NOISE-INDUCED HEARING LOSS IN TEENAGERS

Robert S. Schlauch
Department of Speech-Language-Hearing Sciences
University of Minnesota
Minneapolis, MN 55455

Introduction

The present author was invited to write the following article for Acoustics Today as a result of a memo he had sent to Thomas Rossing, the Editor of ECHOES, in regard to a recently published item. The Summer 2013 issue (Vol. 23, No. 3) of *ECHOES* carried the following news item (page 7) in its section titled "Acoustics in the News:"

> "Noise, not age, is the leading cause of hearing loss, an article in the March 26 issue of the *New York Times* reminds us. Tens of millions of Americans, including 12 to 15 percent of school-age children, already have permanent hearing loss caused by everyday noise that we take for granted. After poor service, noise is the commonest complaint about restaurants. Yet many proprietors believe that their customers spend more on food and drink in bustling eateries and do little to minimize sound levels. A survey by the American Speech-Language-Hearing Association found that 35 percent of adults and up to 59 percent of teenages reported listening to portable music devices at loud volumes. Some toys meant for young children, such as talking dolls, vehicles with horns, rubber squeaky toys, and musical instruments generate ear-damaging levels of noise."

"Pure-tone audiometry is the gold standard for quantifying hearing loss, but it is limited in its precision when identifying a small change in hearing or a mild hearing loss caused by incipient noise-induced hearing loss."

The cited article in the New York Times is available online at the site http://well.blogs.nytimes.com/2013/03/25/what-causes-hearing-loss/

It has the title "What causes hearing loss," and is authored by Jane E. Brody, who is the personal health columnist for the Times. (She has been called the "high priestess of health" by Time Magazine.) The article carries the provocative statement, "Tens of millions of Americans, including 12 to 15 percent of school-age children, already have permanent hearing loss caused by everyday noise that we take for granted," that was included in the *ECHOES* piece cited above, but the Times article does not include any explicit source for the stated statistic.

Such statements are not unusual in the popular literature, and it may well be that the percentage range, 12 to 15 percents, is a commonly accepted premise regarding teen-age hearing loss.

Research that the author and his colleagues have reported over the past few years has shown that this percentage range, 12 to 15, is highly inflated, and seeing this in the news (again) motivated the present author to write this article for *Acoustics Today*.

Possible sources of the 12 to 15 percent assertion

The NY Times article did not list a citation for the high prevalence of school-aged children's noise-induced hearing loss (NIHL), but the likely source is one of two published analyses of National Health and Nutrition Examination Survey (NHANES) data (Niskar et al., 2001; Shargorodsky et al., 2010). NHANES data are collected periodically from a representative sample of adults and children throughout the United States to provide health statistics and an understanding of the risk factors that contribute to diseases and health conditions. Hearing is one of the conditions assessed in these surveys. NHANES data are stored online and can be accessed by researchers. Table 1 summarizes the findings of several analyses of NHANES data from children along with their methods, controls, and findings. Subsequent sections of this article will expand on the content of this table to reveal what is known about NIHL in school-aged children.

Studies that reported a high prevalence of NIHL in school-aged children

Niskar et al. (2001) analyzed NHANES children's data collected between 1988-1994 (http://www.cdc.gov/nchs/nhanes/nh3data.htm) for notched hearing loss configurations, a loss often seen in persons with NIHL caused by workplace exposure. In early NIHL, hearing loss usually is seen first for frequencies between 3 kHz and 6 kHz. Even though most sounds that cause NIHL are broadband, the ear canal and concha can boost the level of high frequency sounds at the eardrum by more than 20 dB relative to that for other frequencies: this makes regions of the cochlea that code frequencies between 3 and 6 kHz more susceptible to damage. Niskar et al. selected criteria for defining a notched audiogram that required reduced thresholds at 3, 4 or 6 kHz and better thresholds for lower frequencies and for 8 kHz. Figure 1shows a typical notched audiogram that exceeds Niskar et al.'s criteria for a hearing loss configuration they labeled as a noise-induced threshold shift (NITS). The author and his colleagues prefer the term high-frequency notched (HFN) audiogram rather than NITS because these notched audiograms have other causes, including genetic hearing loss and measurement variability. Their analy-

Table 1. A summary of studies that estimated school-age hearing loss using national survey data. Percentages in Niskar et al. (2001) and Shargarodsky et al. (2010) represent an estimate of prevalence in the United States; Percentages in Schlauch and Carney (2011,2012) represent the percentage of the sample.

Study	NHANES data	Selection Criteria	Method	Findings
Niskar et al. (2001)	1988-1994 (N = 5249) ages 6-19	Required normal middle-ear function, complete audiometric data, and no ear drainage at the time of the test	Counted audiograms with high-frequency notches (HFNs)	12.5% of children had HFNs, consistent with NIHL
Schlauch and Carney (2011)	1988-1994 (N = 5089) ages 6-19 + simulation	Required normal middle ear function, complete audiometric data and no ear drainage at the time of the test	Computer simulations of "flat" audiograms used to estimate false-positive HFNs	7 -10% of simulated children had HFN audiograms (depending on the assumptions) compared with 7.7% of children aged 6-11 and 14.9% of children aged 12-19
Schlauch and Carney (2012)	1988-1994 N= 134, ages 6-11; N=175 ages 12-19	Required normal middle ear function, complete audiometric data and no ear drainage at the time of the test	Each child tested twice and audiograms a veraged before applying notch criteria	No notches observed in the young group (6-11); 6.3% of children in the older group (12-19) had HFNs Averaging audiograms improves precision (reduces false positive identification of NIHL)
Shargadrodsky et al. (2010)	(N = 1951) ages 12-19	Children with incomplete audiometric data, ear pain, and cochlear implants were excluded	Calculated pure tone averages to identify low-frequency and high-frequency (HF) hearing loss (average threshold > 15 dB HL)	1 in 5 teens have hearing loss; 16.4% have HF hearing loss
Schlauch and Carney (2012)	1988-1994 & 2005-2006 Ages 6-19 (all of the children from both cohorts of NHANES studies)	Examined selected (excluded children with possible middle and external ear problems, earaches and impacted ear wax) and unselected (criteria identical to those of Shargardsky et al.) groups of children	Estimated the percentage of children with HF and low frequency hearing loss using Shargorodsky et al.'s criteria	6% of selected (otologically normal) teens (NHANES 2005-2006) found to have HF hearing loss (with no low-frequency component) 18% of a group of children 6-8, who have no risk factors for NIHL, have HF hearing loss, even after excluding children with abnormal middle-ear function 15 dB HL is too low of a pass-fail criterion for boundary between normal hearing and hearing loss

sis found that 12.5% of children 6-19 years old had HFNs. Children were divided into two age groups, 6-11 year olds and 12-19 year olds, and the prevalence rate of these notched audiograms was 8.5% and 15.5% in the younger and older children, respectively.

Shargorodsky et al. (2010) analyzed a more recent sample of NHANES data collected between 2005-2006 (http://www.cdc.gov/nchs/nhanes/nhanes2005-2006/nhanes05_06.htm) for 12-19 year olds and replicated Niskar et al.'s finding of a high percentage of notched audiograms. They also reported the prevalence of high-frequency hearing loss (average thresholds for 3, 4, 6 and 8 kHz) – a new metric - and found that that between 1988-1994 and 2005-2006 this prevalence increased in teens. Shargorodsky et al. found that 1 in 5 teens in the more recent sample of NHANES data have hearing loss. They suggested that the higher prevalence of hearing loss in the more recent survey could be a result of noise exposure related to the use of personal stereo devices, such as iPods. They urged caution in the interpretation of their data because they could not establish causality with their methods nor did they rule out conductive hearing loss.

Despite Shargorodsky et al.'s cautions, following publication of their study newspaper headlines and television broadcasts around the United States led with the news that 1 in 5 teens has hearing loss and that the loss may be linked to exposure from personal stereo devices. A Google search of "1 in 5 teens" and "hearing loss" found 12,900 results, nearly all of which are related to Shargorodsky et al.'s study. This 20% prevalence figure is higher than the 12-15% cited by the NY Times article summarized in *ECHOES*. These percentages could be related to the percentage of notched audiograms found in the earlier study by Niskar et al. At the time my article was submitted to *Acoustics Today* (August, 2013), a CDC website (http://www.cdc.gov/healthyyouth/noise/index.htm) claims that 12.5% of school-age children have NIHL. The CDC cites Niskar et al. (2001) for this statistic.

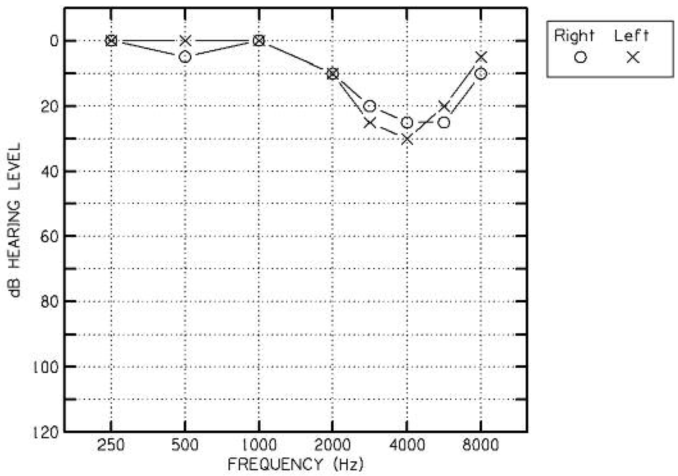

Figure 1. An audiogram with a high-frequency notch typical of a person with hearing loss caused by exposure to intense sound. Niskar et al. labeled an audiogram as notched if it met all of the following criteria: 1) thresholds at both 0.5 kHz and 1.0 kHz of 15 dB HL or better; 2) the poorest threshold at 3.0, 4.0 or 6.0 kHz at least 15 dB higher (poorer) than the poorer threshold at 0.5 or 1 kHz; 3) the threshold at 8 kHz had to be 10 dB or more lower than the poorest threshold at 3.0, 4.0 or 6.0 kHz.

Computer simulations to estimate the percentage of false-positive notched audiograms

My colleagues and I (Schlauch and Carney, 2011,2012; Jin et al., 2013) arrived at a different conclusion about the prevalence of NIHL in teens by using a variety of techniques, including computer simulation. Schlauch and Carney (2011) used Monte Carlo methods to derive an estimate of the "false positive rate" for high-frequency notched (HFN) audiograms by considering limits in the precision of pure tone audiometry. The simulation procedure is shown in Figure 2. For purposes of simulating audiograms, children were assumed to have flat audiograms (i.e., equal dB HL values at each frequency in Figure 1) with thresholds within the normal range (less than 15 dB HL). A "measured" threshold was obtained from a continuous sampling distribution centered on the actual threshold that considered the variability of threshold measurement (a 5-dB standard deviation). These measured values were then discretized because audiometric thresholds are measured in discrete, 5-dB steps. Next, Niskar et al.'s rule for a notched audiogram was applied to the result for each simulated person's audiogram. Our simulated population sample size matched the more than 1000 persons in the NHANES survey. Using this approach, we found that roughly 10% of the simulated audiograms had HFNs. This is consistent with a10% false-positive rate. The audiograms in Figure 3 represent a sample of ones obtained from our simulation that were found to have HFNs meeting Niskar et al.'s criteria.

Retesting Thresholds to Improve Accuracy

There is additional evidence that the high-frequency notches found in the NHANES data represent false positive findings for NIHL. Schlauch and Carney (2012) found a subsample of about 10% of the NHANES child participants from 1988-1994 that were retested a short time after the first test. The first test of this subsample was representative of the overall sample in its percentage of HFNs. The second test showed a much smaller percentage of notches, perhaps because the audiometry was done more carefully. Further, when the thresholds from the first test and the retest were averaged, none of the 134, 6-11 year old children had HFNs. By contrast, the analysis of averaged audiograms yielded 6.3% HFNs in the 175, 12-19 year old children, a drop from 16% found for the first test. This finding demonstrates that audiometry is improved by making multiple measurements of threshold. It also shows that the teen group had more HFNs after averaging audiograms than did the younger group. Does this mean that the teens are more likely to have NIHL than the younger group? That is a possibility but we also found that the younger group consistently showed higher thresholds for 8 kHz than the teens. Higher thresholds at 8 kHz in the younger group make it less likely that a notch will be observed because the criteria for a HFN require better thresholds at 8 kHz than at 3, 4 or 6 kHz. That is, the right side of the notch is defined by a better threshold at 8 kHz than for 3, 4 or 6 kHz. The cause of the higher thresholds at 8 kHz in the younger group is unknown.

Excluding children from the sample with hearing loss unrelated to NIHL

Schlauch and Carney (2012) also addressed Shargorodsky et al.'s finding that 1 in 5 teens have hearing loss. Shargorodsky et al. selected 15 dB HL as the cut off between "normal hearing" and "mild hearing loss." Normal hearing is a range of levels rather than a single level. Zero dB HL defines average normal hearing at a particular frequency, and these norms are based on data obtained using very carefully administered audiometry from a group of highly motivated participants selected to be otologically normal.

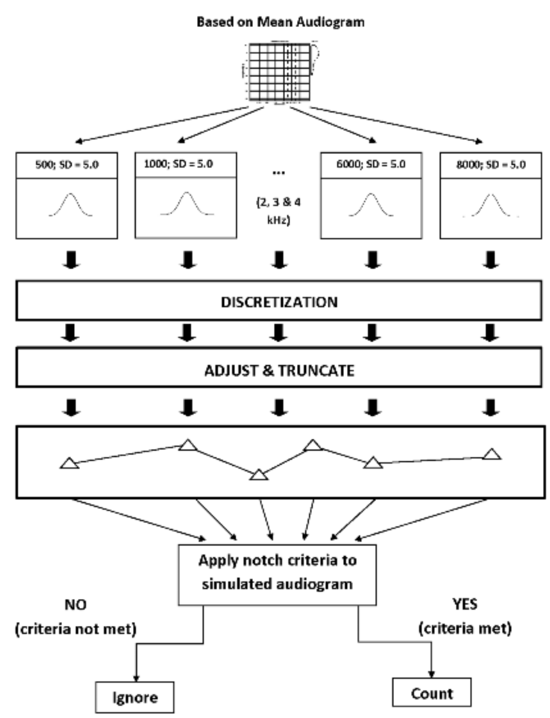

Figure 2. The computer simulation procedure used by Schlauch and Carney (2011) to estimate the likelihood of spurious, high-frequency notched audiograms due to measurement variability. The input to the simulation was a flat audiogram with equal thresholds at each frequency. The standard deviation of threshold was assumed to be 5 dB at each frequency.

Shargorodsky et al used an unselected sample of the NHANES data for their analysis and these survey data were not collected with the same rigor as the laboratory methods used to define the reference values for dB HL (Schlauch and Carney, 2012). In Shargorodsky et al.'s cohort, children with conditions that are known to elevate thresholds, such as abnormal middle-ear function (such as with otitis media) or impacted earwax, were not excluded from their analysis. At the time the NHANES audiograms were collected, participants' middle ear function was assessed and otoscopy was performed. Schlauch and Carney (2012) performed an independent analysis of the NHANES 2005-2006 data (the same data that Shargorodsky et al. used in their study) and excluded persons who had abnormal middle-ear function, abnormal otoscopy, or any other factor that could have affected thresholds that is unrelated to NIHL. We found that only 6% of 12-19 year old children had high-frequency losses (with no low-frequency component).

Selecting the boundary (cut off) between "normal hearing" and "hearing loss"

Another concern with Shargorodsky et al.'s analysis is the cut off for normal hearing. An examination of the audiograms from the selected group in our analysis of the NHANES teens judged to be otologically normal showed that their average thresholds were between 5 and 10 dB HL at each frequency rather than 0 dB HL, the expected value.

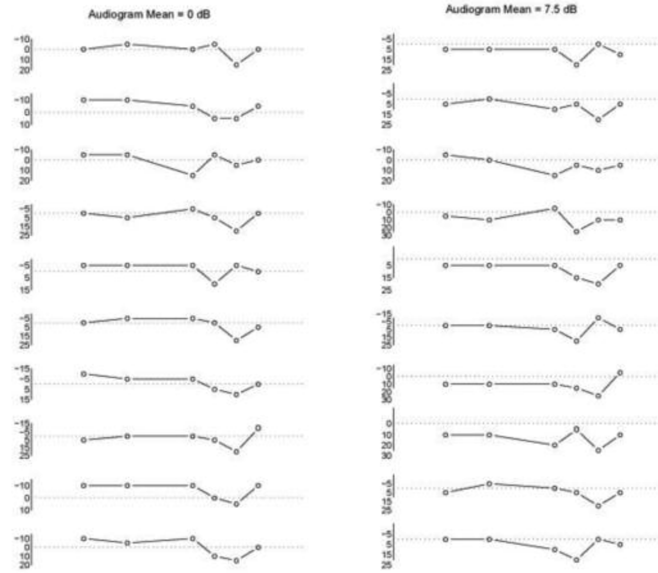

Figure 3. Examples of simulated, flat audiograms labeled as having high-frequency notches using criteria proposed by Niskar et al. (2001). These deviations from a flat a audiogram represent "false positive" notches that reflect variability caused by the imprecision of pure tone audiometry. For illustration purposes, the mean value for the flat audiogram that was the input to the simulation was fixed at either 0 dB HL or 7.5 dB HL rather than drawn from a normal distribution

Given these elevated average thresholds in the otologically normal group and the known variability of pure-tone audiometry, 15 dB HL is too low a cut-off to define the boundary between normal hearing and hearing loss. This is particularly true for thresholds at 6 and 8 kHz which are much more variable than ones for frequencies between 0.5 kHz and 4 kHz when measured using supraaural earphones, the type used in the NHANES study. This problem of high variability with supraaural earphones is exacerbated at 6 kHz because of a calibration error that makes thresholds about 5 dB poorer at this frequency than those at adjacent frequencies in young persons with no history of ear disease and or noise exposure (Lutman and Qasem, 1998). This calibration error makes it much more likely a false-positive HFN will be observed and, consequently, increases the chance of observing a false high frequency hearing loss. Using Shargorodsky's criteria for a high-frequency hearing loss, we found the same high prevalence for hearing loss in a group of 6-8 year olds in the NHANES 1988-1994 data that Shargorodsky et al. reported for teens in their study. Children who are 6-8 years old are at a low risk for NIHL.

Conclusions

Our studies (Schlauch and Carney 2011, 2012) demonstrate that the percentage of children with NIHL is much lower than suggested by some other analyses of the NAHNES data. Pure tone audiometry is the gold standard for quantifying a hearing loss, but it is limited in its precision when identifying a small change in hearing or a mild hearing loss caused by incipient NIHL. The diagnosis of incipient NIHL can be improved by making multiple measurements of thresholds and averaging (Schlauch and Carney 2011, 2012; Jin et al., 2013) and by completing a complete diagnostic audiometric exam, which includes an assessment of middle-ear function, otoscopy, and bone-conduction thresholds. Bone-conduction thresholds were not measured as part of the NHANES protocol.

There is some evidence (Schlauch and Carney, 2007) that insert earphones may produce less variable (more precise) high-frequency thresholds than the supraaural earphones required by OSHA for industrial hearing monitoring. Insert earphones can also be calibrated in the ear canal using a probe-tube microphone to correct for deviations of the targeted SPL at the eardrum in individual ears (see Scheperle, Goodman & Neely, 2011). It is also important to have accurate baseline thresholds and complete personal history information (Jin et al., 2013).

Finally, the absence of evidence of widespread hearing loss in teens does not mean children are not at risk for NIHL. Kujawa and Liberman (2009) have reported extensive damage to the cochlea following noise exposure that is not measurable using pure-tone thresholds. The hearing loss may appear years after the damage to the cochlea occurred. Youth should be taught about the risks that intense sounds pose to hearing and about the use of hearing protection devices.**AT**

References

Jin, S., Nelson, P.B., Schlauch, R.S. and Carney E. (**2013**). "Hearing conservation program for marching band members: risk for noise-induced hearing loss?," American Journal of Audiology 22, 26-39.

Kujawa, S. G., and Liberman, M. C. (**2009**). "Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss," Journal of Neuroscience 29, 14077-14085.

Lutman, M. E. and Qasem, H. Y. N. (**1998**). "A source for notches at 6.0 kHz. In Advances in Noise Research: Biological Effects of Noise", Vol. I (Edited by D. Prasher & L. Luxon). (Whurr Publishers Ltd., London), pp 170-176

Niskar, A. S., Kieszak, S. M., Holmes, A. E., Esteban, E., Rubin, C., and Brody, D. J. (**2001**). "Estimated prevalence of noise-induced hearing threshold shifts among children 6 to 19 years of age: The third national health and nutrition examination survey, 1988-1994, United States," Pediatrics108, 40-43.

Occupational Safety and Health Administration. (**1983**). Occupational noise exposure: hearing conservation amendment. Occupational Safety and Health Administration, 29 CFR 1910.95; 48 Federal Register, 9738–9785.

Scheperle A., Goodman S.S., and Neely S. (**2011**). "Further assessment of forward pressure level for in situ calibration," Journal of the Acoustal Society of America 130, 3882-3892.

Schlauch R.S., and Carney E. (**2007**). "A multinomial model for identifying significant pure-tone threshold shifts," Journal of Speech, Language, and Hearing Research 150, 1391–1403.

Schlauch R.S., and Carney E. (**2011**). "Are false-positive rates leading to an overestimation of noise-induced hearing loss?," Journal of Speech, Language and Hearing Research 54, 679-692.

Schlauch R.S., and Carney E. (**2012**). "The challenge of detecting minimal hearing loss in audiometric surveys," American Journal of Audiology 21, 106-119.

Shargorodsky, J., Curhan, S., Curhan, G., and Eavey, R. (**2010**). "Change in prevalence of hearing loss in US adolescents," Journal of the American Medical Association 304, 772-778.

Robert Schlauch is a professor in the Department of Speech-Language-Hearing Sciences at the University of Minnesota where he joined the faculty in 1989. His research interests include intensity perception (psychoacoustics), cognitive factors influencing hearing, and diagnostic audiology. He is a Fellow of the Acoustical Society of America and of the American Speech Language Hearing Association.