Prevalence of hearing loss in the United States by industry: An alternative approach

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Abstract: This study aimed to identify occupations that displayed hearing levels that differed significantly from the national norms in Annex B. Hearing conservation programs and practices in the occupations evaluated in this study appear to be effective in terms of reducing the effects of NIHL on the audiometric thresholds of industrial workers.
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Abbreviations

OSHA = Occupational Safety and Health Administration

NIOSH = National Institute for Occupational Safety and Health

HCA = Hearing Conservation Amendment

ISO = International Organization for Standardization

NHANES = National Health and Nutrition Examination Survey

NHES = National Health Examination Survey

NIHL = Noise-induced Hearing Loss

OHL = Occupational Hearing Loss

CI = Confidence Interval

HCP = Hearing Conservation Program

NIPTS = Noise-induced Permanent Threshold Shift

dB = Decibels

dBA = Decibels, A-weighted
Introduction

In 1970, the United States Occupational Safety and Health Act was adopted, and shortly after in 1971 the Occupational Safety and Health Administration (OSHA) adopted a Noise Exposure Regulation that included the original Walsh-Healy standard (Paragraphs 29 CFR 1910.95(a) and 29 CFR 1910.95(b)) (Occupational Safety and Health Administration [OSHA], 1971; “Noise and Hearing Conservation Technical Manual Chapter,” n.d.). Then, in 1972, the National Institute for Occupational Safety and Health (NIOSH) released a criteria document that outlined a recommended standard for occupational exposure to noise that initiated the launch of a committee to further evaluate the elements within the regulation (National Institute for Occupational Safety and Health [NIOSH], 1972, 1998). This evaluation ultimately led to an amendment known as the Hearing Conservation Amendment (HCA) that would require the inclusion of necessary additional components to the Noise Exposure Regulation that would further introduce significant changes to industrial hearing conservation programs. This amendment, later accepted in 1983, provided new implementations that were valuable to the development and enhancement of effective hearing conservation programs (OSHA, 1983). However, even with these necessary additions, there continues to be opposing perspectives on the effectiveness of the current OSHA Noise Exposure Regulation.

When addressing the effectiveness of hearing conservation programs there are many elements that can and should be evaluated, but when the effectiveness is based purely on audiometric surveillance data then one fundamental question should be considered: are the audiometric thresholds of occupationally noise-exposed workers better, worse, or similar to what we expect for individuals of similar ages and gender but without excessive occupational noise exposure (Dobie, 2006)? According to Hoffman, Dobie, Ko, Themann, and Murphy (2010,
2012), when two different nationally representative surveys of hearing levels (NHANES 1999-2004 & NHES I 1959-1962) were compared, the results revealed that high frequency (3,000, 4,000, and 6,000 Hz) threshold levels in men and women of specific ages are better today (1999-2004) than they were in 1959-1962. This study also found that prevalence of hearing impairment was reduced in the recent survey compared to the older survey. The authors attributed many factors to these improved thresholds but, in the context of our investigation, the most relevant factors that may have contributed to the better hearing results are: 1) the implementation of hearing conservation programs for workers exposed to hazardous noise, and 2) the reduction of individuals exposed to high level noise in the U.S. due to improvements in manufacturing technology and the reassignment of noisy jobs to factories in other countries (Hoffman et al., 2010).

The passage of the HCA has encouraged better hearing conservation practices that have further led to some significant improvements in hearing conservation programs (Reilly, Rosenman, & Kalinowski, 1998; Daniell et al., 2006; Middendorf, 2004; Joy & Middendorf, 2007; Suter, 2009), including those not enforced under the OSHA Occupational Noise Exposure Standard 1910.95 (Joy & Middendorf, 2007). Another important factor to recognize with regard to a decrease in noise exposure throughout different industries is the increasing use of modern technology in industrial workplaces. A new industrial revolution that concentrates on the utilization of industrial technology is overtaking industrial sectors where thousands of jobs were once occupied by a human workforce. These changes are removing a large amount of the workforce from different work environments therefore dramatically affecting the number of individuals who are exposed to workplace hazards (Dietz & Orr, 2006; Middendorf, 2004). Based on this decline and in combination with the documented improvements in hearing
conservation programs, it is likely that noise exposures may be reducing and the hearing levels of workers who are enrolled in hearing conservation programs may be improving or reflect similar levels compared to prior analyses. However, there are still specific industries where research has consistently shown a higher risk of noise-induced hearing loss (NIHL) as well as unsatisfactory implementations of effective hearing conservation programs including a lack of consistent hearing protection device use. Those industries include occupations within the construction, mining, lumber, wood product manufacturing, and agriculture domains (Barkokebas, Vasconcelos, Lago, & Alcoforador, 2012; Neitzel, Seixas, Camp, & Yost, 1999; House, Sauvé, & Jiang, 2010; Tak, Davis, & Calvert, 2009; McCullagh, Lusk, & Ronis, 2002). These industries are known for their higher risks of noise exposure but, more importantly, some of these occupations are not covered under every aspect of OSHA’s Noise Exposure Regulation. This could affect the success of hearing conservation practices in these industries compared to industries that are covered under all aspects of the Noise Exposure Regulation. This indicates the need for continuous evaluation and research of hearing conservation efforts in these industries to ensure NIHL does not increase and effective efforts are reaching the workers before hazardous noise causes a problem.

NIOSH has conducted numerous surveys of workplace hazards, including those specific to occupational noise exposure since the 1970’s, and they continue to contribute significant amounts of knowledge to the current understanding of occupational noise exposure. However, there has been little extensive research regarding the exploration of audiometric data since that time (Boiano & Hull, 2001; Middendorf, 2004). Fortunately, a recent publication by Masterson et al. (2013) highlighted the creation of a new dataset that contains a tremendous amount of audiometric surveillance data. This diligent collection of audiometric surveillance data by
NIOSH has provided an abundant and essential resource for hearing conservation researchers. This dataset demonstrates the application of data mining to hearing healthcare which can further provide professionals and researchers opportunities to discover new facts, organize data for complex issues, and potentially forecast future trends from the variables analyzed (Kudyba, 2010).

This dataset (referred to as NIOSH dataset for the remainder of this paper) was generated by the NIOSH Occupational Hearing Loss (OHL) Surveillance Project (“OHL Worker Surveillance Data”, 2014) and led to the publication by Masterson et al. (2013). Their study investigated the prevalence of occupational NIHL across a number of industries in the United States through reported audiometric surveillance data. Prevalence was defined by comparing hearing levels of each occupation in the dataset to the best hearing occupation within the group of industries studied. This approach led to some unexpected conclusions, which may be related to the methodologies employed. The recent 2013 revision of the ISO 1999 International Standard for Acoustics-Estimation of noise-induced hearing loss (International Organization for Standardization [ISO], 2013) also included an updated statistical distribution of hearing levels of an unscreened population from the United States (Annex B – B.3 database, referred to as Annex B throughout the remainder of this paper) and is based on the National Health and Nutrition Examination Survey (NHANES) 1999-2004 data (from the work of Hoffman et al. 2010). This revised standard includes a database that is representative of the United States adult population (Dobie, 2012), hence providing a normed, representative population that can be utilized for the purpose of comparisons.

The objective of this capstone was to reanalyze some of the data included in Masterson et al. (2013) which identified occupational environments that included a high prevalence of hearing
loss and to re-assess their data by comparing age and gender-specific data by occupation to the recently-published national standard that includes Annex B.3, a sample representative of hearing levels of unscreened U.S. adults by gender and age group (ISO 1999-2013). Rigorous statistical methodologies that have been recently described for these types of studies (Dobie, 2006) and they were used to identify occupations or groups that displayed hearing levels that differed significantly from the national norms in Annex B, and to assess the relation of the findings with the workers’ occupational noise histories.

**Methods and Materials**

*Study Design*

This study was a cross-sectional analysis of a retrospective cohort from the NIOSH OHL Surveillance Project dataset comparing age-matched hearing level data of workers (males and females) in various industries to a normed, unscreened, US population standard. The dataset was made publicly available at http://www.cdc.gov/niosh/data/datasets/SD-1001-2014-0/) in the form of an excel file. Detailed information describing the populations found within the dataset as well as data collection methods are provided by Masterson et al. (2013). All audiograms were de-identified prior to the dataset being provided to the public, and were declared exempt (no human studies involved) by the Washington University Human Research Protection Office (HRPO) Institutional Review Board (IRB).

*Materials*

The total audiogram count provided by Masterson et al. (2013) of the NIOSH dataset was 1,122,722 audiograms. Our total audiogram count included 1,114,966 audiograms and 7,756
audiograms were not located or identified from the excel file that was downloaded from the above mentioned website. While these differing totals limit an exact comparison, the absent audiograms represent less than one percent of the total number of audiograms included in the Masterson et al. (2013) study, which is considered negligible.

Hearing levels of workers in the NIOSH dataset were sorted by occupation, gender, and aged group and compared to those included in Annex B.3 of the ISO standard. Our comparison design of the NIOSH dataset preserved the same descriptors as those found within Annex B to ensure appropriate comparisons were made between the predicted levels in Annex B and those found within the NIOSH dataset. These included using the composite better ear thresholds for analysis, using the median (50th percentile) values for comparison, and correcting the median values to reflect absolute threshold values using the midpoint method (Dobie, 2006; Hoffman et al., 2010). It is important to note that the defined age group intervals for the NIOSH dataset and Annex B differ by one year (e.g. NIOSH dataset age group 4 (50 year olds) = 46-55 years and Annex B age group 4 (50 year olds) = 45-54 years). Date of birth information was requested prior to initial analysis of the dataset for the purpose of adjusting ages so a more exact comparison to the age group interval in Annex B could be completed, however, date of birth information was declined to the investigators. Although this difference limits an exact comparison, the disparity of one year would present insignificant differences in threshold levels.

For the purpose of this study, the evaluation of specific industries was determined based on the cited prevalence ratios by Masterson et al. (2013). Their analysis of the industries was further divided into the analysis of sub-sectors of specific industries (of eight major industries) that revealed the highest prevalence ratios. Higher prevalence ratios were considered to be those around 1.50 and higher; therefore we chose our group inclusion factors along similar guidelines.
We evaluated all eight major industry categories (at the two digit NAICS 2007 code level) found in Masterson et al. (2013) (this included some groups that had prevalence ratios below 1.50) and any sub-sector industries with a prevalence ratio of 1.50 or higher. This criterion netted 24 industrial groups (outlined in Table 1) that could be analyzed. However, the dataset contained both male and female data, so the 24 groups were further separated into male and female subgroups, reflecting a total of 48 gender-specific groups. Only age group 4 (50-year-olds: 46-55 years) from each industry was analyzed. Age group 4 was chosen because it reflects the age range when a change in audiometric thresholds will most likely be detected due to noise exposure. This age group also customarily reflects individuals who have worked at least 15 or more years (amount of time it takes for a maximum change in hearing to occur due to occupational noise) and their audiogram should not possess an overwhelming amount of age-related hearing loss (Glorig, Ward, & Nixon, 1961; OSHA, 1993; Clark & Ohlemiller, 2007).

**Audiogram Inclusion and Exclusion Criteria**

There were several occupations within the dataset that had missing or coded variables of interest. For the purpose of this study, coded variables included any number that was assumed to represent “no response,” “did not test,” or “could not test” variables. There were multiple codes found throughout our dataset. Those codes are as follows: 96, 97, 98, 99, 997, 998, and 999. These codes are commonly utilized within industrial hearing conservation programs when computer-controlled audiometers are utilized for obtaining audiometric thresholds, however, they are uncommon values when utilized in a clinical audiology context. A clinical audiologist would recognize those values to represent something other than a valid threshold value. The utilization of specific codes is different depending on the brand of computer-controlled
audiometer used, and since no specific audiometer or code details were provided, the investigators were not able to interpret what each specific code represented. Although audiological pattern interpretation of the thresholds could assist the investigators in the determination of code representation, there was no uniform use of the different codes throughout the dataset. This ambiguity required the investigators to exclude any threshold value that was greater than 95 (the highest threshold value typically used with computer-controlled audiometers). This approach allowed the investigators to refrain from removing entire audiograms that still contained some valid threshold values, but the ambiguous values were removed to ensure that questionable data was excluded, therefore providing a more appropriate representation of true hearing levels throughout the industries included in the analysis. Further, audiograms that were missing gender or had code values across the entire audiogram were not included in our analysis. Table 1 includes the number of audiograms that were removed for each industry. Since 8,000 Hz is not commonly tested in industrial audiology or utilized when determining the contribution of noise-induced hearing loss (OSHA, 1983; Kirchner et al., 2012), we elected not to include it in our analysis. Of the 1,114,966 total audiograms in the NIOSH dataset (this total includes all age groups), 234,762 audiograms were distinguished as age group 4 and were included in our analysis. Two occupations (Other Heavy and Civil Engineering Construction and Real Estate: Automotive Equipment Rental and Leasing) did not include females in the age group 4 category, so only males were analyzed for those two groups. In total 46 gender-specific groups were analyzed (24 male and 22 female groups).

Statistical Analysis
The appropriate comparisons recommended by Dobie (2006) and Hoffman et al. (2010) were utilized. 95% confidence intervals (CI) for the NIOSH dataset thresholds were calculated if the frequency-specific median threshold fell outside of the CI for the corresponding Annex B threshold. Statistically significant differences in thresholds were determined by evaluating confidence intervals and calculating z-scores (further described by Dobie, 2006). The investigators were only interested in determining if the median thresholds would be significantly worse than Annex B median thresholds, so significantly better thresholds were not addressed.

Results

Median thresholds from 500-6,000 Hz were compared to Annex B median thresholds for the 46 male and female groups included in our analysis. If any NIOSH dataset median threshold fell outside of the Annex B confidence interval (CI), that threshold (occupation and frequency-specific) was included in the subsequent analysis. This criterion yielded 18 gender-specific groups that were then evaluated for statistically significant differences. First, 95% confidence intervals were calculated for those 18 NIOSH dataset groups and were compared to the Annex B CIs. This analysis revealed that the Annex B and NIOSH dataset CIs overlapped at every threshold evaluated. Tables 2 and 3 present gender-specific information regarding median and lower and upper CI limit values, and Figures 1-18 show median thresholds (500-6,000 Hz) of the NIOSH dataset compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Since all CIs overlapped and statistical significance of the difference between the NIOSH dataset median thresholds and Annex B median thresholds could not be
explicitly determined, z-scores were calculated for each median threshold that reflected overlapping CIs. Z-scores above 1.96 were considered significant at the Alpha = 0.05 level. Of the 18 groups that underwent z-score analyses, 11 groups revealed statistically significant threshold differences. These statistically significant differences are denoted by asterisks (*) in Figures 1-11 and are numerically presented in Tables 4 and 5.

Discussion

Much of the previous research in hearing conservation has focused predominantly on areas such as what sound levels should be considered hazardous when considering different exchange rates (NIOSH, 1998; Suter, 1993, 2009; Daniell et al., 2006; Dobie & Clark, 2014) and the use and effectiveness of hearing protection devices (Suter, 2002; Verbeek, Kateman, Morata, Dreschler, & Mischke, 2012; Nelisse, Gaudreau, Boutin, Voix, & Laville, 2013). While these research areas continue to play an important role in furthering the success of hearing conservation practices, research has lacked in terms of addressing what is actually being observed out in the real world. Alice Suter, a prominent leader in the field of hearing conservation stated in her 2009 publication that we (hearing healthcare professionals) need to “perform a major assessment of hearing loss in American workers to determine the effectiveness of current HCPs, and to identify and address the weaknesses of these programs” (p. 7), and the dataset created from the NIOSH OHL Surveillance Project has provided researchers with a tool that can help accomplish that goal. The dataset is an updated, essential and feasible resource that contains many possibilities for analyses of the possible effects of noise exposure in different industrial occupations. The creation of this dataset is exactly what hearing conservation
researchers have needed to begin practically assessing the effectiveness of current hearing conservation practices.

Based on the comparison of the NIOSH dataset 50-year-old workers to a normed and representative age-matched US population, results indicate that the hearing levels of industrial workers, both male and female, in the 24 groups evaluated were similar to those expected for men and women of similar ages. While some statistically significant differences were found, it is important to consider the magnitude of those differences to determine how meaningful they may be in terms of occupational noise exposure. Figure 19 represents a graph of the daily occupational noise exposure (Lex 8hr, dBA) required to produce the median threshold changes observed for the workers (ages 46-55 with approximately 30 years’ exposure to occupational noise and assumed hire age at around 20 years old) engaged in Construction (of Buildings and Specialty Trade Contractors), Mining (of Oil/Gas and Coal), and Wood Product Manufacturing. The figure was derived from ISO 1999:2013, section 6.3, and Annex D of the same document and demonstrates the predicted contribution of NIPTS at 3, 4, and 6kHz when evaluated with differing levels of noise exposure. It can be recognized that NIPTS is predicted to contribute less than 4.3 dB to measured hearing levels when the noise exposure is 85 dBA and below. Based on the observed median threshold differences (no more than 5.5 dB) found in these five occupations and the corresponding NIPTS exposure level, it would appear that the workers in the evaluated occupations worked in noise levels of no more than 86 dBA to produce these small changes in their hearing levels. However, this interpretation does not coincide with the current understanding of the noise exposure in many of these occupations. A large majority of the NIOSH dataset audiograms were collected from providers who tested hearing levels because workers were required to be in a hearing conservation program (suggesting their noise exposures
were at least 85 dBA and above). So, if noise exposures of 85 dBA and greater played a predominant role in the threshold differences observed in our investigation, then we would expect to see larger differences based on the NIPTS graph, however, those large differences in median threshold levels were not observed.

So, why might we be seeing these small changes in the occupations where we would expect larger changes in workplaces with higher levels of noise? One interpretation suggests that these workers and workplaces have been practicing effective hearing conservation efforts. This could include the implementation of effective and successful administrative and engineering controls in the workplace, especially if we are seeing NIPTS that correspond to lower noise levels. Another consideration refers to the numerous factors that affect hearing levels that are not evaluated in this study. These factors include worker health, age, race, socioeconomic status, smoking status and recreational exposure history. All of these factors should be considered to potentially affect hearing levels to some degree and could possibly represent some of the small decibel differences observed in our comparisons of the NIOSH dataset to Annex B even if they are practicing effective hearing conservation efforts (Lutman & Davis, 1994; Dawes et al., 2014b; Dawes et al., 2014a). Nevertheless, this information was not accessible and limited our ability to confidently attribute similarities or differences to these variables.

While the results of our investigation suggest successful and effective hearing conservation practices in the industries evaluated, the results also highlight poorer threshold trends in some groups such as construction, mining, and wood product manufacturing (see Figures 1-4 and 11). These trends were not unexpected based on the well-known considerable amounts of noise exposure commonly observed in these occupations, but there is also the possibility that there is just not as much NIHL as we would expect. Still, the redundancy of these
findings with other research suggests the need for improved and achievable hearing conservation practices to ensure NIHL does not become a more prevalent repercussion of inadequate hearing conservation program practices. Additionally, it is of substantial importance that these improvements be applied to industries where valuable hearing conservation program elements are not required, specifically in construction and mining. Joy and Middendorf (2007) found significant improvements in hearing conservation practices of miners after the revised Mine Safety and Health Administration (MSHA) noise standard became effective in 2000 (Mine Safety and Health Administration [MSHA] “Compliance Guide to MSHA’s Occupational Noise Exposure Standard”, n.d.), but the authors also observed an increase in shift length in combination with the other improvements which could eliminate the initial progress that was being made. These types of shortfalls are also observed within construction industries where compliance for hearing protection devices is low and program enforcement is inadequate (Reilly et al, 1998; Suter, 2002). This lack of compliance can produce detrimental effects to the workers, and these implications, along with the trends observed in this study, suggest the need for continued monitoring and enhancement of their hearing conservation programs and practices.

Another industry where poorer thresholds were observed was Real Estate. This unexpected finding was also present in the Masterson et al. (2013) results. Their interpretation of this finding was that, although realtors have a very limited exposure to hazardous noise on the job, they typically have heavy cell phone usage and they work in offices that are similar to call centers, which have been suggested to possess some noise hazards (NIOSH, 2011). This interpretation warrants further investigation. If realtors have a heavy cell phone usage, then we would generally expect to see asymmetric hearing loss patterns due to their cell phone use. Studies have shown effects of hearing loss from cell phone use, but the hearing loss has always
been observed in the dominant ear where usage was most common, which, in turn, should reflect an asymmetrical hearing loss pattern on an audiogram, specifically in the high frequencies (Velayutham, Govindasamy, Raman, Prepageran, & Ng, 2014; Patel & Qureshi, 2013). Our analysis of threshold levels included using a composite better ear audiogram, which is described by Dobie (2006, p. 529) as an audiogram where “at each frequency, the better of the thresholds for the two ears” is selected. This approach allowed our audiograms to contain the best threshold levels for each worker not specific to either ear. If cell phone use played a major role in the cause of hearing loss for this group of workers, then our audiogram threshold levels should have captured the non-dominant ear (better ear) threshold levels. While this may have been the case, we would not expect to see thresholds that are commonly observed with NIHL in the non-dominant ear, however, this is the hearing loss pattern that is shown throughout our analysis of Real Estate workers. Also, our composite better ear threshold results would also suggest that a hearing loss of similar or worse thresholds is present in both ears since we captured the best thresholds from both ears. Masterson et al. (2013) pointed out that the informal evaluation of realtor exposure to hazardous noise on the job showed very limited exposure. So, it appears that the Real Estate noise exposure patterns must originate from somewhere other than occupational noise or from their cell phone use based on the audiometric patterns observed and their lack of hazardous noise exposure on the job. This interpretation is also confirmed by the earlier evaluation of NIPTS because of the low probability of noise exposure in this group. This would reflect a low, if not absent NIPTS contribution and would further indicate that the threshold differences observed are caused from factors other than occupational noise.

While it is compelling to see that median threshold levels of industrial workers are similar to what we expect to see in males and females of similar ages, it is important to reflect on
why we might be seeing this trend. The first and most encouraging interpretation may be the possibility that the current hearing conservation programs and practices used within the groups that were analyzed are effective at reducing the risk of noise-induced hearing loss. However, there are unknown elements to consider. We are unaware of the actual status of the hearing conservation programs and practices that are utilized and enforced within these specific workplaces. According to Masterson et al. (2013), the audiograms were voluntarily supplied by companies who completed audiometric tests within different industries across the United States, and a majority of the tests were conducted in order to comply with regulations or safety recommendations. This suggests that most workers in the sample were exposed to noise at or above 85 dBA and further indicates that the workers had to be enrolled in hearing conservation programs. It would not be incorrect to speculate that hearing protection devices were being routinely worn or that noise exposures were limited to safe levels since the majority of the workers in the database were enrolled in regulated hearing conservation programs when their hearing was tested. This, in combination with our results, could indicate the effectiveness of current hearing conservation practices. However, no measurements of noise exposure were available and hearing protection device use and compliance was unknown, so our results cannot be attributed exclusively to these assumptions.

Another interpretation of our positive findings could be from the augmentation of the HCA in combination with the adoption of the NIOSH recommended standards by many industries across the United States. There have been some significant improvements in hearing conservation practices and programs since the enactment of the HCA, but NIOSH has also contributed a significant amount of progress toward successful and effective hearing conservation efforts through various approaches. It is well-recognized that NIOSH promotes a
more stringent hearing conservation standard that is more widely accepted throughout international hearing conservation practices (NIOSH, 1998; Arenas & Suter, 2014), but they also advocate and facilitate hearing loss prevention through hearing loss research programs, hearing conservation toolkits and checklists for industries, and publications detailing practical guidelines and recommended best practice techniques (NIOSH, 1998; “Noise and Hearing Loss Prevention”, 2014). The absence of NIHL in the 50-year-old workers of this study is not only a compelling finding, but also a desirable finding. The goal of a hearing conservation program is to effectively prevent noise-induced hearing loss, and our results suggest that we are observing successful hearing conservation practices. Since no specific information was available about which hearing conservation practices were being adopted within these workplaces (e.g. OSHA regulations versus NIOSH recommendations), our results cannot be entirely credited to this general interpretation, but the results suggest that the current practices being utilized are effective in reducing the hazardous effects of noise on hearing levels.

Limitations

This study had several limitations. The first is the differing values in total audiograms in our analysis versus what Masterson et al. (2013) reported in their analysis. The investigators of this study attempted numerous downloads of the excel file containing the dataset information, however, each download yielded a shortage of data compared to the dataset described by Masterson et al. (2013). As stated before, this small amount of missing data produced negligible differences to our analysis, but it still limits an exact comparison to their findings. Another cause for differing totals was because of our removal of certain ambiguous audiograms. While Masterson et al. (2013) reported that they “excluded audiograms with attributes unlikely to be
related to OHL [occupational hearing loss]” (p. 678), there were considerable amounts of data in some of the groups that included such ambiguities and, therefore, needed to be removed from our dataset and analyses.

The second limitation of our study involves the size of the samples found within a few of the specific industries where some of the poorest threshold trends were observed. Specifically, the Real Estate groups yielding a high prevalence ratio in the Masterson et al. (2013) study were also found to yield some of the poorest threshold trends within our study. The Real Estate group titled “Activities Related to Real Estate” supplied the highest prevalence ratio in the Masterson et al. (2013) study as well as the poorest high-frequency median thresholds in our analysis of the dataset. However, our analysis only included those individuals in age group 4 (50-year-olds) which consisted of small sample sizes of worker audiograms (16 for males and 6 for females). Sample sizes are known to play a critical role in determining statistical significance in various types of studies, and in our analysis, the small sample sizes and wide variability in threshold levels throughout some of the specific groups generated large CIs and did not allow for median thresholds to be determined with precise accuracy. This obstacle could be overcome with larger sample sizes and should be considered for future studies and analyses.

The third limitation of this study was the investigator’s shortage of specific information concerning the actual hearing conservation programs that were being utilized in the workplaces. The NIOSH dataset was created to start a national repository of audiometric data and was not intended to hold information about daily noise exposures, hearing conservation program duration or enforcement, worker health status, etc., but it is well-known that all of these elements can contribute to the analysis of NIHL in each occupation and worker. This prevents our results from
being exclusively attributed to any one explanation and only allows inferences to be made about the industries that were analyzed.

The fourth limitation of this study relates to the use of the NIOSH dataset and the investigator’s ability to make inferences about generalizing the data to other industries throughout the United States that were not included in the dataset. The data within the NIOSH dataset was gathered through a convenience sample which can produce both positive and negative consequences on the results of the studies that utilize them. First, convenience sampling may under or over-represent specific groups within the sample (“Convenience sampling,” n.d.). A more robust and representative sample of these industries would allow for results to be more generalizable to the entire United States industrial population. Second, the investigators must be cognizant of the intentions behind the providers giving information to this repository of audiometric information (“Convenience sampling,” n.d.). There may be various reasons behind the intentions of the providers that may affect the dataset in different ways (both positively and negatively), but it creates a bias that must be noted. Third, convenience sampling does not generally allow researchers to make definite generalizations because the study sample is unlikely to be representative of the population (“Convenience sampling,” n.d.). The under-representation of certain industries can be observed in our analysis as the sample sizes for certain groups are very small and produce variable results in median threshold levels. It is also appropriate to acknowledge that, although the dataset created by NIOSH provides an invaluable tool to the field of hearing conservation and has initiated a crucial repository that is necessary to the future of hearing conservation, it does not supply audiometric data for every industry throughout the United States, so generalizations of the results cannot be unconditionally accepted. However, the investigators of this paper understand the difficulties of accumulating audiometric data and
applaud NIOSH for gaining the invaluable data they have gained thus far because of its significance and contribution to the field of hearing conservation.

**Future Directions**

While this study had several limitations, there are promising avenues for continued research. This study only analyzed and compared the 50-year-old workers. The dataset includes four other age groups that need to be evaluated so other trends or significant findings can be established. Another important consideration for future work would be the use of different approaches for analyzing the NIOSH dataset. This study took one approach of evaluating the data, but other approaches would also provide useful information to our current knowledge about the effectiveness of hearing conservation programs. It would be beneficial not only for more data to be collected so generalizations could be more accurately established, but it would also be valuable to begin evaluating the longitudinal data within the dataset. A longitudinal interpretation of the data could provide a better understanding of the trends of the measured hearing levels instead of evaluating the success of programs based upon the evaluation of audiograms at one point in time.

**Implications**

Based on the results of this study, hearing conservation programs appear to be effective and successful in the groups evaluated for this study. However, it is essential to be aware of the trends that were found in this study and to continue using best practice techniques in hearing conservation programs. This study did not aim to establish if hearing conservation programs were necessary, rather, its aim was to determine how the current practices appear to be working
in a recently assessed population and to identify and address any weaknesses. As stated before, information about the industries’ specific hearing conservation programs or practices were not provided, so the components of a “successful” program cannot be established from this study. However, it can be concluded from this study that the hearing conservation practices being utilized in these industries, in combination with the critical efforts of NIOSH, OSHA and hearing conservationists, appear to be effective in terms of reducing the effects of NIHL on the audiometric thresholds of industrial workers.
References


Table 1.
*Characteristics of the NIOSH Dataset*

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<th>Industry</th>
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*Note. Industries (8 major and 16 sub-sector) evaluated and number of audiograms removed due to missing gender data or whole audiogram containing code values. Boldfaced industries indicate a major industry.*
Table 2.  
*Males: Comparison of Annex B and NIOSH Dataset Median Threshold Values and Upper and Lower 95% Confidence Values*

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<th>Frequency</th>
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</tr>
<tr>
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<td>15 (13.6, 16.5)</td>
<td>22 (19.2, 25)</td>
<td>25 (23, 26.8)</td>
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<td></td>
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<td>27.5 (22.5, 32.5)</td>
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<td>32.5 (12.5, 57.5)</td>
<td>28 (17.5, 47.5)</td>
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<tr>
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<td>20 (13.2, 26.9)</td>
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<td>Real Estate (Commercial &amp; Industrial Machinery and Equipment Rental)</td>
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<td></td>
<td></td>
<td>26 (24.7, 27.3)</td>
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*Note. Median thresholds and Lower and Upper 95% Confidence Limits for Annex B (50-year-olds) provided for comparison to the 11 male NIOSH Dataset industries where differences in thresholds were observed.*
### Table 3.

**Females: Comparison of Annex B and NIOSH Dataset Median Threshold Values and Upper and Lower 95% Confidence Values**

<table>
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<tr>
<th>Frequency</th>
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<td>Mining (Except Oil and Gas)</td>
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<tr>
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<td>(7.7, 14.3)</td>
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<td>(5.75, 12.3)</td>
<td>(6.5, 17.5)</td>
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**Note.** Median thresholds and Lower and Upper 95% Confidence Limits for Annex B (50-year-olds) provided for comparison to the 7 female NIOSH Dataset industries where differences in thresholds were observed.
Table 4.  
Z-score results for the Male groups with overlapping Annex B and NIOSH dataset confidence intervals.

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<th></th>
<th>Frequency</th>
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<th>2kHz</th>
<th>3kHz</th>
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<tr>
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Note. Boldfaced scores represent statistically significant differences between the NIOSH dataset median threshold and the Annex B median threshold. Z-scores above 1.96 were considered significant at the Alpha = 0.05 level.
Table 5.
Z-score results for the Female groups with overlapping Annex B and NIOSH dataset confidence intervals.

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</table>

Note. Boldfaced scores represent statistically significant differences between the NIOSH dataset median threshold and the Annex B median threshold. Z-scores above 1.96 were considered significant at the Alpha = 0.05 level.
Figure 1. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Construction (of Buildings) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 2. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Construction (Specialty Trade Contractors) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*)
Figure 3. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Mining occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 4. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Mining (Except Oil and Gas) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 5. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Real Estate occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 6. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Real Estate occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 7. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Real Estate (Activities Related to Real Estate) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 8. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Real Estate (Automotive Equipment Rental & Leasing) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 9. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Real Estate (Commercial & Industrial Machinery & Equipment Rental) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 10. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Apparel Manufacturing occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 11. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Wood Product Manufacturing occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). Statistically significant threshold differences are denoted by asterisks (*).
Figure 12. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Agriculture occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). There were no statistically significant threshold differences found in this group.
Figure 13. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Construction (Other Heavy & Civil Engineering) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). There were no statistically significant threshold differences found in this group.
Figure 14. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Mining occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). There were no statistically significant threshold differences found in this group.
Figure 15. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Mining (Except Oil and Gas) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). There were no statistically significant threshold differences found in this group.
Figure 16. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Real Estate (Activities Related to Real Estate) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). There were no statistically significant threshold differences found in this group.
Figure 17. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Real Estate (Commercial & Industrial Machinery & Equipment Rental) occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). There were no statistically significant threshold differences found in this group.
Figure 18. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Machinery Manufacturing occupation compared to Annex B. The median thresholds of each group are plotted in audiometric format and include 95% confidence intervals for Annex B (also shown in audiometric format) and any NIOSH dataset median threshold that fell outside of the corresponding Annex B CI (shown as error bars). There were no statistically significant threshold differences found in this group.
Figure 19. Daily occupational noise exposure (Lex 8hr, dBA) required to produce the median threshold changes observed for the workers engaged in wood manufacturing, construction (buildings, specialty trade), oil/gas mining, and coal mining. Data from workers ages 46-55; with approximately 30 years’ exposure to occupational noise. NIPTS derived from ISO 1999:2013, section 6.3, and Annex D of the same document.
Figure A1. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Agriculture occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Agriculture median thresholds fell within the Annex B confidence intervals.
Figure A2. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Construction occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Construction median thresholds fell within the Annex B confidence intervals.
Figure A3. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Construction occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Construction median thresholds fell within the Annex B confidence intervals.
Figure A4. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Construction (of Buildings) occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Construction (of Buildings) median thresholds fell within the Annex B confidence intervals.
Figure A5. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Construction (Specialty Trade Contractors) occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Construction (Specialty Trade Contractors) median thresholds fell within the Annex B confidence intervals.
Figure A6. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Services occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Service median thresholds fell within the Annex B confidence intervals.
Figure A7. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Services occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Service median thresholds fell within the Annex B confidence intervals.
Figure A8. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Transportation, Warehousing, & Utilities occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Transportation, Warehousing, & Utilities median thresholds fell within the Annex B confidence intervals.
Figure A9. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Transportation, Warehousing, & Utilities occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Transportation, Warehousing, & Utilities median thresholds fell within the Annex B confidence intervals.
Figure A10. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Couriers occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Couriers median thresholds fell within the Annex B confidence intervals.
Figure A11. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Couriers occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Couriers median thresholds fell within the Annex B confidence intervals.
Figure A12. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A13. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A14. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Apparel Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Apparel Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A15. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Wood Product Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Wood Product Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A16. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Non-metallic Mineral Product Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Non-metallic Mineral Product Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A17. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Non-metallic Mineral Product Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Non-metallic Mineral Product Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A18. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Primary Metal Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Primary Metal Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A19. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Primary Metal Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Primary Metal Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A20. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Fabricated Metal Product Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Fabricated Metal Product Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A21. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Fabricated Metal Product Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Fabricated Metal Product Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A22. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Machinery Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Machinery Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A23. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Transportation Equipment Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Transportation Equipment Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A24. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Transportation Equipment Manufacturing occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Transportation Equipment Manufacturing median thresholds fell within the Annex B confidence intervals.
Figure A25. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Wholesale and Retail Trade occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Wholesale and Retail Trade median thresholds fell within the Annex B confidence intervals.
Figure A26. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Whole Sale and Retail Trade occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Whole Sale and Retail Trade median thresholds fell within the Annex B confidence intervals.
Figure A27. Median thresholds (500-6,000 Hz) of males (50-year-olds) from the Health Care and Social Assistance occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Health Care and Social Assistance median thresholds fell within the Annex B confidence intervals.
Figure A28. Median thresholds (500-6,000 Hz) of females (50-year-olds) from the Health Care and Social Assistance occupation compared to Annex B. The median thresholds of each group and 95% confidence intervals for Annex B are plotted in audiometric format. All Health Care and Social Assistance median thresholds fell within the Annex B confidence intervals.