Prevalence of Hearing Loss in US Children and Adolescents
Findings From NHANES 1988-2010

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IMPORTANCE There have been concerns about increasing levels of hearing impairment in children and adolescents, especially in relation to noise exposure, because even mild levels of hearing loss can affect educational outcomes.

OBJECTIVE To further characterize changes in prevalence of hearing loss and noise exposures in the US pediatric population over time.

DESIGN, SETTING, AND PARTICIPANTS This is a retrospective analysis of demographic and audiometric data from the Third National Health and Nutrition Examination Survey (NHANES III, 1988-1994), NHANES 2005-2006, NHANES 2007-2008, and NHANES 2009-2010. The NHANES are nationally representative survey data sets collected and managed by the US National Center for Health Statistics, and this study includes a total of 7036 survey participants ages 12 to 19 years with available audiometric measurements.

EXPOSURES Hearing-related behaviors and risk factors such as history of ear infections, noise exposures, firearm use, and hearing protection use.

MAIN OUTCOMES AND MEASURES Level of hearing loss measured by pure-tone audiometry, as well as high-frequency and low-frequency hearing loss and noise-induced threshold shifts.

RESULTS Overall, data from 7036 survey participants ages 12 to 19 years with available audiometric measurements were analyzed. The prevalence of hearing loss increased from NHANES III to NHANES 2007-2008 (17.0% to 22.5% for >15 dB hearing loss; absolute difference, 5.5%; 95% CI, 6.1%-10.3%) but decreased in the NHANES 2009-2010 to 15.2% (absolute difference, 7.2%; 95% CI, 2.0%-12.4%) with no significant overall secular trend identified. There was an overall rise in exposure to loud noise or music through headphones 24 hours prior to audiometric testing from NHANES III to NHANES 2009-2010. However, noise exposure, either prolonged or recent, was not consistently associated with an increased risk of hearing loss across all surveys. The most recent survey cycle showed that nonwhite race/ethnicity and low socioeconomic status are independent risk factors for hearing loss.

CONCLUSIONS AND RELEVANCE This analysis did not identify significant changes in prevalence of hearing loss in US youth ages 12 to 19 years over this time period despite increases in reported noise exposures. No consistent associations were shown between noise exposure and hearing loss, though there was an association between racial/ethnic minority status and low socioeconomic status and increased risk of hearing loss. Ongoing monitoring of hearing loss in this population is necessary to elucidate long-term trends and identify targets for intervention.
Hearing impairment in children is a major public health burden given its impact on early speech and language development, and subsequently on academic and workforce performance later in life. Even mild levels of hearing loss have been found to negatively affect educational outcomes and social functioning. With multiple existing classifications of hearing impairment and limited availability of objective measures, assessing the epidemiology of pediatric hearing loss has been challenging. There have been growing concerns that the prevalence of hearing loss in children and adolescents, particularly noise-induced hearing loss, is rising, possibly due to recreational noise exposure.

Two studies using the National Health and Nutrition Examination Surveys (NHANES) have described changes in the prevalence of hearing loss from 1988 to 1994 through 2005 to 2006 in US youth ages 12 to 19 years. In 2010, Shargorodsky et al reported an increase in prevalence of any hearing loss from 14.9% to 19.5%. In 2011, Henderson et al reported an increase in noise-induced threshold shifts (NITS) among female youth over the same time period, as well as an increase in exposure to loud noise or music with headphones within 24 hours of the testing session.

There are now audiometric data available from NHANES through 2010 for US children and adolescents ages 12 to 19 years. We aimed to further characterize changes in prevalence of hearing loss and noise exposures in this population from 1988 to 2010, to evaluate whether the previously described trends have continued.

Methods

**NHANES**

The NHANES is an ongoing, nationally representative series of surveys designed to provide estimates of health and nutritional status for the noninstitutionalized civilian population of the United States. Each cycle consists of questionnaires and a standardized health examination. Individual cycles and survey design have been previously described.

The third NHANES, or NHANES III, was conducted from 1988 to 1994 and provides cross-sectional estimates for the period as a whole. The health examination included an audiometry component. Starting in 1999, the NHANES became a continuous survey with data released in 2-year cycles. The audiometry component for participants ages 12 to 19 years was only conducted during NHANES 2005-2006, 2007-2008, and 2009-2010.

**Sample**

The study population consisted of all survey participants ages 12 to 19 years in NHANES III (n = 3425), NHANES 2005-2006 (n = 2288), 2007-2008 (n = 1238), and 2009-2010 (n = 1339). Participants with a missing or incomplete audiometric exam, or a greater than or equal to 10 decibel (dB) difference between 1 kHz test-retest thresholds, were excluded from the analysis.

**Audiometric Measures**

For all NHANES cycles, standardized audiology protocols were conducted in a sound-isolated room by technicians trained by a certified audiologist from the National Institute for Occupational Safety and Health. The equipment and testing protocols changed between NHANES III and NHANES 2005-2006, but did not change from 2005 to 2010. Air-conduction thresholds for each ear were determined, using standard diometric headphones, from 0.5 to 8 kHz, across an intensity range of −10 dB to 110 dB in NHANES III and −10 dB to 120 dB in NHANES 2005-2010. The 1 kHz frequency was tested twice in each ear to assess reliability of participant response.

A retesting protocol was used to prevent signal crossover between ears through bone conduction. If there was a difference in threshold between ears at any frequency by 40 dB in NHANES III, a masking procedure was performed and the masked values were used for analysis. From 2005 to 2010, if there was a difference in threshold between ears of 25 dB at 0.5 and 1 kHz, or by 40 dB at all higher frequencies, retesting was performed using insert earphones and the retest values were used. Participants with cochlear implants or unable to tolerate headphones were excluded. NHANES III also did not test participants with drainage or discharge from either ear. Full audiometric procedure manuals for each cycle are available online (http://www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm).

**Demographic and Hearing-Related Variables**

Participants were grouped into 2-year categories by age (12-13, 14-15, 16-17, and 18-19 years), as done in preceding studies. Race and ethnicity were recorded differently between NHANES III and 2005 to 2010, and for this analysis were grouped into the following categories: non-Hispanic white, non-Hispanic black, Mexican-American, and other (including other Hispanic, and nonblack, non-Hispanic groups such as Asian-American, native American, mixed race). The surveys had insufficient sample size for reliable estimates of all Hispanic persons prior to 2007, and for non-Mexican-American Hispanic subgroups from 1999 to 2010. Poverty-income ratio (PIR) was determined by family income divided by the federal poverty threshold each year. For comparison with prior studies, 3 PIR categories were created: 1.3 or less (low), 1.4 to 3.5 (middle), and higher than 3.5 (high).

In NHANES III, participants were asked about number of ear infections, if they had ever worn a hearing aid, if they had been exposed to loud noise in the 24 hours prior to the exam,
and if they had listened to music through headphones in the past 24 hours. In NHANES 2005-2010, participants were asked if they had ever had 3 or more ear infections, and so the corresponding NHANES III answers were re-coded into “less than 3” and “3 or more” ear infections; NHANES 2005-2010 also included the same question on hearing aids but combined the recent noise and music with headphones exposures into a single question, so for this analysis we combined the NHANES III responses into 1 group (“yes” meaning either noise or music exposure). Additionally, NHANES 2005-2010 asked about both job-related and non-job-related exposure to loud noise of at least 5 hours per week, firearm use, and how often participants used hearing protection. For ease of analysis, answers to the question on hearing protection were dichotomized to “most or some of the time” and “rarely or never.”

Hearing Loss and Noise-Induced Threshold Shifts Criteria

We replicated definitions of hearing loss used by Shargorodsky et al.19 Henderson et al20: low-frequency hearing loss (LFHL) was defined as a pure-tone average (PTA) at 0.5, 1, and 2 kHz thresholds of 15 or more dB in either ear. High-frequency hearing loss (HFHL) had separate definitions in those 2 studies (Shargorodsky et al defined as PTA at 3, 4, 6, and 8 kHz ≥15 dB; Henderson et al used PTA at 3, 4, and 6 kHz ≥15 dB).20 We created a variable of HFHL for participants that met criteria for either of the definitions. Overall hearing loss, as defined by Shargorodsky et al was any hearing loss 15 or more dB in either ear (including HFHL or LFHL).20 A second, more conservative measure of overall hearing loss was defined as PTA 20 or more dB at 0.5, 1, and 2 kHz.

Noise-induced threshold shifts (NITS), as defined in prior studies,19 show a noise-notch audiometric pattern meeting the following 3 criteria: (1) thresholds at 0.5 and 1 kHz both 15 dB or less; (2) the maximum threshold at 3, 4, or 6 kHz is 15 or more dB higher than the highest threshold at 0.5 and 1 kHz; and (3) the threshold at 8 kHz is 10 or more dB lower than the maximal threshold at 3, 4 or 6 kHz.19

Statistical Analysis

Analytical techniques accounting for the multistage survey sampling and clustering design were used to obtain descriptive statistics using NHANES-provided sampling weights for each survey cycle. Data are reported as weighted and nationally representative estimates of means and frequencies unless otherwise stated. Sample means were compared using 2-sided t tests, and sample proportions were compared using Rao-Scott $x^2$ tests. The z score test was used for comparison of proportions between survey cycles, and 95% CIs were constructed using the Wald method. Multivariate logistic regression accounting for survey design was used to evaluate the relationship of dependent variables such as demographic characteristics and hearing-related risk behaviors to the odds of hearing loss or NITS for each survey cycle. The 3 cycles from 2005 to 2010 were also appended, using appropriate new sampling weights as provided by NHANES,17 into an aggregated data set for further regression analysis (for identifying secular trends in prevalence as well as increasing statistical power to identify risk factors for hearing loss).

Audiometric results of “no response” were recoded as the maximum dB threshold tested. Questionnaire responses of “refused” or “don’t know” were recoded as missing. Missing values were treated as not missing at random. SAS version 9.4 (SAS Institute) was used for all analyses, and all statistical tests were performed with a significance level of $P \leq .05$.

Because of the NHANES sampling design, estimates based on a denominator of less than 30 unweighted sample events are considered unreliable.17,20 Some variables (hearing aid use and race/ethnicity categories) were collapsed or excluded from regression models due to small sample size.

Results

Longitudinal Demographics

A total of 7036 participants were included across the 4 NHANES cycles; 1254 were excluded for incomplete examinations or discrepancy in the 1-kHz test-retest thresholds. The percentage of excluded participants was 23.7% from NHANES III, 18.0% from NHANES 2005-2006, 14.9% from NHANES 2007-2008, and 15.2% from NHANES 2009-2010. There were no significant differences between the sample and excluded participants by age, sex, race/ethnicity, or PIR except in NHANES III (mean PIR of sample is higher by 0.34) and NHANES 2009-2010 (average age of sample is 0.5 years older).

We assessed general and hearing-specific demographic features of the populations across all survey cycles (Table). Sex and age distribution remained stable. PIR increased significantly from 2.34 in NHANES III to 2.74 (difference in means, 0.4; 95% CI, 0.12-0.67) in NHANES 2005-2006 and was unchanged through NHANES 2009-2010. The percent of participants reporting 3 or more ear infections decreased from 71.1% in NHANES III to 34.2% to NHANES 2005-2006 (difference, 32.6%; 95% CI, 26.8%-38.4%); however, there were many missing responses in NHANES III (34.0%) compared with subsequent cycles (<1.0%), making this comparison unreliable. The proportion of participants exposed to loud noise or music with headphones 24 hours before audiometry increased from 20.8% in NHANES III to 44.7% in NHANES 2007-2008 (difference, 24.0%; 95% CI, 19.3%-28.6%) before stabilizing in NHANES 2009-2010. Job-related and job-unrelated exposures to loud noise, as well as firearm use, did not change. Hearing protection use decreased from NHANES 2005-2006 with 22.4% reporting use at least some of the time to only 14.6% in 2010 (difference, 7.8%; 95% CI, 2.4%-13.2%).

Hearing Loss Prevalence

The prevalence of hearing loss defined as a PTA of 20 or more dB did not show significant change from NHANES III to NHANES 2009-2010 (Figure 1). With a PTA of 15 or more dB, the prevalence was much higher. From NHANES III to NHANES 2007-2008, the proportion rose from 17.0% to 22.5% (difference, 5.5%; 95% CI, 0.6%-10.4%), before dropping to 15.2% (difference, 7.3%; 95% CI, 2.1%-12.5%) in NHANES 2009-2010. Prevalence of HFHL and LFHL followed a similar pattern of rise from NHANES III to a peak in NHANES 2007-2008 before decreasing in NHANES 2009-2010; though the change in HFHL...
was significant, the changes in LFHL were not. The prevalence of NITS also increased, though not significantly, from 15.8% in NHANES III to 17.5% in NHANES 2007-2008 (difference, 1.7%; 95% CI, −1.9% to 5.3%), then dropped to 12.8% by NHANES 2009-2010 (difference, 4.7%; 95% CI, 1.4%-8.0%).

To investigate for secular trend, the 3 survey cycles from 2005 to 2010 were appended into a single aggregated dataset, as has been done in previous studies.21 Linear regression analysis of hearing loss prevalence (including HFHL, LFHL, and NITS), with survey cycle year as the dependent variable, did not reveal any significant trend over time (data not shown).

Predictors of Hearing Loss
Overall, multivariate regression analysis showed little consistency among risk factors associated with hearing loss or NITS across survey cycles (eTable in the Supplement). Male sex and older age were associated with increased odds of hearing loss by certain definitions, and high PIR with lower odds of hearing loss, which have been previously described.9,18,19 Adjusted odds ratios (ORs) for hearing loss at 15 or more dB in the most recent cycle NHANES 2009-2010 are shown in detail in Figure 2. Non-Hispanic whites and those with high PIR (>3.5) had a lower likelihood of hearing loss than any other race/ethnicity category (OR, 0.659; 95% CI, 0.444-0.976) or the low PIR category (OR, 0.538; 95% CI, 0.295-0.979). History of 3 or more ear infections was also associated with increased odds of hearing loss (OR, 2.159; 95% CI, 1.463-3.185).

In Figure 3, individuals with 3 or more ear infections or low PIR maintained a higher prevalence of hearing loss compared to those with less than 3 ear infections or high PIR across all survey cycles. In contrast, whereas white, non-Hispanic children had a lower prevalence of hearing loss compared with all nonwhites through NHANES 2007-2008, this relationship changed in NHANES 2009-2010. By NHANES 2009-2010, non-white children had a significantly higher incidence of hearing loss when compared with white children. To increase statistical power (but at the cost of temporal resolution), we aggregated the 3 NHANES survey cycles from 2005 to 2010 and

### Table. Demographic Characteristics for US Children and Adolescents From NHANES III, NHANES 2005 to 2010

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>% of Weighted Sample</th>
</tr>
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<tr>
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<tr>
<td>Weighted†</td>
<td></td>
</tr>
<tr>
<td>Age, mean, y</td>
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</tr>
<tr>
<td>12-13</td>
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<td>18-19</td>
<td>23.2</td>
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<td>Female</td>
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<tr>
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</tr>
<tr>
<td>Worn a hearing aid</td>
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<td>the past 24 h</td>
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<td>noise for 5 h a week</td>
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<tr>
<td>Had exposure (non-job related) to loud</td>
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<tr>
<td>noise for 5 h a week</td>
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<tr>
<td>Used firearms</td>
<td>NA</td>
</tr>
<tr>
<td>Wear hearing protection</td>
<td>NA</td>
</tr>
</tbody>
</table>

Abbreviations: NA, not applicable; NHANES, National Health and Nutrition Examination Surveys; PIR, poverty income ratio.

† All percentages shown are of weighted sample.


analyzed this data set with multivariable logistic regression at a single time point. In this model, male sex, a history of 3 or more ear infections, and low PIR were found to be significantly associated with increased odds of hearing loss at 15 or more dB (Figure 4).

None of the regression models tested above demonstrated any constant, significant associations between NITS and noise exposure, including reported exposure to loud noise or music through headphones 24 hours prior to testing, prolonged job-related or job-unrelated noise exposures, firearm use, or hearing protection habits.

Discussion

As was previously reported through NHANES 2005-2006, we confirmed an increase in the prevalence of hearing loss and NITS from 1988 to 1994 through 2007 to 2008.9,10 Those trends did not continue, and prevalence of hearing loss actually decreased significantly between 2007 and 2010 to levels even lower than in NHANES III. Meanwhile, the percentage of participants reporting exposure to loud noise or music through headphones increased and remained elevated, and use of hearing protection declined. Notably, despite these seemingly concurrent changes in hearing loss prevalence and reported noise exposure through 2008, regression analysis did not reveal an association between noise exposures and hearing loss. There was also no association between NITS and noise exposures. In aggregate analysis of all survey cycles, we identified male sex, a history of 3 or more ear infections, and lower socioeconomic status as risk factors for hearing loss, corroborating results from NHANES III and NHANES 2005-2006.9,18,19 These findings in total call into question previous conclusions that increasing noise exposure is responsible for increasing levels of pediatric hearing loss.10,19

In NHANES 2009-2010, participants with the lowest PIR were more likely to have hearing loss than those participants with high PIR, even adjusting for known associations with sex and number of ear infections (as a proxy for access to medical care). This finding, while consistent with the literature and also
present globally, is concerning because it has persisted from 1988 through 2010.\(^9,16,22\) Participants from racial/ethnic minority backgrounds were also shown in NHANES 2009-2010 to have a higher likelihood of hearing loss than non-Hispanic whites.

When comparing hearing loss in NHANES with rates of hearing loss identified via universal newborn hearing screenings across the United States, the prevalence is higher in the 12-to-19-year-old age group by any PTA definition of hearing loss (when compared with an average of 1.1% of newborns in 2004-2006).\(^4,23\) Yet, this comparison is likely misleading, given that these early detection and intervention programs vary widely between states. Furthermore, over 40% of infants who fail the newborn screen are lost to audiologic follow-up, which suggests the true prevalence of newborn hearing loss may be higher than is currently reported.\(^23\)

Limitations
Large survey databases can only provide cross-sectional estimates, often primarily based on participant self-report, and so must be interpreted with caution. Though NHANES has been used widely for a myriad of conditions, it shares those limitations: hearing-related behaviors such as noise exposure and hearing protection use were all self-reported.\(^23,24\) However, because NHANES conducts standardized audiometric examinations, we did not use self-reported data in calculating prevalence of hearing loss. There is evidence too that such survey participants tend to underreport information such as health care use.\(^25,26\) It is therefore possible that the levels of noise exposure and hearing-related behaviors presented here underestimate the true prevalence.

This study included 3 sampling designs across 4 survey cycles; participant selection, questionnaires, and audiometric protocols and equipment for NHANES III were distinctly

Figure 3. Prevalence Estimates for Hearing Loss of 15 dB or More Among Different Demographic Groups

A. Overall prevalence and 95% CIs for hearing loss of 15 dB or greater; B, prevalence and 95% for hearing loss by white non-Hispanic and nonwhite status; C, hearing loss by history of 3 or more vs fewer than 3 ear infections; and D, hearing loss by high or low PIR. Error bars represent 95% CIs.

AOM indicates acute otitis media; HL, hearing loss; NHANES, National Health and Nutrition Examination Survey; PIR, poverty income ratio.
different from the 3 cycles between 2005 and 2010.\textsuperscript{11,12,15,16} From 2005 to 2010, only the sampling design changed in 2007 in terms of study locations and oversampling of minority groups.\textsuperscript{13} It is possible the observed increase in hearing loss from NHANES III to NHANES 2007-2008 was an artifact of sampling design or change in audiologic methods. There were no design changes from 2007 to 2010, and yet a large and significant decrease in prevalence of hearing loss was seen. Another potential source of bias is the group of participants excluded on the basis of incomplete examinations. Examinations may have been left incomplete because of uncooperative subjects, potentially with more severe hearing loss. These interactions are not recorded in survey documentation.

Despite those limitations, this study is the first to describe audiometric data and hearing-related behaviors in this population age 12 to 19 years from the NHANES cycles from 2007 to 2010. Though definitions of hearing loss, HFHL, and LFHL have not been standardized across disciplines,\textsuperscript{4} this analysis included several definitions used previously and found no significant trends in prevalence throughout. Similar associations between hearing loss, race/ethnicity, and low socioeconomic status were suggested in prior studies, but this study is the first study that we know of to demonstrate these findings in a nationally representative sample with the most up-to-date, comprehensive, and standardized audiometric testing available.\textsuperscript{18,27-29} The effects of PIR and race/ethnicity in NHANES 2009-2010 are independent of each other, and the underlying causes of these disparities are still not well understood.\textsuperscript{30} This fact, that a racial and ethnic disparity exists beyond socioeconomic status, has crucial implications for future efforts to prevent and treat hearing loss, especially if prevalence continues to rise in these populations.

It may be that there was a true increase in the prevalence of hearing loss in youth ages 12 to 19 years between 1988 and 2008, during an upswing in recreational noise exposure through headphones or personal music players. This increase may have subsequently stabilized due to awareness efforts of the risks of noise exposure, though the relationship to hearing loss remains unclear.\textsuperscript{31} It could be that these differences between survey cycles are owing to changes in sampling or examination methods, or represent fluctuations over a larger pattern requiring more data to visualize. Our findings have demonstrated significant and independent associations between hearing loss and characteristics such as sex, history of ear infections, and in the most recent cycle, socioeconomic status, and race/ethnicity. All of these subgroups may be of interest as targets for policymakers and public health interventions, particularly since even mild hearing loss in children has been demonstrated to impact educational and functional outcomes.\textsuperscript{1} Unfortunately, though the NHANES continues to conduct survey cycles, most recently through 2016, the survey design no longer includes audiometric evaluation of children and adolescents in this age group of 12 to 19 years. Continuation of NHANES-based audiometric analysis of this cohort will be essential to determine the ultimate future course of these trends.

Conclusions

In contrast to prior studies, this analysis of nationally representative survey data from 1988 through 2010 did not identify significant increasing or decreasing trends in prevalence of hearing loss among US children and adolescents ages 12 to 19 years. While reported exposure to loud noise increased and use of hearing protection declined over the same period, there were no consistent associations between noise exposures and hearing loss or NITS. The most recent survey data showed increased risk of hearing loss among participants of racial/ethnic minority status and from lower socioeconomic backgrounds. Further investigation into factors influencing these changes and continued monitoring of these groups are needed going forward.
Prevalence of Hearing Loss in US Children and Adolescents

Original Investigation Research

With hearing loss.

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functional status.

prevalence, educational performance, and

with minimal sensorineural hearing loss:

REFERENCES

National Institutes of Health.

necessarily represent the official views of the

the responsibility of the authors and do not

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authors.

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All authors.

Conflict of Interest Disclosures:

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All authors have completed and submitted the ICMJE Form for

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Conflict of Interest Disclosures:

Disclosure of Potential Conflicts of Interest and

Conflict of Interest Disclosures:

Conflict of Interest Disclosures:

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REFERENCES


