Published in final edited form as:
*Am J Ind Med*. 2014 September ; 57(9): 1001–1010. doi:10.1002/ajim.22323.

# Do Hearing Protectors Protect Hearing?

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## Abstract

**Background—**We examined the association between self-reported hearing protection use at work and incidence of hearing shifts over a 5-year period.

**Methods—**Audiometric data from 19,911 workers were analyzed. Two hearing shift measures—OSHA standard threshold shift (OSTS) and high-frequency threshold shift (HFTS)—were used to identify incident shifts in hearing between workers' 2005 and 2009 audiograms. Adjusted odds ratios were generated using multivariable logistic regression with multi-level modeling.

**Results—**The odds ratio for hearing shift for workers who reported never versus always wearing hearing protection was nonsignificant for OSTS (OR 1.23, 95% CI 0.92–1.64) and marginally significant for HFTS (OR 1.26, 95% CI 1.00–1.59). A significant linear trend towards increased risk of HFTS with decreased use of hearing protection was observed (P = 0.02).

**Conclusion—**The study raises concern about the effectiveness of hearing protection as a substitute for noise control to prevent noise-induced hearing loss in the workplace. Am. J. Ind. Med. 57:1001–1010, 2014. Published 2014. This article is a U.S. Government work and is in the public domain in the USA.

### Keywords

noise; hearing protection; occupational hearing loss; noise-induced hearing loss

## INTRODUCTION

Noise is a serious occupational hazard, which can lead to hearing loss, tinnitus, impaired communication, sleeping disorders, stress, and cardiovascular disease [Nelson et al., 2005]. Noise exposure is widespread in the workplace, with 22 million workers in the U.S. self-reporting hazardous noise exposure in their current job [Tak et al., 2009]. The most effective strategies against the effects of noise are to reduce noise at the source (noise control) or remove the worker from the noisy environment (administrative control). When these two

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methods prove insufficient to reduce noise to safe levels due to technologic or economic constraints, workers must use hearing protectors.

Hearing protectors are personal protective equipment worn over the ears (ear muffs) or in the ear canals (ear plugs) to block hazardous noise from reaching the sensory structures of the ear. When appropriate hearing protectors are properly fit and consistently worn, they can effectively prevent development of noise-induced hearing loss. Workers must be trained—and retrained—in their use in order to obtain long-term, effective levels of noise attenuation [Murphy et al., 2004]. The U.S. Occupational Safety and Health Administration (OSHA) [1983] requires employers in most industries to provide hearing protectors and appropriate training to their noise-exposed workers as part of an effective hearing conservation program. Hearing conservation programs also include noise monitoring, hearing testing, program evaluation, and other requirements. However, some U.S. industries are regulated by less comprehensive noise regulations (e.g., construction) [Occupational Safety and Health Administration, 2002] or have no noise regulation at all (such as agriculture).

Although hearing protectors can be effective in reducing occupational noise exposures to safe levels, previous studies have repeatedly shown that many workers do not achieve the expected level of protection from a hearing protector [Lempert and Edwards, 1983; Hempstock and Hill, 1990; Berger, 1994]. Furthermore, selection of hearing protectors has historically focused primarily on the noise attenuation characteristics of the device, without consideration of other factors such as comfort and ease of use. As a result, many workers do not wear hearing protectors consistently or correctly, leading to an increase in noise dose over the workday [Hsu et al., 2004].

As hearing protectors are frequently used to reduce noise to safe levels, and as prior research indicates that many workers do not wear their hearing protectors correctly or consistently, it is essential to evaluate whether these devices, as they are used in the workplace, are effective in preventing occupational hearing loss (OHL). However, relatively few studies have examined this question and those that have produced equivocal results. One small study [Neitzel and Seixas, 2005] found no association between self-reported use of hearing protection and hearing ability among construction workers. Another larger study involving the longitudinal analysis of Canadian sawmill workers' audiometric records found that regular use of hearing protectors reduced the risk of threshold shift by 30% and delayed the median age at which the shift occurred by 2.4 years [Davies et al., 2008]. However, despite hearing-protector interventions, the workers were still at substantial risk for noise-induced hearing loss.

The purpose of this study was to evaluate the efficacy of hearing protectors in preventing OHL among noise-exposed U.S. workers using longitudinal audiometric data from the National Institute for Occupational Safety and Health (NIOSH) OHL Surveillance Project. This project maintains a large repository of audiometric data collected from workers in thousands of companies in a variety of industries across the U.S.

# MATERIALS AND METHODS

## Study Design and Population

We employed a retrospective cohort study design to investigate the effect of self-reported use of hearing protectors on the 5-year incidence of hearing shifts among workers exposed to hazardous noise. We analyzed audiometric records from 2005–2009 for 19,911 male and female workers ages 18–65 years. These data were collected by the NIOSH OHL Surveillance Project from audiometric service providers (i.e., providers) who perform audiometric testing for U.S. workers in regulated industries. Audiometric service providers shared de-identified audiograms with NIOSH as described in Masterson et al. [2012]. Because the audiograms were de-identified before being sent to NIOSH, a project exemption was obtained from the NIOSH Institutional Review Board.

Each audiogram includes: an arbitrary employee identification number unique to the individual worker (employee ID); date of test; hearing threshold values at frequencies 0.5, 1, 2, 3, 4, 6, and 8 kHz; industry code classified using the 2007 North American Industry Classification System (NAICS); and limited demographic data including the worker's age and sex. Some audiograms also include responses to questions posed to workers during testing, such as whether they wear hearing protection, have non-occupational noise exposures (hunting, military, or other recreational), are taking any medications, have an infection at the time of the test, etc. However, the extent to which these fields are populated varies, such that some providers never recorded these responses, some did so intermittently, and others did so fairly consistently.

This analysis utilized audiometric records from one provider that consistently recorded data on workers' self-reported use of hearing protection at work. Our analytic sample dataset included the most recent (last) audiogram from each of the years 2005–2009 for all workers ages 18–65 years who had at least one valid audiogram in both 2005 and 2009 and who had at least one additional valid audiogram during the three intermediate years of the study period (i.e., had no more than 2 years without an audiogram during the study period). These criteria were adopted to provide sufficient evidence to infer continuous employment with exposure to hazardous noise. Substantial reductions in sample size would have resulted if audiograms were required for every year of the study period.

While there are exceptions, such as when companies choose to test all of their employees regardless of noise exposure, the vast majority of the audiograms included in the database were conducted because the workers were exposed to hazardous noise and were included in government-mandated hearing conservation programs (HCPs). For example, the OSHA Occupational Noise Exposure regulation for general industry requires that employers administer a continuous, effective HCP—including baseline and subsequent annual audiograms—for all employees whose noise exposures equal or exceed an 8-hr time weighted average of 85 dBA [Occupational Safety and Health Administration, 1983]. In this study, audiometric testing is assumed to imply that the worker was exposed to hazardous noise.

## Audiogram Inclusion and Exclusion Criteria

Because the audiograms included in the NIOSH repository were originally collected for administrative rather than research purposes, records may be incomplete or inaccurate [Laurikkala et al., 2000]. Consequently, audiograms that did not meet quality standards were removed from the analysis. Audiograms indicative of hearing impairment due to non-occupational factors or pathology were also removed. Specifically, audiograms were excluded if they contained unlikely threshold values suggesting testing errors, negative slope indicative of excessive background noise during testing, or large inter-aural differences suggesting non-occupational pathology and possible “crossover” from the bad ear to the good. Procedures for identifying these audiograms are described elsewhere [Masterson et al., 2012]. Audiograms with missing values for age, sex, NAICS (industry) code, or threshold values at frequencies 2, 3, 4, or 6 kHz were also dropped from the analysis. Finally, audiograms from workers in the mining industry sector were excluded due to insufficient numbers.

## Variables

The dependent variable in this study was change in hearing between each worker's 2005 audiogram (designated baseline) and 2009 audiogram (current). We analyzed two measures of hearing shift. The first measure was an OSHA standard threshold shift (OSTS), defined as a 10 dB or greater increase in the average pure-tone hearing threshold across the frequencies 2, 3, and 4 kHz in either ear from the baseline audiogram to the current audiogram. OSTS is commonly used among hearing conservationists and incorporates frequencies within the speech range. The second measure was a high frequency threshold shift (HFTS), defined as a 10 dB or greater increase in the average pure-tone hearing threshold across the frequencies 3, 4, and 6 kHz in either ear—again comparing the 2009 audiogram with the 2005 baseline. HFTS is a measure of hearing change at the frequencies which are usually the first to be impaired by exposure to hazardous noise. Both outcome variables were dichotomous and coded as 1 if a shift was present and 0 if not. Because OSTS and HFTS were defined in relation to a 2005 baseline—corresponding to the beginning of our study period—all shifts were considered incident cases.

Our main independent variable, self-reported use of hearing protection at work, was constructed from 2005–2009 questionnaire responses collected from workers prior to audiometric testing and included in their audiometric record. Workers completed a survey which included the question “Do you normally work in noise *WITHOUT* using your hearing protection in required areas?” Workers’ responses were used to create an ordered categorical exposure variable with three levels: 1-never, 2-sometimes, and 3-always. If a worker reported not wearing hearing protection (i.e., answered “yes”) for every available audiogram during 2005–2009, the variable was coded 1-never. Conversely, if a worker reported on every audiogram that he or she did wear hearing protection (i.e., answered “no”), it was coded 3-always. If, however, a worker answered “yes” on at least one audiogram and “no” on at least one audiogram during 2005–2009, the variable was coded 2-sometimes.

Worker age (in 2009) and sex were included in the analysis as covariates. We also controlled for industry sector, comprised of groupings of two-digit NAICS codes.

Additionally, dichotomous variables reflecting workers' self-reported exposure to recreational target shooting or hunting and other non-occupational hazardous noise were included. These questions were also part of the questionnaire that workers completed prior to audiometric testing. Workers who reported these exposures on any audiogram from 2005 to 2009 were considered positive for that exposure. Finally, we included a continuous variable reflecting the number of years each worker had an audiogram prior to 2005 as a proxy measure to control for variability in the duration of workers' exposure accumulated before the 2005–2009 observation period. Data on other potentially important covariates such as smoking, race, income, education, and occupation were unavailable.

## Statistical Analysis

The 5-year cumulative incidence of OSTS and HFTS was calculated as the proportion of workers with a given shift at their last audiogram in 2009. Point estimates and 95% confidence intervals for the incidence proportion of both shift measures were produced for the full sample and by sex, industry sector, exposure to recreational shooting or hunting, exposure to other recreational noise, and hearing protector use.

The bivariate association between self-reported use of hearing protection at work (an ordinal variable) and the incidences of OSTS and HFTS was assessed using the Cochran–Armitage test for trend. Associations between nominal independent variables (sex, industry sector, exposure to recreational shooting or hunting, and exposure to other recreational noise) and the outcome variables were assessed using the Chi-square test for independence. For continuous variables (age and duration of exposure), we used the *t*-test for equal means or, where necessary, the Cochran and Cox approximation of the *P*-value for the *t*-test to account for unequal variances. Statistical significance for all tests was indicated based on an Alpha level of 0.05. All analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC).

To evaluate the relationship between self-reported use of hearing protection at work and the 5-year cumulative incidences of OSTS and HFTS, while controlling for other factors, we modeled adjusted odds ratios and their 95% confidence intervals using logistic regression. However, because our data consisted of workers clustered within companies, and company may strongly influence the safety culture, including the use of hearing protection, we also wished to quantify the inter-company variability in the risk of hearing shifts. Therefore, we employed a multi-level analysis which takes into account the hierarchical structure of the data [Searle, 1987; Goldstein, 1995; Hox, 2002]. Using the logit link function for binomial data, we fit a generalized multilevel, multivariable model using the SAS GLIMMIX procedure to estimate adjusted odds ratios for OSTS and HFTS for all independent variables (fixed effects), while specifying company as a random effect. Also using the SAS GLIMMIX procedure, we performed linear trend tests of the levels of self-reported use of hearing protection at work for the OSTS and HFTS outcomes.

We described the degree to which the company effect influenced the risk of OSTS and HFTS in terms of the median odds ratio (MOR) [Larsen et al., 2000]. The MOR is a simple function of the cluster (company-level) variance and converts it to the familiar odds ratio scale, where 1 is the null value. That is, when the MOR = 1, there is no company effect. The MOR is always ≥1. Here, the MOR is defined as the median value of the odds ratio between the higher and lower risk of two randomly selected companies, that is, the median increase in risk that would result from a worker moving to another company with a higher risk [Merlo et al., 2006]. As the company influence on the risk of workers experiencing an OSTS or HFTS increases, so does the MOR.

For categorical variables, we used the following reference groups: “Female” for sex, “Manufacturing” for industry sector, “No” for both recreational target shooting or hunting and other recreational or non-occupational noise exposures, and “Always” for hearing protection use at work. With the exception of industry sector, we chose these categories to make comparisons with putative lower-risk groups. We chose “Manufacturing,” which is not considered a lower-risk group, as the referent due to very small numbers in the other industry sectors which could result in unstable comparisons [Hardy, 1993]. For continuous variables, the mean value was used as the reference, with risk ratios expressed as the effect of a 1-unit offset from the mean.

## RESULTS

At the time of this analysis, the NIOSH audiometric database contained 517,619 audiograms for U.S. workers aged 18–65 years conducted during 2005–2009 by the provider which captured hearing protection information. Of these, a total of 122,066 were excluded for failing to meet pre-established audiometric quality criteria defined as negative slope (n = 76,242), large inter-aural differences (n = 31,959), missing threshold values necessary for calculating outcome variables (n = 623) or a combination of these (n = 13,242). A further 10,275 records were discarded because they did not represent the worker's last test of the year in which it was conducted.

From the remaining 385,278 audiograms, we assembled a dataset representing the 5-year audiometric histories of 25,939 workers who had audiograms in both 2005 and 2009 by matching on the unique employee ID. Of these, 25,193 met our inclusion criteria of having at least three audiograms during the study period, two of which were in 2005 and 2009. Finally, excluding records for workers missing data regarding hearing protection use (n = 5,261) or other exposures (n = 5), as well as 16 workers employed in the mining industry sector gave us our final analytic sample representing 19,911 workers.

Table I summarizes the available demographic, industry, and noise exposure characteristics of the workers in our study. Our sample was comprised largely of men (74%) and workers employed in the manufacturing industry sector (86%). The average age of workers was 46 years. The average duration of occupational exposure to hazardous noise prior to the beginning of the study period was 5.87 years. Twenty percent of workers reported that they engaged in recreational shooting or hunting and 33% reported that they were exposed to other non-occupational hazardous noise. A large majority of workers (71%) reported that they always wore hearing protection at work, while 26% reported that they sometimes wore hearing protection and 3% reported that they never wore it.

The incidence proportions of OSTS and HFTS in our sample were 8.04% (95% CI 7.66–8.42) and 13.34% (95% CI 12.87–13.82), respectively (Table II). Results of the bivariate analyses were similar for both outcomes for all variables except industry sector. Workers who had shifts in hearing of either type were, on average, older (OSTS mean = 50 years [$P < 0.01$], HFTS mean = 50 years [$P < 0.01$]) and had previously been exposed to hazardous occupational noise longer (OSTS mean = 6 years [$P < 0.01$], HFTS mean = 6 years [$P < 0.01$]) than those who did not. Men had a higher incidence for both OSTS and HFTS than women. There were no significant differences in the incidence of OSTS or HFTS between workers who were or were not recreational shooters or hunters, nor between workers who reported exposure to other sources of non-occupational noise and those who did not ($P > 0.05$). The use of hearing protection at work was strongly related ($P < 0.01$) to the incidence of both OSTS and HFTS, exhibiting a protective dose-response effect. Bivariate results for industry sector differed for OSTS and HFTS. Industry sector was not significantly associated with the incidence of OSTS, but was significantly associated with the incidence of HFTS.

The results of the multivariable, multilevel analyses are presented in Table III. After controlling for the effects of available covariates and the random effect of company, self-reported use of hearing protection at work was not significantly associated with the odds of OSTS or HFTS. The odds of OSTS for workers who reported never (OR 1.23, 95% CI 0.92–1.64) or sometimes (OR 1.08, 95% CI 0.96–1.22) wearing hearing protection at work did not differ significantly from the odds of OSTS for those who reported always wearing it. However, there was a non-significant linear trend towards increased risk of OSTS with decreased frequency of self-reported hearing protector use. Workers who reported never wearing hearing protection had an estimated 26% higher odds of HFTS than those who reported always wearing hearing protection, a difference which was marginally significant (OR 1.26, 95% CI 1.00–1.59 [$P = 0.0546$]). The difference in odds for an OSTS for those who never wore hearing protection compared with those who always wore it was nonsignificant (OR 1.23, 95% CI 0.92–1.64). The odds of a HFTS for workers who reported sometimes wearing hearing protection at work were also not significantly different than for workers who reported always wearing it. However, there was a significant linear trend for increased risk of HFTS with decreased protector use ($P = 0.02$). The linear trend for increased risk of OSTS with decreased protector use was nonsignificant ($P = 0.09$).

For the other independent variables, model results for both OSTS and HFTS were very similar. The duration of prior exposure, industry sector, and exposure to non-occupational hazardous noise from recreational shooting, hunting or other sources were not significantly associated with the odds of either OSTS or HFTS. Men had significantly higher odds than women of both OSTS (OR 1.28, 95% CI 1.12–1.47) and HFTS (OR 1.28, 95% CI 1.14–1.43). Increasing age was associated with significantly higher odds of both OSTS (OR 1.05, 95% CI 1.05–1.06) and HFTS (OR 1.06, 95% CI 1.05–1.06) as well. We also found that the between-company variation in the odds of both outcomes was moderate, with an MOR of 1.48 for both measures of threshold shift.

## DISCUSSION

The principal objective of this study was to determine whether self-reported use of hearing protection at work was associated with the risk of hearing shift over a 5-year period using two measures—OSTS as a measure of hearing shift in the speech range and HFTS as a measure of hearing shift in the frequencies first affected by noise. Bivariate analyses showed an increased risk of hearing shift by either measure with decreased self-reported use of hearing protection at work. When multi-level modeling was used to control for demographic and work covariates with company specified as a random effect, the linear trend became non-significant for OSTS but remained significant for HFTS.

Our findings are similar to those reported by Davies et al. [2008] in their study of sawmill workers in British Columbia using a similar methodology. We found a 23% (OSTS) or 26% (HFTS) increase in the risk of hearing shift among never wearers versus continuous wearers of hearing protection, which agrees closely with the 30% reduction in the risk of OSTS among workers who self-reported regular use of hearing protection across the study period reported by Davies and colleagues.

If hearing protection use was an effective substitute for noise control, we would have expected to see a large and clearly significant difference between the odds of hearing shift among workers who did and did not report consistent use of hearing protectors. We found no association between hearing protector use and the odds of OSTS and only marginal evidence for a modest association with the odds of HFTS. These findings raise concerns about the effectiveness of hearing protection as a substitute for noise control to prevent noise-induced hearing loss in the workplace and underscore the need to wear hearing protection consistently and correctly in order to achieve effective protection against the adverse effects of occupational noise.

While these findings are troubling, they are not altogether surprising given the numerous studies in the literature suggesting that hearing protector use in the workplace is inconsistent and, as a result, not fully effective [Daniell et al., 2002; Davis and Sieber, 2002; Daniell et al., 2006; Tak et al., 2009]. For example, in an investigation of hearing protector use among construction workers in Washington state, Neitzel and Seixas [2005] found that workers wore hearing protection only about 25% of the time they were exposed to hazardous noise and that, although workers were able to achieve more than 50% of the protector's rated attenuation, when hearing protector usage and measured hearing protector attenuation were considered together, the authors concluded that hearing protection provided construction workers only 3 dB of effective noise attenuation and reduced hazardous noise exposures to safe levels only about 20% of the time. Such a finding is consistent with the poor correlation between hearing protector use and odds of hearing shift found in our study.

Other findings in this study are consistent with previous reports. Increased age and male sex were significantly positively associated with both measures of hearing shift and these findings are consistent with other studies that have found that hearing loss varies significantly across non-occupational characteristics [Toppila et al., 2000; Tambs et al., 2006; Tak and Calvert, 2008]. Noise-induced threshold shifts are typically larger and more prevalent among males than females, though it is unclear whether this results from intrinsic biological differences or extrinsic lifestyle differences. Increasing hearing loss with increasing age—presbycusis—is also a well-established phenomenon. It is a multifactorial sensorineural loss whose etiology may include the cumulative effect of exposure to noise and other peripheral factors, as well as a central auditory processing component [Pacala and Yueh, 2012].

After adjusting for the effect of measured covariates, industry sector was not associated with either measure of hearing risk. While other studies have found significant variation in the risk of hearing loss across industry categories [Franks, 1988; Tak et al., 2009], at least two reasons could explain why we did not find such differences. First, while the overall risk of noise-induced hearing loss varies considerably across industries, virtually all of our subjects were enrolled in hearing conservation programs, meaning their exposures were likely more similar than would be those of subjects selected without regard to their noise exposure status. Second, the overwhelming majority of our sample was employed in a single industry sector, manufacturing. The small sample sizes in other industry sectors could have prevented our finding significant differences.

Our study also found that neither years of prior occupational noise exposure nor self-reported non-occupational exposures (i.e., hunting and recreational noise) were associated with hearing risk. Hearing shifts are usually differentially distributed across years of preceding exposure, with hearing deteriorating faster during the early years of exposure and slowing as years of exposure increase [Rosler, 1994]. However, the average years of prior occupational noise exposure in our sample was estimated to be less than 6 years, and the accumulation of noise-induced threshold shift does not begin to slow until after about 10 years of exposure. This would explain the lack of association noted in our analysis. Exposure to noise from hunting or other recreational activities may have been under-reported. Furthermore, several studies have shown that cumulative noise exposures away from work are typically below 80 dBA, which is insufficient to produce hearing shifts [Berger and Kieper, 1994; Neitzel et al., 2004a,b].

We found moderate between-company variation in the risk of hearing loss among workers in our sample. This finding was expected. The attitude of management and senior employees, size of operations, and other within-company factors heavily influence the health and safety culture at a particular workplace. This, in turn, influences the risk of hearing loss.

The results of this study also indicate that HFTS is a more sensitive measure of change in worker hearing than OSTS. This is expected, as the HFTS measure is calculated using frequencies which are usually the first to be affected by exposure to hazardous noise.

## Limitations and Strengths

The findings of this study are subject to several limitations which arise from both the composition of our study sample and the nature of the data available on sample subjects. First, selection bias may have influenced our results. We utilized a convenience sample from data contributed by a single audiometric service provider who operated primarily in one geographic region of the U.S. and served companies from a limited range of industries. Such a sample does not allow the generalizability which could have been drawn from a representative, probability sample of U.S. workers enrolled in hearing conservation programs. Furthermore, we excluded workers with less than three annual audiograms from the sample. Some of these may reflect non-compliance with audiometric testing programs, and such workers may also be less compliant with the requirement to wear hearing protection in hazardous noise. Removing these workers from the sample may have under-represented the population of noise-exposed workers who do not wear hearing protectors, skewing the results toward the null. In addition, we excluded a large number of audiograms due to quality issues. Audiometric testing for hearing conservation purposes often takes place in a background noise environment compliant with OSHA regulations but not with current practice guidelines, resulting in artificially elevated thresholds [Frank and Williams, 1994; Lankford et al., 1999]. The audiometric technicians who collect the data usually are not audiologists and may not have the experience to notice and retest unlikely thresholds. Excluding a substantial number of audiograms from our dataset may have introduced bias if those exclusions differentially represented subsets of workers with higher or lower risk for shifts in hearing.

Second, like all studies that make use of self-reported data from questionnaires, our study is subject to both recall and social desirability biases. Respondents were asked to recall behaviors occurring over the course of the previous year. Furthermore, workers were required to classify their hearing protector use as either “yes” or “no,” and some workers with mildly intermittent protector use may have had difficulty deciding whether they “normally” wore hearing protectors when exposed to loud noise. Workers also may have been inclined to respond in a way that would reflect compliance with their employers’ policies, leading to misclassification of workers along the independent variable.

Furthermore, even workers who accurately reported hearing protector use may not have been properly protected from their noise exposure due to improper or inconsistent use of the device. Most workers do not receive the level of noise reduction predicted by its labeled Noise Reduction Rating (NRR), and removing a hearing protector for even short amounts of time during a workday substantially reduces the effective level of protection [Occupational Safety and Health Administration, 1983; National Institute for Occupational Safety and Health, 1998].

Misclassification also may have resulted due to lack of actual noise exposure data on the workers in the study sample. Although audiometric testing as part of a mandated hearing conservation program is a strong indicator that a worker is noise-exposed, some proactive employers may offer hearing testing to all of their workers regardless of exposure status. Therefore, our study sample may have included some unexposed individuals who would not be expected to show noise-related shifts regardless of hearing protector use. We could not assess whether or to what extent this was actually the case because those data were not available from the audiometric service provider, but we believe it would have occurred rarely if at all because companies have an economic incentive to test only those workers required by regulation. Additionally, because of the way the survey question assessing HPD use was worded—workers were asked if they worked without hearing protection in noisy areas wear it was required—any unexposed workers included in the sample would likely have answered “no” and been classified as “always” wearers of hearing protection. So any bias introduced would have been in favor of a protective effect of HPD use. Even among workers exposed to hazardous noise, there is likely to have been considerable variation in the intensity and duration of individual workers’ exposure.

Additionally, confirmation of threshold shifts in a subsequent audiogram is recommended to rule out temporary threshold shifts which recover over time or result from short-term medical conditions, subject inattention, or tester error [National Institute for Occupational Safety and Health, 1998]. This was not possible using our dataset, so some of the OSTS or HFTS recorded in this study may have been spurious.

Finally, our study was observational and our findings regarding the minimal association between hearing protector use and hearing shifts do not imply lack of a causal relationship. While we attempted to control for as many confounding variables as possible, our results may have been influenced by other key factors. For example, although we included an adjustment for the effect of non-occupational exposure in the analysis, only crude non-occupational exposure measures were available and identified hearing losses could have resulted from unprotected noise exposure outside of the work place. We were unable to control at all for the effect of other potentially important variables such as smoking status, race and education. And, as no job or medical histories were available, the work-relatedness of identified shifts in hearing must be inferred.

Despite these limitations, this study also had a number of strengths. First, the dependent variables—hearing shifts—were based on audiometric data rather than self-report. We also used two different hearing outcome measures—the traditional OSTS utilized in OSHA-mandated HCPs and the HFTS based on audiometric test frequencies initially affected by noise exposure and therefore more sensitive to early evidence of threshold shift. The repository of available audiograms was large enough to allow excluding records with quality issues or evidence of non-occupational pathology, resulting in a clean dataset from which to evaluate the effectiveness of hearing protectors in preventing noise-induced hearing loss. In addition, sufficient employees had serial audiometric records available across a 5-year period to allow examination of a time interval long enough to observe hearing changes and monitor patterns of hearing protective behavior.

The survey question used to define the independent variable—hearing protector use—was asked consistently across all years included in the study. The response was completed by each worker in writing prior to arriving at the mobile audiometric test unit. Consistency of protector use across the study period was categorized along a continuum of always, sometimes, and never.

Finally, we were able to control for the effect of a number of important covariates in the analysis including, age, sex, industry sector, duration of exposure, prior occupational exposure, and exposure to non-occupational noise.

## CONCLUSIONS

Our study suggests that, as currently practiced, the use of hearing protectors is an inadequate substitute for effective engineering or administrative control of noise in the workplace. In order to be effective, hearing protectors must be worn correctly and consistently whenever the worker is in a hazardous noise environment. Workers who are not taught the proper techniques for insertion of ear plugs obtain little attenuation [Murphy et al., 2004].

Additionally, in order to improve consistency of use, hearing protectors must be selected with as much attention to comfort, convenience, and communication as to attenuation characteristics [Arezes and Miguel, 2002]. Our study underscores the importance of training workers in the effective use of hearing protectors.

Furthermore, although our analysis found no association between hearing thresholds shifts and non-occupational exposures, encouraging workers to wear their hearing protection during noisy, off-work activities can only improve overall protection and foster a culture of hearing loss prevention. If noise control measures cannot be introduced to reduce employee exposures to safe levels, a thorough overhaul of hearing protection practices should be considered.

In our sample, the self-reported use of hearing protectors appears to have little effect on the adjusted 5-year incidence of shifts in hearing in the range-of-speech frequencies. We did find evidence for a small protective effect in the higher frequencies first affected by noise. Hearing protection is not currently working as an effective substitute for noise control; our findings emphasize the importance of eliminating hazardous noise exposure in the workplace rather than relying on the use of hearing protectors. If they are used, however, employers should conduct effective worker training in their correct and consistent use and provide hearing protectors that offer comfort, convenience and that do not restrict communication.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions of David K. Wall in administering and querying the NIOSH OHL Surveillance Project data repository, and of James A. Deddens, for providing expert statistical advice related to the linear trend test. The authors also acknowledge the contributions of SangWoo Tak and Geoffrey M. Calvert, who initiated the NIOSH OHL Surveillance Project, and of our data providers, without whom this research would not be possible.

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## TABLE I

Distribution of Selected Characteristics Among Workers in Workplace Hearing Conservation Programs 2005–2009 (n = 19,911)

| **Characteristic** | **Number of workers (%)** |
|---|---|
| Mean age, years (SE) | 46.1 (0.07) |
| Sex | |
| Male | 14,817 (74.4) |
| Female | 5,094 (25.6) |
| Mean duration of prior exposure, year (SE) | 5.87 (0.04) |
| Industry sector | |
| Agriculture, fishing, and forestry | 69 (0.4) |
| Construction | 892 (4.5) |
| Manufacturing | 17,127 (86.0) |
| Services | 770 (3.9) |
| Transportation, warehousing, and utilities | 190 (1.0) |
| Wholesale and retail trade | 863 (4.3) |
| Recreational shooting or hunting | |
| No | 15,932 (80.0) |
| Yes | 3,979 (20.0) |
| Other non-occupational hazardous noise exposure | |
| No | 13,338 (67.0) |
| Yes | 6,573(33.0) |
| Hearing protection use | |
| Never | 563 (2.8) |
| Sometimes | 5,158 (25.9) |
| Always | 14,190 (71.3) |

## TABLE II

Factors Associated With the Riskof OSHA Standard Threshold Shift (OSTS) and High-Frequency Threshold Shift (HFTS) Among Workers in Workplace Hearing Conservation Programs 2005–2009 (n = 19,911)

| | OSTS | | | HFTS | | |
|---|---|---|---|---|---|---|
| **Characteristic** | **Number of workers or mean (SE)** | **Incidence proportion, % (95% CI)** | ***P*-value[a]** | **Number of workers or mean (SE)** | **Incidence proportion, % (95% CI)** | ***P*-value[a]** |
| Total | 1,601 | 8.0 (7.7–8.4) | — | 2,657 | 13.3 (12.9–13.8) | — |
| Age, years | 50.5 (0.23) | — | <0.01[b] | 50.3 (0.17) | — | <0.01[b] |
| Sex | | | | | | |
| Male | 1,263 | 8.5 (8.1–9.0) | | 2,090 | 14.1 (13.5–14.7) | |
| Female | 338 | 6.6 (6.0–7.3) | <0.01[c] | 567 | 11.1 (10.3–12.0) | <0.01[c] |
| Mean duration of prior exposure, years | 6.5 (0.13) | — | <0.01[d] | 6.4 (0.10) | — | <0.01[d] |
| Industry sector | | | | | | |
| Agriculture, fishing, and forestry | 8 | 11.6 (4.0–19.2) | | 9 | 13.0 (5.1–21.0) | |
| Construction | 73 | 8.2 (6.4–10.0) | | 154 | 17.3 (14.8–19.7) | |
| Manufacturing | 1,361 | 8.0 (7.5–8.4) | | 2,251 | 13.1 (12.6–13.7) | |
| Services | 69 | 9.0 (6.9–11.0) | | 106 | 13.8 (11.3–16.2) | |
| Transportation, warehousing, and utilities | 16 | 8.4 (4.5–12.4) | | 27 | 14.2 (9.3–19.2) | |
| Wholesale and retail trade | 74 | 8.6 (6.7–10.4) | 0.75[c] | 110 | 12.8 (10.5–15.0) | 0.02[c] |
| Recreational shooting or hunting | | | | | | |
| No | 1,258 | 7.9 (7.5–8.3) | | 2,093 | 13.1 (12.6–13.7) | |
| Yes | 343 | 8.6 (7.8–9.5) | 0.13[c] | 564 | 14.2 (13.1–15.3) | 0.09[c] |
| Other non-occupational hazardous noise exposure | | | | | | |
| No | 1,066 | 8.0 (7.5–8.5) | | 1,778 | 13.3 (12.8–13.9) | |
| Yes | 535 | 8.1 (7.5–8.8) | 0.72[c] | 879 | 13.4 (12.5–14.2) | 0.93[c] |
| Hearing protection use | | | | | | |
| Never | 60 | 10.7 (8.1–13.2) | | 102 | 18.1 (14.9–21.3) | |
| Sometimes | 452 | 8.8 (8.0–9.5) | | 753 | 14.6 (13.6–15.6) | |
| Always | 1,089 | 7.7 (7.24–8.11) | <0.01[e] | 1,802 | 12.7 (12.2–13.3) | <0.01[e] |

[a] For the difference between those with and without hearing loss.

[b] From the Cochran and Cox approximation of the *P*-value for the *t*-test for equal means.

[c] From the Chi-square test for independence.

[d] From the Student's *t*-test for equal means.

[e] From the Cochran–Armitage trend test.

## TABLE III

Adjusted Odds Ratios for OSHA Standard Threshold Shift (OSTS) and High-Frequency Threshold Shift (HFTS) Among Workers in Workplace Hearing Conservation Programs 2005–2009

| Characteristic | Odds ratio (95% CI)[a] | |
|---|---|---|
| | OSTS | HFTS |
| Age[b] | 1.05 (1.05–1.06) | 1.06 (1.05–1.06) |
| Sex | | |
| Male | 1.28 (1.12–1.47) | 1.28 (1.14–1.43) |
| Female | Ref | Ref |
| Duration of prior exposure[b] | 1.00 (0.99–1.02) | 1.00 (0.99–1.01) |
| Industry sector | | |
| Agriculture, fishing, and forestry | 1.36 (0.62–3.00) | 0.87 (0.41–1.86) |
| Construction | 0.89 (0.64–1.24) | 1.25 (0.95–1.65) |
| Manufacturing | Ref | Ref |
| Services | 1.04 (0.75–1.43) | 0.89 (0.67–1.19) |
| Transportation, warehousing, and utilities | 1.03 (0.55–1.92) | 0.97 (0.57–1.68) |
| Wholesale and retail trade | 1.11 (0.79–1.56) | 0.98 (0.72–1.34) |
| Recreational shooting or hunting | | |
| No | Ref | Ref |
| Yes | 1.09 (0.95–1.26) | 1.07 (0.96–1.21) |
| Other non-occupational hazardous noise exposure | | |
| No | Ref | Ref |
| Yes | 1.04 (0.92–1.18) | 0.98 (0.89–1.09) |
| Hearing protection | | |
| Never | 1.23 (0.92–1.64) | 1.26 (1.00–1.59) |
| Sometimes | 1.08 (0.96–1.22) | 1.08 (0.98–1.20) |
| Always | Ref | Ref |
| Between-company variance (SE) | 0.17 (0.04) | 0.17 (0.03) |
| Median odds ratio[c] | 1.48 | 1.48 |

[a] Odds ratios statistically adjusted for the effects of all other variables in the table and the random effect of company.

[b] Change in odds associated with 1-year deviation from the mean in predictor.

[c] The median odds ratio is a measure of the degree to which the company effect resulting from the hierarchical, clustered nature of the data—in which workers are clustered within companies—influenced the odds of OSTS and HFTS. It is defined as the median value of the odds ratio between the higher and lower risk of any two randomly selected companies, that is, the median increase in the odds of OSTS or HFTS that would result from a worker moving to another, higher risk company.