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Prevalence of Workers with Shifts in Hearing by Industry: A Comparison of OSHA and NIOSH Hearing Shift Criteria

Elizabeth A. Masterson, PhD, CPH, COHC, NIOSH, **Marie Haring Sweeney, PhD, NIOSH**, **James A. Deddens, PhD, NIOSH**, **Christa L. Themann, MA, CCC-A, NIOSH**, and **David K. Wall, MAS, NIOSH**

National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention

Abstract

Objective—The purpose of this study was to compare the prevalence of workers with National Institute for Occupational Safety and Health significant threshold shifts (NSTS), Occupational Safety and Health Administration standard threshold shifts (OSTS), and with OSTS with age correction (OSTS-A), by industry using North American Industry Classification System codes.

Methods—2001-2010 worker audiograms were examined. Prevalence and adjusted prevalence ratios for NSTS were estimated by industry. NSTS, OSTS and OSTS-A prevalences were compared by industry.

Results—20% of workers had an NSTS, 14% had an OSTS and 6% had an OSTS-A. For most industries, the OSTS and OSTS-A criteria identified 28-36% and 66-74% fewer workers than the NSTS criteria, respectively.

Conclusions—Use of NSTS criteria allowing for earlier detection of shifts in hearing is recommended for improved prevention of occupational hearing loss.

Introduction

Approximately twenty-two million workers in the United States are exposed to hazardous noise[1]. Exposure to loud noise and/or ototoxic chemicals[2-4] in the workplace can lead to occupational hearing loss (OHL)[5,6]. The federal government has regulated occupational noise exposures in select industries since 1969[7]. Current regulations are developed and enforced by a number of government entities, including the Occupational Safety and Health Administration (OSHA). OSHA regulates noise exposures for many industries under 29 CFR 1910.95, Occupational Noise Exposure[8], the OSHA regulation for general industry, and 29 CFR 1904.10, Recording Criteria for Cases Involving Occupational Hearing Loss[9]. General industry refers to industries not included in construction, maritime or agriculture. Hearing loss and changes in hearing are detected and quantified by pure-tone audiometric

Corresponding Author: Elizabeth A. Masterson Division of Surveillance, Hazard Evaluations and Field Studies National Institute for Occupational Safety and Health 4676 Columbia Parkway, MS-R17 Cincinnati, Ohio 45226 Phone: 513-841-4291 Fax: 513-841-4489 EMasterson@cdc.gov.

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testing[10]. While the exact proportion is not known, within industry, a substantial portion of this testing is considered to be conducted by audiometric service providers, hereafter referred to as providers.

Noise exposure regulations generally include 8-hour time weighted average (TWA) noise exposure limits for workers, calculations for shifts in hearing, noise controls, training and reporting requirements, exchange rates (increases in permitted noise exposure levels associated with halving of exposure time), and other provisions. Shifts in hearing are considered early indicators of hearing loss and a measure of the effectiveness of hearing conservation programs[11]. The primary purpose of monitoring workers for shifts is not to document losses in hearing. Rather it is to identify affected workers and trigger preventive interventions before their loss worsens and to preserve remaining hearing[12].

OSHA 29 CFR 1910.95 requires that significant shifts in hearing called OSHA “standard threshold shifts” (OSTS) be identified by employers and maintained in the worker's audiometric record[8]. An OSTS is indicated when there is a 10 dB or greater increase in the average of the 2,000, 3,000 and 4,000 Hz threshold values, in either ear, from the baseline audiogram to the current audiogram[8]. An optional age correction can also be applied if an OSTS is indicated (denoted OSTS-A). Not all OSTS are recorded an OSHA Form 300, Log of Work-Related Injuries and Illnesses[9]. Currently, in order for an OSTS to be recordable, 1) the uncorrected average of the threshold values at frequencies 2,000, 3,000 and 4,000 must be 25 dB or greater; and 2) the loss must be work-related. The determination of work-relatedness must be made by a licensed healthcare professional utilizing the guidelines from 29 CFR 1904.5, Determination of Work-relatedness[13]. In the absence of information to the contrary, shifts are assumed to be work-related.

The 1998 NIOSH Criteria for a Recommended Standard: Occupational Noise Exposure[14] recommends an updated formula for shifts in hearing called NIOSH “significant threshold shifts” (NSTS). An NSTS is indicated if there is a 15 dB or greater increase in any of the threshold values for frequencies 500, 1,000, 2,000, 3,000, 4,000, or 6,000 Hz, in either ear, from the baseline audiogram to the current audiogram. This increase must be repeated on a subsequent audiogram for an NSTS to be established as persistent, i.e., indicative of a permanent change in hearing ability[14]. No age correction is applied. For both OSTS and NSTS, baselines can be revised once a shift has been established, to prevent all subsequent audiograms from identifying the same shift, and to allow for new hearing shifts to be readily identified. Neither the OSHA or NIOSH criteria cover detecting other occupational hearing damage, such as tinnitus.

An age correction is a value subtracted from hearing thresholds to account for hearing loss due to assumed age-related factors apart from occupational exposures[14]. The OSHA 29 CFR 1910.95 age correction values were adopted from the 1972 NIOSH Criteria for a Recommended Standard: Occupational Exposure to Noise[11]. These values were derived from 1968-1972 cross-sectional study data[15] as no longitudinal data were available at that time[11,14]. NIOSH updated its recommended criteria in 1998 and advocated dropping the age correction[14]. This reversal of recommendation was based on recognition that age-related hearing loss develops differently across individuals, i.e., not everyone loses clinically

measurable hearing sensitivity with age, and that applying population statistics to an individual was inappropriate[14]. Correcting for age would "overestimate the expected hearing loss" due to age "for some and underestimate it for others"[14]. The difficulty in applying group data without consideration of individual characteristics is recognized across medical specialties[16].

A few published papers have evaluated the criteria for identifying shifts in hearing or early flags for occupational hearing loss[12,17-20]. The main objective of these papers was to determine which shift criteria were 'best' such that they were persistent or predictive of hearing loss (meeting a case definition), while not identifying large numbers of employees with expected variability in their threshold values from test to test[12]. Evaluating the time between the identification of a shift and hearing loss was also an important objective, as sufficient time is needed for intervention[19]. Some of these evaluations included limited comparisons of the numbers of workers identified with NSTS and OSTS[12,17-19]. These comparisons indicated, in general, that fewer workers were identified with an OSTS than an NSTS, and that workers with an OSTS were less likely to have a shift in hearing that persisted on subsequent tests (i.e., had fewer "true positives")[12,18-19]

These studies, while evaluating the essence of the shift criteria, were not designed to estimate the prevalence of workers with NSTS, OSTS and OSTS-A. To our knowledge, no studies have estimated the prevalence of NSTS and OSTS across industries. Sample sizes in the existing studies have also been limited, as were the number of industries included.

The purpose of this study was to 1) estimate the prevalence of workers with shifts in hearing, using NSTS, and the risks of workers developing an NSTS, by industry; and 2) compare the prevalence of workers with NSTS, OSTS, OSTS-A among U.S. industries, utilizing the results of worker audiograms collected through the NIOSH OHL Surveillance Project[21]. The risk for workers to develop an NSTS was also estimated by industry. This study will help identify whether current regulations are effective in identifying workers with shifts in hearing as part of a hearing loss prevention program.

Materials and Methods

Study Design and Population

This was a cross-sectional study of a retrospective cohort comparing the prevalence of worker NSTS, OSTS and OSTS-A among industries. Worker audiograms and related information from the NIOSH OHL Surveillance Project were used and are described in detail elsewhere[21]. In short, de-identified audiograms previously conducted by providers predominantly for workers exposed to high noise (≥85 dBA) were shared with NIOSH and assigned arbitrary employee IDs. Male and female workers ages 18 to 65 years with at least three audiograms in total meeting study quality standards during the years 2001-2010 were included. We chose this time period to limit the time interval for period prevalence, because 2010 was the latest year of available data, and some providers expressed confidence in the superior quality of audiograms beginning in 2000. It was necessary that each worker have three audiograms to calculate whether an NSTS, OSTS or OSTS-A had occurred and compare the prevalence of the three shifts. OSTS and OSTS-A require two audiograms (a

first and last) for the calculation. NSTS requires three audiograms (a first, next-to-last and last), since the shift must be confirmed on a second audiogram. The worker age was determined from the last audiogram, which was the only audiogram maintained in the analysis after shifts were identified. Since all audiograms were de-identified, this project was determined by the NIOSH Institutional Review Board to be research not involving human subjects.

Beginning with 5,258,660 U.S. audiograms for workers ages 18-65 during 2001-2010, 1,404,604 were eliminated from the analysis due to the characteristics identified in Table 1, followed by 2,234,332 audiograms for workers who did not have at least three audiograms. Audiogram exclusions are further described in the Audiogram Inclusion and Exclusion Criteria section. Our final study sample contained 1,619,724 audiograms for 539,908 workers at 17,348 companies.

Materials

The results of worker audiograms were used to identify shifts in hearing. Audiometric records included threshold values at frequencies 500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz, gender, dates of birth, and North American Industry Classification System (NAICS)[22,23] codes. NAICS codes range from two-digit to six-digit numbers, and industry specificity increases with each digit. No income, education, race, smoking status, noise or ototoxic chemical exposure information was available. Information on employee tenure determined from date of hire, and type of work (occupation) were not available for most cases and were not analyzed.

Audiogram Inclusion and Exclusion Criteria

The audiograms utilized in this study were not conducted for research purposes and could contain incomplete or inaccurate information[24]. In consultation with a licensed audiologist, we excluded audiograms that did not meet quality standards[21] (discussed below) or displayed attributes indicating that shifts in hearing may be due to pathology or non-occupational factors. The entire audiogram was excluded if the gender, year of birth, NAICS code or state were missing. Missing birth months and days were imputed as July and 15, respectively, and July 1 was imputed if both fields were missing. Audiograms with unlikely birth years were removed by restricting the age range to 18-65. Audiograms that did not include frequencies necessary for determining NSTS and OSTS (500, 1,000, 2,000, 3,000, 4,000 and 6,000 Hz) were excluded for the affected ear.

The other audiogram exclusions and their rational, which were developed by senior NIOSH audiologists, are described in detail in Masterson et al[21]. Briefly, audiograms with threshold values of “no response at maximum value” were excluded for the affected ear. We also eliminated audiograms for ears with unlikely threshold values suggesting the presence of testing errors. Audiograms with threshold values depicting negative slope in either ear, which is an indication that background noise may have been excessive during testing[25] or middle ear pathology[7,26], were also removed from the analysis. Finally, if large inter-aural differences were observed such that a threshold at a given frequency in one ear differed by 40 dB or more from a threshold at the same frequency in the other ear, then the entire

audiogram was excluded. Such large differences are rarely due primarily to occupational noise exposure[27], and inaccurate thresholds may be recorded for the poorer ear without proper masking[28].

Statistical Analysis

Each worker was assigned an arbitrary ID number which stayed consistent for all of his/her audiograms. The independent variables were the assigned NAICS code (industry) and the type of hearing shift criteria utilized (NSTS, OSTS and OSTS-A). The outcomes were the presence of NSTS, OSTS and OSTS-A, which were determined from the results of worker audiograms. Each outcome was coded as a 0 or 1, with a 1 indicating that the worker had a shift in hearing. For all shifts, the earliest valid audiogram available for a worker in the time period 2001-2010 was used as the baseline audiogram, hereafter referred to as the reference baseline. The last two valid audiograms for each worker in the same time period were used for comparison with the reference baseline audiogram. Once these comparisons were made and workers with NSTS, OSTS, and OSTS-A were identified, only the last valid audiogram for each worker was retained for inclusion in the statistical analyses.

An NSTS was indicated for a worker when, on two consecutive tests, there was an increase of 15 dB or more from the reference baseline audiogram at any of the following frequencies in either ear: 500, 1000, 2000, 3,000, 4,000 or 6,000 Hz[14]. To have an NSTS, both the last and next to last audiogram for a worker had to indicate a shift for the same ear and frequency. This is an approximation of the NIOSH recommended criteria, which includes the stipulation that the confirmation audiogram occur within 30 days of a 15 dB shift at any of the frequencies identified above. Since employers do not test for NSTS, there would have been few available audiograms for analysis if we required that the confirmation audiogram occur within 30 days.

An OSTS was indicated for a worker if the average of the thresholds at 2,000, 3,000 and 4,000 Hz increased by 10 dB or more from the reference baseline audiogram. A shift on one test is sufficient to warrant an OSTS, so only the last audiogram was compared with the reference baseline[8]. An OSTS can occur when an NSTS does not, and vice versa.

An OSTS-A was indicated for a worker as follows. If an OSTS was identified, the worker's gender and age at reference baseline and at the time of the last audiogram were identified. The OSHA age correction values in 29 C.F.R. pt. 1910.95 were then used to recalculate the average of frequencies 2,000, 3,000 and 4,000 Hz[8].

Five descriptive categories were used for worker age. States of employment were condensed into six geographical regions based on the U.S. Embassy region groupings[29]. Arbitrary numbers were assigned to providers. For each worker, the number of years between the reference baseline audiogram and the last audiogram in the time period, hereafter referred to as number of years, was calculated by subtracting the year of the reference baseline audiogram from the year of the last audiogram. SAS version 9.2 statistical software was utilized for analyses (SAS Institute Inc., Cary, NC).

Prevalence percentages and adjusted prevalence ratios (PRs) for NSTS were estimated by industry and demographic utilizing the SAS® genmod procedure for log-binomial regression[30]. PRs, which are risk estimates, were adjusted for gender, age group, region, provider and number of years. Confidence intervals were also calculated for the prevalence percentages and PRs. We examined specific groupings of industries, beginning with all industries at the two-digit NAICS level of specificity and then focused on the Mining, Construction, and Manufacturing industries at the three-digit level of specificity. These three industries are a priority for the NIOSH OHL Surveillance Project[21]. Audiograms for NAICS code 55 (Management of Companies and Enterprises) were removed from the industry analyses due to insufficient sample size. Only 60 audiograms were available.

Couriers and Messengers (NAICS code 492) was designated ‘a priori’ as the PR reference group for the industry analyses, based on examination of the literature, preliminary analyses of the NIOSH dataset[21], consistency and statistical considerations. Previous analyses indicated that this industry sub-sector had the lowest prevalence of workers with hearing loss as defined by NIOSH[14], and as such, is being utilized as the reference group for other NIOSH papers. Studies indicate a fairly low risk or prevalence of hearing loss for mail carriers and message distributers[31,32] and this industry had a large sample size desirable when choosing a reference group.

Covariate reference groups were designated as female for gender, ages 18-25 for age group, Southwest for region, and Provider 1 for provider. An increase in the prevalence of hearing loss is associated with an increase in age[10] and more men experience hearing loss than women[31,33]. Preliminary analyses indicated that the Southwest region and Provider 2 had the lowest prevalence of hearing loss, but Provider 2 had insufficient sample size to serve as the reference group.

McNemar's Test[34,35] for matched pairs was performed to compare the prevalence of NSTS with the prevalence of OSTS for each industry, and to compare the prevalence of NSTS with the prevalence of OSTS-A for each industry. Comparisons of the overall prevalence of workers with NSTS, OSTS and OSTS-A were also performed. P-values were generated for each comparison. The SAS® freq procedure with the agree option was utilized for all tests.

Results

Our sample included 539,908 workers. Sample demographics and NSTS prevalence estimates are provided in Table 2. Most workers were males (78%). As age increased, the number of workers increased and then declined in the oldest age group (56-65). The largest age group was 46-55 (29%) and the smallest was 18-25 (6%). Most workers were employed in the Midwest region of the United States (45%) followed by the South (20%), Mid-Atlantic (16%) and the West (14%). The percent of workers from each provider was very disparate, with Provider 5 (44%), Provider 1 (18%), and Provider 4 (13%) contributing the most and the fewest workers came from Provider 2 (<1%). The number of years between workers’ first and last audiograms varied from 0-9 years and the majority of workers had 2-4 years between their first and last audiogram (55%) [data not shown]. As discussed in the Method section, only 5% of workers had a confirmation audiogram during the same year as

the first audiogram, although 82% of confirmations occurred within one year and 95% within two years. About 20% of the workers in our sample had a NSTS during 2001-2010.

NSTS were more prevalent among men than women (22% vs. 16%) and males were also at greater risk for NSTS (PR=1.39, CI=1.37-1.41). The prevalence and risk of NSTS increased linearly with age. Workers ages 56-65 years were nearly four times more likely to have an NSTS than workers ages 18-25 years. Workers in the Mid-West had the highest risk for NSTS and workers in the West had the lowest risk when compared to workers in the Southwest region.

Table 3 includes the estimated prevalence of workers with NSTS across the entire spectrum of industries, with each two-digit NAICS code represented. Industry sample sizes varied widely. The prevalence of NSTS for the reference group, Couriers and Messengers, was 16%. Most industry NSTS prevalence percentages fell in the range of 17-23%. Industries with the highest prevalence were Utilities (27%), Finance and Insurance (25%), Professional, Scientific and Technical Services (24%), and Healthcare and Social Assistance (24%). The lowest prevalence industries were Accommodation and Food Services (15%) and Couriers and Messengers (16%). In comparison with the reference group, the highest risk industries were Finance and Insurance (PR=1.58, CI=1.32-1.89), Retail Automobiles, Furniture, Electronics, Food, Gas, Apparel (PR=1.38, CI=1.32-1.43), Agriculture, Forestry, Fishing and Hunting (PR=1.32, CI=1.23-1.41), and Professional, Scientific and Technical Services (PR=1.27, CI=1.20-1.34). A few industries had a non-significant risk lower than 1.00, primarily because the reference group did not have the lowest prevalence for NSTS. Overall, a majority of the industry PRs were significantly different from the reference group.

Table 4 focuses on the prevalence of workers with NSTS within the Mining, Construction and Manufacturing industries with specificity at the three-digit NAICS level. The majority of the NSTS prevalence percentages fell in the range 18-24%. Overall, workers in sub-sectors of the Manufacturing industry had the highest prevalence and risks for NSTS, followed by Mining and Construction workers who were fairly similar. Workers in Leather and Allied Project Manufacturing (25%), Machinery Manufacturing (24%) and Miscellaneous Manufacturing (24%) had the highest prevalence of NSTS. Industry sub-sectors with the lowest prevalence were Support Activities for Mining (14%) and Couriers and Messengers (16%). In comparison with Couriers and Messengers, the risks for NSTS were highest in Miscellaneous Manufacturing (PR=1.36, CI=1.30-1.42), Machinery Manufacturing (PR=1.34, CI=1.30-1.39), and Construction of Buildings (PR=1.32, CI=1.18-1.49).

Comparisons of prevalence estimates for workers with NSTS, OSTS and OSTS-A utilizing McNemar's Test are presented in Tables 5-7. Table 5 provides the overall prevalence of workers identified using each set of hearing shift criteria. The prevalence of workers with OSTS was 32% less than the prevalence of workers with a NSTS, and the prevalence of workers with OSTS-A was 68% less than the prevalence of workers with NSTS. Sixty-seven percent of workers with an OSTS had a hearing threshold average ≥25 dB for frequencies 2,000, 3,000 and 4,000, which is one requirement for recordability. McNemar's Test p-values comparing NSTS to OSTS and NSTS to OSTS-A were <.0001, indicating the NSTS

criteria identified significantly more workers with shifts in hearing than the OSTS and OSTS-A criteria. While not the focus of this paper, the McNemar's Test p-value comparing OSTS to OSTS-A was also <.0001. There were however 23,612 workers (4%) who had an OSTS but did not have an NSTS, with a sub-set of 7,590 workers (1%) who had an OSTS-A but not an NSTS.

Hearing shift criteria comparisons by industry at the 2-digit NAICS level of specificity are presented in Table 6. For most industries, the prevalence of workers with OSTS was 28-33% less than the prevalence of workers with NSTS, and the prevalence of workers with OSTS-A was 65-72% less. Exceptions of note were 1) the Arts, Entertainment, and Recreation industry OSTS prevalence which was 41% lower than the NSTS prevalence, and 2) the Postal Service, Warehousing and Storage industry OSTS prevalence which was only 18% lower than the NSTS prevalence. All McNemar's Test p-values comparing NSTS to OSTS and NSTS to OSTS-A, by industry, were <.005. In Table 7, which focuses on workers in the Mining, Construction and Manufacturing industries, the same general pattern was observed related to the magnitude of the prevalence estimates. In most industries, the prevalence of workers with OSTS was 28-36% less than the prevalence of workers with NSTS and the prevalence of workers with OSTS-A was 66-74% less. With the exception of one industry, all McNemar's Test p-values comparing NSTS to OSTS and NSTS to OSTS-A were <.005. The prevalence of workers with OSTS within the Support Activities for Mining industry was not significantly lower than the prevalence of workers with NSTS.

There was consistency in the industries identified as having the highest and lowest prevalences of shifts in hearing whether utilizing the NSTS, OSTS or OSTS-A criteria. Among all industries at the 2-digit NAICS level (Table 6), the highest prevalences for NSTS, OSTS, and OSTS-A included Utilities (27%, 19%, and 8%), Finance and Insurance (25%, 16%, and 9%), Professional, Scientific and Technical Services (24%, 17%, and 8%), Healthcare and Social Assistance (24%, 17% and 8%), and Retail Automobiles, Furniture, Electronics, Food, Gas, Apparel (23%, 16% and 8%). The same industries also had the lowest prevalences utilizing all three shift criteria, including Accommodation and Food Services (15%, 12%, and 5%) and Couriers and Messengers (16%, 11%, and 5%).

Discussion

The purpose of this study was to estimate and compare the prevalence of workers with NSTS, OSTS, OSTS-A among U.S. industries utilizing the results of worker audiograms. We also estimated worker risks for developing an NSTS by industry. In our sample, 20% of the workers had at least one NSTS, 14% had at least one OSTS and 7% had at least one OSTS-A in a ten-year time period. The prevalences of OSTS and OSTS-A were each significantly lower than the prevalence of NSTS (p<.0001) with 32% fewer workers with OSTS and 68% fewer workers with OSTS-A. When we examined hearing shifts by industry, the size pattern of the prevalence estimates for OSTS and OSTS-A in relation to the prevalence of NSTS remained remarkably consistent. Also, whether utilizing the NSTS, OSTS or OSTS-A criteria, there was consistency in the industries identified with the highest and lowest prevalences of shifts in hearing.

The consistent pattern of the magnitude of the prevalence estimates, in addition to the observation that most of the same industries, across shift criteria, had similarly elevated or non-elevated prevalence estimates, suggests that the NSTS, OSTS and OSTS-A criteria all seem to measure hearing shifts on some level, but with differing levels of sensitivity. The NSTS criteria identify significantly more workers at risk for a more severe loss in hearing than the OSTS and OSTS-A criteria. Employers who are using the OSTS criteria likely do not identify 28-36% of the workers who need intervention to prevent additional hearing loss. However, there was a small percentage of workers with an OSTS who did not have an NSTS. While some of these workers may have had shifts with frequency configurations that were not detected utilizing the NSTS criteria, some prior research comparing hearing shift criteria has indicated that the OSTS criteria identify among the lowest percentage of shifts that are persistent, i.e., shifts that will be confirmed on a follow-up audiogram[12,17,18]. As such, it may be that some of these OSTS were temporary and would have disappeared on a confirmation audiogram.

Employers who use age correction (OSTS-A) may be missing 65-74% of the workers with a shift in hearing. The rationale underlying age correction is to avoid making employers responsible for shifts in hearing that resulted from normal aging processes. However, the 2003 American Academy of Audiology position statement on Preventing Noise-Induced Occupational Hearing Loss states that an otherwise healthy person “will have essentially normal hearing at least up to age 60 if his or her unprotected ears are not exposed to high noise levels (i.e., levels above 85 dBA)”[36]. Therefore, age alone will rarely lead to an OSTS. Age adjustment also does not take into account the variability in susceptibility or risk factors across individuals[14]. As such, many hearing losses due to or aggravated by occupational exposures may be misclassified, delaying the identification of noise-induced injury. Determination of work-relatedness could be used in lieu of age correction to avoid employer responsibility for shifts in hearing unrelated to occupational exposures.

Some unexpected results included the lower than usual prevalence estimates for hearing shifts within the Mining and Construction industries. While the prevalences in these industries were not low, these industries typically have a very high prevalence of workers with hearing loss[6,31,32]. However, hearing loss can be determined from a single audiogram and will be identifiable on every audiogram after the loss has occurred. Shifts require multiple audiograms for identification and ‘disappear’ once the baseline is revised. Also, as noise-induced hearing loss accumulates more quickly in the earlier years of employment (exposure) and slows over years of additional exposure, it is possible that these workers had already sustained substantial shifts preceding the study period and therefore fewer shifts during the study period[37,38].

Neither industry is regulated under the OSHA regulation for general industry[8], although the Mining regulation is similar[39]. Since the OSHA regulation for the Construction industry[40] does not specifically require audiometric testing, Construction audiograms in our sample may not include all types of workers, i.e., contractors, sub-contractors, and the self-employed; or all types of Construction occupations. Larger firms that manage construction projects may provide audiometric testing for their employees while their contractors do not receive testing. The Construction workforce is also very mobile. Smaller firms may work

multiple job sites in a single month and workers may have multiple breaks in service. These are all obstacles to the regular audiometric testing necessary for identifying shifts, and may even exclude workers with higher exposures.

Nearly 900,000 workers were excluded from the analysis because they did not have at least three audiograms in our ten-year time period after removing audiograms due to poor quality or non-occupational etiologies. No industry had a disproportionate number of workers excluded due to our requirement for 3 audiograms, i.e., this observation was true of every industry. While short employment tenures or breaks in service may explain the lack of audiograms for some workers, this may also point to a larger problem of program quality. Many occupational audiograms show evidence of poor quality testing, and missing audiograms may reflect lack of support for hearing loss prevention programs or insufficient record-keeping. This issue deserves further attention. NIOSH and professional organizations such as the National Hearing Conservation Association and the American Industrial Hygiene Association have published best practices recommendations and program evaluation checklists which may be useful in improving the consistency and quality of occupational audiometric testing[41-43].

Other counter-intuitive results included the elevated prevalence among workers in the Professional, Finance and Insurance industries. These industries have typically been reported as low risk for hearing loss[6,31,33,44], although a recent study also found higher risks for these industries[21]. Typically ‘low risk’ industries may target audiometric testing for only their most highly exposed workers, and since these exposed workers represent a smaller subset in these industries, the overall hearing loss prevention efforts and culture in these industries may be insufficient.

Our study had limitations. The data utilized were not part of a random sample but rather a convenience sample from providers who agreed to share their data with NIOSH. Although a hearing shift can be identified from an audiogram, the work-relatedness of this shift can only be inferred without more information than is available in our study, such as job and medical history. Audiograms with attributes unlikely to be related to OHL were excluded from the analysis to strengthen this inference of work-relatedness. The collection of information on race, smoking status, and occupation is not required by current regulations and was not available. We were unable to require that confirmation audiograms for NSTS occur within 30 days following the first audiogram with an identified shift in hearing, as per the NSTS criteria. Our reference baseline audiograms were also designated within the confines of a ten-year time period.

The audiograms in the NIOSH sample were performed by different providers and their contractors across the country, and the level of quality assurance may have varied. The industry (NAICS) coding was also performed by providers in some cases, again with the potential for inconsistencies in quality and accuracy. Due to missing or invalid birth years, many audiograms were removed from the analysis. It is not known if these exclusions represented higher (or lower) risk subsets within industries.

The workers in our reference industry were not free of exposure since most if not all of the audiograms were required due to high occupational noise exposures. The risk estimates in this study must be interpreted as a worker's risk for developing a shift in hearing in an industry as compared with the reference industry rather than compared with the general population (an audiometric dataset with a sufficient number of non-exposed workers from the general population was not available for comparison). Lower-exposed groups exist within the dataset, but in the absence of noise exposure information, other similar studies are not available to compare our reference industry's 16% shift prevalence. We know that the prevalence of hearing loss in our reference industry is low (8%) and comparable to a study reference group (8%) with low-exposed individual data from a population survey[31]. Risk estimates will also be biased towards the null when using a reference group with a modestly elevated prevalence, so the risks may be higher than reported here.

Finally, NAICS is an economic classification system. Workers with similar noise and ototoxic chemical exposures may not be grouped together within industry codes, and there may be heterogeneous risks for shifts in hearing within NAICS code categories. As such, some higher-risk workers may be classified under a category one could expect to be lower-risk and vice versa.

Limitations aside, this is the first known study to estimate and compare the prevalence of workers with NSTS, OSTS and OSTS-A, and the first to do so by industry. This study used audiograms from workers employed at thousands of U.S. companies rather than relying on self-reported hearing ability. The large sample size allowed us to perform analyses for all industries at the 2-digit NAICS level and the option to exclude the large number of audiograms with negative slope. We also excluded audiograms of poor quality or depicting characteristics likely due to non-occupational exposures. The demographics of these excluded audiograms and the study sample were very similar, meaning no gender, age group, geographical region, provider or industry was disproportionately removed from the study sample by instituting these quality measures [data not shown]. This suggests that these excluded audiograms represented generally non-systematic issues, and their removal did not introduce bias. The audiograms eliminated for practical reasons, i.e., to exclude workers with less than three audiograms, also had a demographic similar to the study sample, with the exception that disproportionately more younger workers were eliminated. For example, the proportion of workers ages 18-25 was 9% higher in the excluded group than in the study sample. It was expected that younger workers may have a shorter tenure and fewer opportunities for audiometric testing.

Conclusions

The field of occupational hearing conservation has significantly progressed since the current occupational noise exposure regulations were enacted. Targeted research has been conducted to identify better strategies for preventing hearing loss. Significant technological improvements in the areas of hearing protection and the development of ‘quiet’ machinery and processes have also occurred. As our knowledge improves, the regulations that protect worker hearing should also be updated based on the best information available. Although the 1998 NIOSH recommendations for hearing shift criteria are already 15 years old, they

would represent an important update to current regulations. Since hearing loss is permanent, prevention is the best and only strategy for reducing the burden of hearing impairment among U.S. workers. Using the NSTS criteria allows shifts in hearing to be identified and confirmed early enough that interventions can successfully prevent more serious losses in hearing. For most workers, when an OSTS or OSTS-A is identified, a substantial hearing loss has already occurred[45]. By default, these indicators have become more mechanisms for documenting loss than tools for prevention.

While hearing shifts due to or exacerbated by ototoxic chemical exposures may be detected by the OSTS or NSTS criteria, required interventions do not include assessment of chemical exposures or changes in chemical handling. The presence of ototoxic chemicals in the workplace in the absence of hazardous noise does not trigger audiometric testing. Ototoxic chemical exposures still need to be meaningfully addressed in the workplace.

Workers in Manufacturing, Healthcare and Social Assistance, and some Services industries such as Finance and Insurance have a higher prevalence of hearing shifts and need additional hearing loss prevention efforts. Our results indicate that industries for Professional workers, which would traditionally be viewed as ‘low exposure’, are not necessarily so. No industry can or should be labeled as safe or be removed from the assessment of noise or ototoxic chemical exposures. The exposed workers within these industries need to be identified and additional efforts put in place to protect them. Additional research is also needed to help identify barriers for testing and strategies for overcoming these barriers.

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Table 1

Audiograms excluded from analysis.

Reason for Exclusion	Number with Characteristic	Total Excluded in Grouping[a]
Missing value for independent variable	181,400	1,404,604
Missing value for dependent variable[b]	15,218	
Unlikely threshold values for left ear	4,670	
Unlikely threshold values for right ear	5,006	
Large inter-aural difference	493,292	
Negative slope	889,404	
Worker did not have at least three audiograms		2,234,332
All Exclusions		3,638,936

[a] Some audiograms were eliminated for more than one reason within groupings.

[b] Includes eliminations of affected ear results due to “no response at maximum value” threshold values

Table 2

Sample Demographics with Estimated Prevalence and Adjusted Prevalence Ratios (PRs) for Workers with NIOSH Significant Threshold Shifts (NSTS), 2001 - 2010 (N = 539,908).

Demographic	n	(%)	Prevalence of NSTS (%)	Prevalence 95% CI[a]	PR[b]	95% CI
Gender						
Male	418,008	77.52	21.62	21.50-21.75	1.39	1.37-1.41
Female (ref)	121,213	22.48	15.63	15.43-15.83	ref	
missing	687					
Age Group (Years)						
18-25 (ref)	32,986	6.11	6.10	5.84-6.36	ref	
26-35	113,872	21.09	10.63	10.45-10.81	1.37	1.31-1.43
36-45	149,082	27.61	17.45	17.26-17.64	2.04	1.95-2.14
46-55	159,121	29.47	25.77	25.56-25.99	2.88	2.75-3.00
56-65	84,847	15.72	33.30	32.98-33.62	3.72	3.56-3.89
missing	0					
Geographical Region						
New England	3,116	0.59	20.15	18.74-21.56	1.07	0.98-1.17
Mid-Atlantic	86,445	16.33	18.43	18.17-18.69	1.00	0.94-1.06
Midwest	253,617	47.90	22.39	22.23-22.55	1.31	1.24-1.38
South	106,467	20.11	18.65	18.42-18.88	1.13	1.07-1.19
Southwest (ref)	7,253	1.37	15.11	14.29-15.93	ref	
West	72,537	13.70	18.68	18.40-18.96	0.95	0.90-1.02
missing	10,473					
Provider						
1 (ref)	98,270	18.20	17.87	17.63-18.12	ref	
2	644	0.12	16.77	13.89-19.66	0.89	0.75-1.07
3	54,542	10.10	19.27	18.94-19.60	1.23	1.17-1.29
4	67,894	12.58	20.13	19.83-20.43	0.88	0.85-0.91
5	237,072	43.91	21.81	21.64-21.98	1.26	1.23-1.29
6	11,395	2.11	24.22	23.43-25.01	1.06	1.02-1.11
7	9,834	1.82	18.28	17.52-19.04	1.09	1.03-1.16
8	14,592	2.70	19.99	19.34-20.64	0.82	0.78-0.85
9	45,665	8.46	18.31	19.96-18.67	1.04	1.00-1.07
missing	0					

[a] CI = 95% confidence limits.

[b] Each demographic variable was adjusted by all of the other demographic variables and the number of years between the first and last audiogram for each worker within the time period 2001-2010.

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Table 3

Estimated Prevalence and Adjusted Prevalence Ratios (PRs) for Workers with NIOSH Significant Threshold Shifts (NSTS) by Industry, 2001 - 2010 (N = 539,848).

Industry (NAICS 2007 Code)	n	Prevalence of NSTS (%)	Prevalence 95% CI[a]	PR[b]	95% CI
Agriculture, Forestry, Fishing and Hunting (11)	**3,884**	**18.67**	**17.45-19.90**	**1.32**	**1.23-1.41**
Mining, Quarrying, and Oil and Gas Extraction (21)	**1,786**	**21.50**	**19.60-23.41**	**1.17**	**1.07-1.28**
Construction (23)	**11,907**	**20.56**	**19.83-21.29**	**1.21**	**1.15-1.26**
Manufacturing (31-33)	**374,558**	**20.57**	**20.44-20.70**	**1.19**	**1.15-1.22**
Food, Beverage, Tobacco, Textile, Leather and Apparel (31)	94,698	18.05	17.81-18.30	1.13	1.09-1.16
Wood, Petroleum, Coal, Chemical, Plastic, Non-Metallic Mineral (32)	110,157	20.14	19.90-20.38	1.16	1.13-1.20
Metal, Machinery, Electronics, Appliances, Equipment, Furniture (33)	169,703	22.26	22.06-22.00	1.21	1.18-1.25
Wholesale and Retail Trade (42, 44-45)	**37,096**	**21.30**	**20.88-21.72**	**1.25**	**1.21-1.29**
Wholesale Trade (42)	22,471	20.48	19.95-21.01	1.19	1.15-1.24
Retail Automobiles, Furniture, Electronics, Food, Gas, Apparel (44)	12,136	23.16	22.41-23.91	1.38	1.32-1.43
Retail Sporting Goods, General Merchandise, Nonstore Retailers (45)	2,489	19.65	18.09-21.21	1.09	1.00-1.18
Transportation, Warehousing and Utilities (48-49, 22)	**59,323**	**17.24**	**16.94-17.54**	**1.07**	**1.03-1.11**
Air, Rail, Water, Transit and Pipeline Transportation and Support (48)	9,154	16.10	15.35-16.85	0.97	0.92-1.02
Postal Service, Warehousing and Storage (491, 493)	2,649	18.12	16.65-19.59	0.93	0.86-1.01
Couriers and Messengers (492) (ref)	40,687	15.83	15.48-16.19	ref	
Utilities (22)	6,833	26.84	25.79-27.89	1.19	1.14-1.25
Health Care and Social Assistance (62)	**2,081**	**23.59**	**21.77-25.41**	**1.25**	**1.16-1.35**
Services (51-56, 61, 71-72, 81, 92)	**49,213**	**20.65**	**20.29-21.01**	**1.16**	**1.12-1.19**
Information (51)	9,086	20.14	19.32-20.97	1.20	1.14-1.26
Finance and Insurance (52)	310	25.48	20.63-30.33	1.58	1.32-1.89
Real Estate and Rental and Leasing (53)	902	17.96	15.46-20.47	1.23	1.07-1.41
Professional, Scientific and Technical Services (54)	4,909	24.20	23.00-25.40	1.27	1.20-1.34
Administrative and Support and Waste Mgt and Remediation Services (56)	9595	19.66	18.87-20.46	1.11	1.06-1.16
Educational Services (61)	853	23.45	20.61-26.29	1.18	1.05-1.33
Arts, Entertainment, and Recreation (71)	920	17.07	14.64-19.50	1.01	0.88-1.16

Industry (NAICS 2007 Code)	n	Prevalence of NSTS (%)	Prevalence 95% CI[a]	PR[b]	95% CI
Accommodation and Food Services (72)	821	15.23	12.77-17.69	0.96	0.82-1.12
Other Services (except Public Administration) (81)	6,421	20.29	19.31-21.27	1.15	1.09-1.21
Public Administration (92)	15,396	20.99	20.35-21.63	1.10	1.05-1.15

[a] CI = 95% confidence limits.

[b] PRs were adjusted for gender, age group, geographical region, provider and the number of years between the first and last audiogram for each worker within the time period 2001-2010.

Table 4

Estimated Prevalence and Adjusted Prevalence Ratios (PRs) for Workers with NIOSH Significant Threshold Shifts (NSTS) for the Mining, Construction and Manufacturing Industries, 2001 - 2010 (N = 425,833).

Industry (NAICS 2007 Code)	n	Prevalence of NSTS (%)	Prevalence 95% CI[a]	PR[b]	95% CI
Mining					
Mining (Except Oil and Gas) (212)	1,600	22.44	20.40-24.48	1.23	1.12-1.35
Support Activities for Mining (213)	173	14.45	9.21-19.69	0.82	0.58-1.18
Construction					
Construction of Buildings (236)	1,053	20.04	17.62-22.46	1.32	1.18-1.49
Heavy and Civil Engineering Construction (237)	5,697	20.98	19.92-22.04	1.21	1.15-1.28
Specialty Trade Contractors (238)	2,065	20.44	18.71-22.00	1.22	1.12-1.32
Manufacturing					
Food Manufacturing (311)	83,204	17.86	17.60-18.12	1.15	1.11-1.18
Beverage and Tobacco Product Manufacturing (312)	4,193	20.15	18.94-21.36	1.13	1.06-1.20
Textile Mills (313)	4,006	18.00	16.81-19.19	1.07	1.00-1.15
Textile Product Mills (314)	2,010	20.05	18.30-21.80	1.03	0.95-1.12
Apparel Manufacturing (315)	817	16.52	13.98-19.07	1.06	0.91-1.23
Leather and Allied Product Manufacturing (316)	648	25.15	21.81-28.49	1.10	0.96-1.25
Wood Product Manufacturing (321)	15,719	20.41	19.78-21.04	1.23	1.18-1.28
Paper Manufacturing (322)	18,773	21.82	21.23-22.41	1.18	1.13-1.22
Printing and Related Support Activities (323)	11,411	17.33	16.64-18.03	1.09	1.04-1.14
Petroleum and Coal Products Manufacturing (324)	2,637	21.81	20.23-23.39	1.08	1.00-1.17
Chemical Manufacturing (325)	11,670	20.54	19.81-21.27	1.18	1.13-1.23
Plastics and Rubber Products Manufacturing (326)	34,544	19.49	19.07-19.91	1.14	1.10-1.18
Nonmetallic Mineral Product Manufacturing (327)	15,403	20.78	20.14-21.42	1.26	1.21-1.31
Primary Metal Manufacturing (331)	18,978	23.59	22.99-24.19	1.21	1.17-1.25
Fabricated Metal Product Manufacturing (332)	33,937	22.35	21.91-22.79	1.24	1.20-1.28
Machinery Manufacturing (333)	20,801	23.91	23.33-24.49	1.34	1.30-1.39
Computer and Electronic Product Manufacturing (334)	3,383	20.40	19.04-21.76	1.12	1.04-1.20

Industry (NAICS 2007 Code)	n	Prevalence of NSTS (%)	Prevalence 95% CI[a]	PR[b]	95% CI
Electrical Equipment, Appliance, and Component Manufacturing (335)	11,180	20.72	19.97-21.47	1.05	1.00-1.10
Transportation Equipment Manufacturing (336)	61,780	22.19	21.86-22.52	1.22	1.18-1.26
Furniture and Related Product Manufacturing (337)	11,142	18.09	17.38-18.81	1.10	1.05-1.16
Miscellaneous Manufacturing (339)	8,502	23.68	22.78-24.58	1.36	1.30-1.42
Couriers and Messengers (492) (ref)	40,687	15.83	15.48-16.19	ref	

[a] CI = 95% confidence limits.

[b] PRs were adjusted for gender, age group, geographical region, provider and the number of years between the first and last audiogram for each worker within the time period 2001-2010.

Table 5

Estimated overall prevalence of workers with NIOSH significant threshold shifts (NSTS), OSHA standard threshold shifts (OSTS) and OSTS with age correction (OSTS-A) (N = 539,848).

	Prevalence of NSTS		Prevalence of OSTS[a]		Prevalence of OSTS-A[a]	
	n	(%)	n	(%)	n	(%)
yes	109,392	20.26	74,785	13.85	34,605	6.41
no	430,516	79.74	465,123	86.15	505,303	93.59

[a] McNemar's Test p-values comparing NSTS to OSTS, NSTS to OSTS-A, and OSTS to OSTS-A were <.0001.

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Table 6

Estimated Prevalence of Workers with NIOSH Significant Threshold Shifts (NSTS) Compared to Workers with OSHA Standard Threshold Shifts (OSTS) and OSTS with Age Correction (OSTS-A), by Industry, 2001 - 2010 (N = 539,908).

Industry (NAICS 2007 Code)	n	Prevalence of NSTS (%)	Prevalence of OSTS (%)[a]	Prevalence of OSTS with Age Correction (%)[a]
Agriculture, Forestry, Fishing and Hunting (11)	**3,884**	**18.67**	**12.00**	**5.56**
Mining, Quarrying, and Oil and Gas Extraction (21)	**1,786**	**21.50**	**15.43**	**6.55**
Construction (23)	**11,907**	**20.56**	**13.76**	**5.31**
Manufacturing (31-33)	**374,558**	**20.57**	**14.06**	**6.52**
Food, Beverage, Tobacco, Textile, Leather and Apparel (31)	94,698	18.05	12.27	5.34
Wood, Petroleum, Coal, Chemical, Plastic, Non-Metallic Mineral (32)	110,157	20.14	14.01	6.41
Metal, Machinery, Electronics, Appliances, Equipment, Furniture (33)	169,703	22.26	15.09	7.26
Wholesale and Retail Trade (42, 44-45)	**37,096**	**21.30**	**14.37**	**7.07**
Wholesale Trade (42)	22,471	20.48	13.76	6.67
Retail Automobiles, Furniture, Electronics, Food, Gas, Apparel (44)	12,136	23.16	15.62	8.08
Retail Sporting Goods, General Merchandise, Nonstore Retailers (45)	2,489	19.65	13.74	5.83
Transportation, Warehousing and Utilities (48-49, 22)	**59,323**	**17.24**	**14.04**	**6.06**
Air, Rail, Water, Transit and Pipeline Transportation and Support (48)	9,154	16.10	10.32	4.69
Postal Service, Warehousing and Storage (491, 493)	2,649	18.12	14.84	6.83
Couriers and Messengers (492) (ref)	40,687	15.83	10.66	5.13
Utilities (22)	6,833	26.84	18.70	7.60
Health Care and Social Assistance (62)	**2,081**	**23.59**	**16.67**	**8.02**
Services (51-56, 61, 71-72, 81, 92)	**49,213**	**20.65**	**14.45**	**6.50**
Information (51)	9,086	20.14	14.76	6.56
Finance and Insurance (52)	310	25.48	16.13	8.71
Real Estate and Rental and Leasing (53)	902	17.96	12.86	6.43
Professional, Scientific and Technical Services (54)	4,909	24.20	16.72	8.45
Administrative and Support and Waste Mgt and Remediation Services (56)	9595	19.66	13.91	6.84
Educational Services (61)	853	23.45	16.06	6.45
Arts, Entertainment, and Recreation (71)	920	17.07	10.00	4.46

Industry (NAICS 2007 Code)	n	Prevalence of NSTS (%)	Prevalence of OSTS (%)[a]	Prevalence of OSTS with Age Correction (%)[a]
Accommodation and Food Services (72)	821	15.23	11.57	4.63
Other Services (except Public Administration) (81)	6,421	20.29	13.71	6.37
Public Administration (92)	15,396	20.99	14.57	5.87

[a] All McNemar's Test p-values comparing NSTS to OSTS and NSTS to OSTS-A were <.005.

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Table 7

Estimated Prevalence of Workers with NIOSH Significant Threshold Shifts (NSTS) Compared to Workers with OSHA Standard Threshold Shifts (OSTS) and OSTS with Age Correction (OSTS-A) for the Mining, Construction and Manufacturing Industries, 2001 - 2010 (N = 425,833).

Industry (NAICS 2007 Code)	n	Prevalence of NSTS (%)	Prevalence of OSTS (%)[a]	Prevalence of OSTS with Age Correction (%)[a]
Mining				
Mining (Except Oil and Gas) (212)	1,600	22.44	16.13	7.06
Support Activities for Mining (213)	173	14.45	9.25[b]	2.31
Construction				
Construction of Buildings (236)	1,053	20.04	14.15	6.65
Heavy and Civil Engineering Construction (237)	5,697	20.98	14.48	5.65
Specialty Trade Contractors (238)	2,065	20.44	12.54	4.60
Manufacturing				
Food Manufacturing (311)	83,204	17.86	12.16	5.36
Beverage and Tobacco Product Manufacturing (312)	4,193	20.15	13.12	5.29
Textile Mills (313)	4,006	18.00	12.36	4.97
Textile Product Mills (314)	2,010	20.05	12.89	4.58
Apparel Manufacturing (315)	817	16.52	12.48	5.14
Leather and Allied Product Manufacturing (316)	648	25.15	18.06	7.72
Wood Product Manufacturing (321)	15,719	20.41	14.18	6.32
Paper Manufacturing (322)	18,773	21.82	15.14	6.02
Printing and Related Support Activities (323)	11,411	17.33	11.86	4.77
Petroleum and Coal Products Manufacturing (324)	2,637	21.81	17.97	7.24
Chemical Manufacturing (325)	11,670	20.54	12.81	5.93
Plastics and Rubber Products Manufacturing (326)	34,544	19.49	13.73	7.08
Nonmetallic Mineral Product Manufacturing (327)	15,403	20.78	14.92	6.89
Primary Metal Manufacturing (331)	18,978	23.59	15.78	7.51
Fabricated Metal Product Manufacturing (332)	33,937	22.35	15.35	7.28
Machinery Manufacturing (333)	20,801	23.91	16.30	7.41
Computer and Electronic Product Manufacturing (334)	3,383	20.40	13.83	6.44

Industry (NAICS 2007 Code)	n	Prevalence of NSTS (%)	Prevalence of OSTS (%)[a]	Prevalence of OSTS with Age Correction (%)[a]
Electrical Equipment, Appliance, and Component Manufacturing (335)	11,180	20.72	13.13	6.13
Transportation Equipment Manufacturing (336)	61,780	22.19	15.15	7.48
Furniture and Related Product Manufacturing (337)	11,142	18.09	12.22	5.61
Miscellaneous Manufacturing (339)	8,502	23.68	16.01	8.66
Couriers and Messengers (492) (ref)	40,687	15.83	10.66	5.13

[a] All McNemar's Test p-values comparing NSTS to OSTS and NSTS to OSTS-A were <.005 unless otherwise specified.

[b] Statistically non-significant difference between NSTS and OSTS prevalence (p>.05).