dB HL.<sup>35</sup>

§Hearing loss 26 to 40 dB HL.<sup>35</sup>

and region using meta-regression in order to further explain heterogeneity, but data quickly became sparse upon subdivision into these additional categories. Most studies did not conduct bone conduction audiometry, or they only reported prevalence for sensorineural losses, which means we were unable to estimate the pooled prevalence of conductive or mixed hearing losses. Second, we excluded studies with sample sizes <100, because small-n studies of low-prevalence conditions rarely represent a random sample of the target population and even if they did are unlikely to provide a precise estimate and reliable answer to the study hypotheses. However, we appreciate that this decision was essentially arbitrary and that adding these 22 studies could have altered our conclusions.

Third, our review underrepresented low-income countries, estimated by 2017 World Bank data as comprising 14% of all countries.<sup>28</sup> As applying international weightings was beyond the scope of this study, we may have somewhat underestimated the true international prevalence because these countries have a higher prevalence of long-term suppurative middle ear disease.<sup>29</sup> Fourth, we were only able to compare secular trends across studies that reported exact year of data collection and used similar audiometric protocols. This meant we were only able to explore the secular trend in the prevalence of audiometric hearing loss >15 dB HL (slight or worse). Ideally, future research would include more studies and examine more severe losses (eg, thresholds >20 dB HL) over a longer period of time. Despite these limitations, our estimates were precise and showed consistency across definitions in terms of declining prevalence with greater severity and rising prevalence with time since 1990.

**INTERPRETATION IN LIGHT OF OTHER STUDIES**

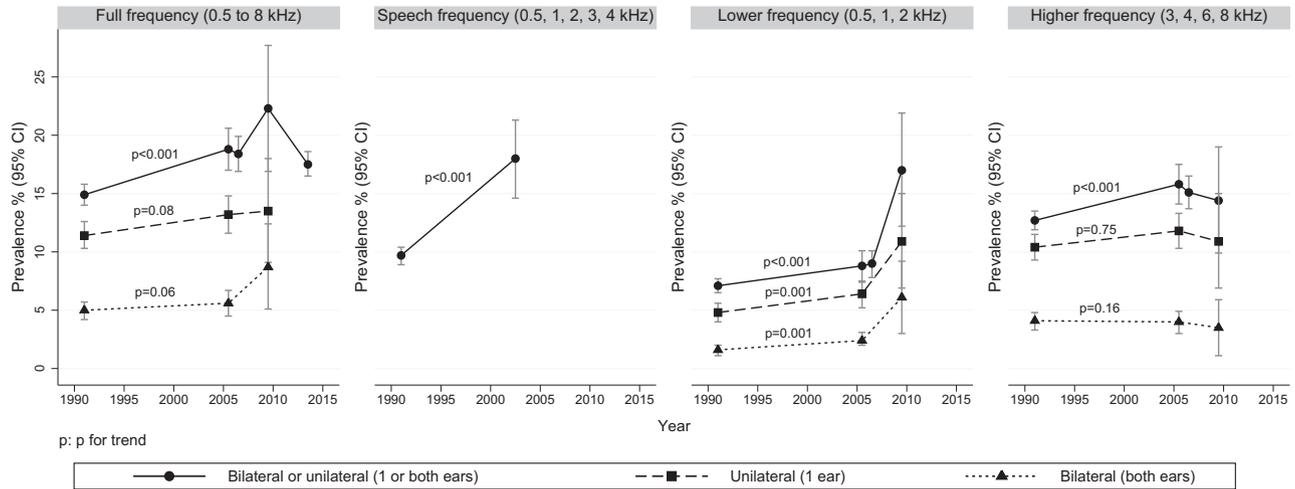
The pooled prevalence estimates of hearing loss in our systematic review are comparable with those reported in previous systematic reviews. For example, the prevalence of lower frequency loss >25 dB HL in 1 or both ears was estimated at 3.1% in the United States<sup>16</sup> compared with 3.5% in our study; bilateral speech frequency loss >30 dB HL was estimated at 1.4% in the WHO study<sup>16</sup> compared with 2.2% in our study. Additionally, our study provides a comprehensive summary of hearing loss by classification, laterality, and severity, which allows thorough exploration of hearing loss prevalence and its secular trends. The decrease in hearing loss prevalence from 2010 to 2013 most likely reflects the younger age of the children in the Dutch study than the US study (9–11 y vs 12–19 y). We found that the prevalence of slight or worse hearing loss has increased from 1990 to 2010, drawing on studies that used the same audiological assessment (air-conduction audiometry) in 4 countries. Although racial/ethnic make-up differs somewhat among the United States, Canada, Brazil, and the Netherlands, this would not explain the changes over time seen within those countries (eg, in the US National Health and Nutrition Examination Survey).<sup>30</sup>

**Table 2.** Overview of Studies Reporting Prevalence of Hearing Loss (>15 dB HL) by Year\*

Study	Location	Data Collection Years	Mid-Year of Data Collection	Age Range (y)	Sample Size	Hearing Loss Prevalence, % (95% CI)		
						Bilateral or Unilateral	Bilateral	Unilateral
Full-frequency hearing loss (0.5–8 kHz) > 15 dB HL								
Niskar et al <sup>36</sup>	United States	1988–1994	1991	6–19	6166	14.9 (14.0–15.8)	—	—
Shargorodsky et al <sup>30</sup>	United States	1988–1994	1991	12–19	2928	—	5.0 (4.2–5.7)	11.4 (10.3–12.6)
Shargorodsky et al <sup>30</sup>	United States	2005–2006	2005.5	12–19	1771	18.8 (17.0–20.6)	5.6 (4.5–6.7)	13.2 (11.6–14.8)
Shargorodsky et al <sup>37</sup>	United States	2005–2008	2006.5	12–19	2535	18.4 (16.9–19.9)	—	—
Marcoux et al <sup>38</sup>	Canada	2009–2010	2009.5	10–17	237	22.3 (16.9–27.7)	8.7 (5.1–12.4)	13.5 (9.1–18.0)
le Clercq et al <sup>39</sup>	Netherlands	2012–2015	2013.5	9–11	5368	17.5 (16.5–18.6)	—	—
Speech frequency (0.5, 1, 2, 3, 4 kHz) > 15 dB HL								
Ross et al <sup>40</sup>	United States	1988–1994	1991	6–19	6101	9.7 (8.9–10.4)	2.8 (2.4–3.2)	6.9 (6.2–7.5)
Coelho et al <sup>41</sup>	Brazil	2002–2003	2002.5	5–12	506	18.0 (14.6–21.3)	—	—
Lower frequency (0.5, 1, 2 kHz) > 15 dB HL								
Niskar et al <sup>36</sup>	United States	1988–1994	1991	6–19	6166	7.1 (6.5–7.7)	—	—
Shargorodsky et al <sup>30</sup>	United States	1988–1994	1991	12–19	2928	—	1.6 (1.1–2.0)	4.8 (4.0–5.6)
Shargorodsky et al <sup>30</sup>	United States	2005–2006	2005.5	12–19	1771	8.8 (7.4–10.1)	2.4 (2.0–3.1)	6.4 (5.2–7.5)
Shargorodsky et al <sup>37</sup>	United States	2005–2008	2006.5	12–19	2535	9.0 (7.8–10.1)	—	—
Marcoux et al <sup>38</sup>	Canada	2009–2010	2009.5	10–17	237	17.0 (12.2–21.9)	6.1 (3.0–9.2)	10.9 (6.9–15.0)
Higher frequency (3, 4, 6, 8 kHz) > 15 dB HL								
Niskar et al <sup>36</sup>	United States	1988–1994	1991	6–19	6166	12.7 (11.9–13.5)	—	—
Shargorodsky et al <sup>30</sup>	United States	1988–1994	1991	12–19	2928	—	4.1 (3.3–4.8)	10.4 (9.3–11.5)
Shargorodsky et al <sup>30</sup>	United States	2005–2006	2005.5	12–19	1771	15.8 (14.1–17.5)	4.0 (3.0–4.9)	11.8 (10.3–13.3)
Shargorodsky et al <sup>37</sup>	United States	2005–2008	2006.5	12–19	2535	15.1 (13.7–16.5)	—	—
Marcoux et al <sup>38</sup>	Canada	2009–2010	2009.5	10–17	237	14.4 (9.9–19.0)	3.5 (1.1–5.9)	10.9 (6.9–15.0)
Sensorineural hearing loss (lower and higher frequency) 16 to 40 dB HL								
Wake et al <sup>35</sup>	Australia	2003–2004	2003.5	7–11	6240	—	0.9 (0.6–1.1)	—

dB HL indicates decibels hearing level; CI, confidence interval; bilateral or unilateral, 1 or both ears; bilateral, both ears; and unilateral, 1 ear.

\*Details of each study are provided in [Supplementary Table 2](#).



**Figure 2.** Secular trends in prevalence of hearing loss >15 dB hearing level.

Compared with audiometric losses >15 dB HL, the prevalence of self-reported hearing loss for children was much lower. On the one hand, true prevalence requires audiometric measurement, because self-report is known to have low sensitivity and specificity. On the other hand, the rates of self-reported hearing loss strikingly resemble rates of measured moderate or worse losses (>40 dB HL) in this review—which is also close to the point at which adults typically voluntarily both seek and use hearing aids.<sup>31</sup> This circumstantially supports self-report being a reasonable indicative measure of experienced functional hearing loss when audiometric measurement is not possible; however, relying on self-report leaves a major gap in identifying milder losses that may have implications for child and long-term hearing outcomes.

## IMPLICATIONS

The high and possibly increasing prevalence of slight or worse hearing loss is concerning, because if (as is likely) this progresses slowly over decades it may culminate in substantial additional late-life population disease burden. It also indicates that, over and above the enormous effort put into newborn hearing screening in the early 2000s, much work remains to be done.

First, deriving the global prevalence and secular trend of hearing loss requires not only consistency in the definitions of hearing loss but also quality of audiometric assessment and protocols. Ideally, this would be achieved via an international repository to deposit de-identified person-level audiometric data across at least the speech frequencies. Such a repository would enable researchers to make direct comparisons between studies, describe characteristics and secular trends as new studies are added, come to consensus on definitions and reanalyze alternative ones, and advance methodological issues. In addition, most included studies reported only cross-sectional data. Longitudinal studies are needed to document rates and inevitability of hearing deterioration to establish whether these children with slight losses are indeed the adults with presbycusis of the future.

Second, causal research investigating risk factors for slight hearing loss could help to discover reasons for secular changes going forward, and perhaps to prevent progression of hearing loss. Although studies focusing on noise exposure remain important, only 16% of the disabling hearing loss is attributed to occupational noise<sup>32</sup> and noise preferentially affects the higher frequencies, which are insufficient to explain the large inter-individual differences in susceptibility to hearing loss and secular increases in lower frequencies. More emphasis may be needed on non-communicable disease risk factors, early life infections (eg, otitis media, congenital cytomegalovirus), and biomarkers of aging (eg, telomere length, oxidative stress, DNA repair).<sup>15,18,33,34</sup> Large-scale population-based children's longitudinal studies typically collect risk factors and phenotypes for many diseases along with bio-samples; we should advocate also including audiometric measurement, with a special emphasis on sufficient precision to capture slight and mild losses.

Last, quantitative and qualitative studies are needed to clarify the impact of slight and mild hearing loss on child outcomes at a population level. Ideally, these would be longitudinal, to investigate how outcomes respond to trajectories of slight-mild hearing loss. This knowledge could help policymakers limit adverse impacts and the progression of slight hearing loss—for example, optimizing classroom listening environments, counseling to avoid loud noise, or implementing school hearing screening.

## CONCLUSIONS

Our study systematically reviewed all the available information, providing a comprehensive summary of prevalence and secular trends in children's hearing loss. If we are to understand hearing loss as a life course issue, then we urgently need better epidemiologic information on childhood hearing loss. This research could be readily enabled through resources such as an international person-level hearing data repository for past and future studies, and advocacy for existing children's longitudinal studies to include audiometric measurement. Such

knowledge will advance understanding of the origins of hearing loss and inform future research priorities and efforts to prevent progression of hearing loss.

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## SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at <https://doi.org/10.1016/j.acap.2019.01.010>.

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