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RISK FACTORS FOR SEVERE WORK-RELATED
NOISE-INDUCED HEARING LOSS

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Amy Sue Sims

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M.S. degree in Epidemiology

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RISK FACTORS FOR SEVERE WORK-RELATED NOISE-INDUCED HEARING LOSS

By

Amy Sue Sims

A THESIS

Submitted to
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ABSTRACT

RISK FACTORS FOR SEVERE WORK-RELATED NOISE-INDUCED HEARING LOSS

By

Amy Sue Sims

This cross-sectional study describes individuals (n=5,758) with work-related noise-induced hearing Loss (NIHL) in Michigan who were reported by health care professionals to the Michigan Department of Energy Labor and Economic Growth from 2003 to 2006 under the Michigan Public Health Code of 1978. Participants confirmed with work-related NIHL were classified into three groups based on audiometric results: 1) bilateral or 2) unilateral material hearing impairment and 3) non-material hearing impairment (reference group) as defined by the Occupational Safety and Health Administration. In the multivariate analyses, risk factors for each group were examined.

Overall, 33% of individuals had bilateral and 27% had unilateral material hearing impairment, while 40% had non-material hearing impairment. The three level outcome was analyzed by multinomial regression using the non-material hearing impairment group as the reference response. Older age, military service, and lack of use of hearing protective devices were statistically significant risk factors for material hearing impairment in the multivariate analysis.

This study provides evidence that the use of hearing protective devices reduces the severity of hearing loss and that noise exposure in the military is a significant contributor to severe hearing loss. The study supports the need for preventive health measures to reduce exposure to noise both in industry and the military.

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ABBREVIATIONS

AOR-	Adjusted odds ratio
BRFSS-	Behavioral Risk Factor Surveillance System
CDC-	Centers for Disease Control and Prevention
CI-	Confidence interval
dB-	Decibel(s)
dBA-	Decibel(s), A-weighted
HCP-	Hearing conservation program
HL-	Hearing loss
HPD-	Hearing protective device
Hz-	Hertz
ICD-9-	International Classification of Disease, 9th Revision
MDELEG-	Michigan Department of Energy Labor and Economic Growth
MSU-	Michigan State University
NHIS-	National Health Interview Survey
NIHL-	Noise-induced hearing loss
NIOSH-	National Institute for Occupational Safety and Health
NSAIDS-	Non-steroidal anti-inflammatory medications
OR-	Odds ratio
OSHA-	Occupational Safety and Health Administration
PEL-	Permissible exposure limit
REL-	Recommended exposure limit

RR-	Relative risk
SIC-	Standard Industrial Classification, 1987 manual
VA-	Veteran's Administration
VBA-	Veterans Benefits Administration

CHAPTER 1: INTRODUCTION

1.1 Overview

According to the National Institute for Occupational Safety and Health (NIOSH), nearly 30 million United States workers have daily exposures to noise at dangerous levels, above 85 decibels (NIOSH, 2008). Of those 30 million, 1 million are estimated to have work-related noise-induced hearing loss, primarily from exposures to noise in manufacturing sections (NIOSH, 1998). Noise-induced hearing loss (NIHL) is one of the most common occupational illnesses (NIOSH, 2008).

Projections to the Michigan population from national estimates, suggest that there are a large number of individuals at risk of developing work-related NIHL: 145,000 manufacturing/production workers, 27,200 blue collar workers in wholesale and retail trade, 20,700 construction workers, 12,100 workers in noisy service sectors, and 500 miners currently exposed to daily noise levels in excess of 85 decibels (NIOSH, 1998, Bureau of Labor Statistics, 1996).

The National Health Interview Survey (NHIS) reported the national prevalence rate of hearing loss was 15% in 2003 (Lethbridge-Cejku et al., 2005). Estimates of the number of individuals with hearing loss in Michigan have been derived from the 2003 Behavioral Risk Factor Surveillance System (BRFSS) by Stanbury et al. The BRFSS is a national telephone random-digit dialed survey administered at the state level and funded by the Centers for Disease Control and Prevention (CDC, 2008). States have the option of adding select questions to their survey. In 2003, Michigan opted to add five additional questions to the survey specifically related to hearing loss. Of the 19% of the Michigan population estimated to have hearing loss, the estimated percentage with work-related noise-induced hearing loss was 30% (Stanbury et al., 2008). Stanbury et al. applied the resulting age specific percentages from the 2003 BRFSS to the Michigan population and estimated that 1.4 million of the 10.3 million residents in Michigan have hearing loss of which 375,000 have work-related noise-induced hearing loss. Additionally, Stanbury et al. reported that noise-induced hearing loss was more likely among men, whites, those with less education, and those with incomes less than $50,000.

Several risk factors for NIHL have been suggested. These are: age, gender, blood pressure, diabetes, high cholesterol, pain medication use, smoking, and prolonged unprotected exposure to levels of noise in excess of 85 decibels (Stanbury et al., 2008).

1.2 Hearing Loss

There are many different reasons why individuals develop hearing loss. Hearing loss can be the result of noise, aging, infection, medications, or genetically from birth (Morioka et al., 1997). Hearing loss can be classified as traumatic hearing loss or sensorineural hearing loss (Morioka et al., 1997). Traumatic hearing loss can be further refined as acute acoustic trauma or acute acoustic sensorineural hearing loss (Morioka et al., 1997). Acute acoustic trauma hearing loss is hearing loss that occurs after sudden unexpected intensive noise exposures in the range of 125-130 decibels (Morioka et al., 1997). Acute acoustic sensorineural hearing loss, sometimes described as "disco hearing loss," is hearing loss that occurs after exposure to intense noise in the range of 100-120 decibels (Morioka et al., 1997). Noise-induced hearing loss is a sensorineural hearing loss and is described as damage to the cochlea of the inner ear from chronic noise exposures in excess of 85 decibels (Morioka et al., 1997).

1.3 Rationale and Study Aim

This study will examine individuals with work-related noise-induced hearing loss in Michigan who were reported to the Michigan Department of Energy Labor and Economic Growth (MDELEG) from 2003 to 2006. The specific aim of this study was to describe the general demographics, health history, health habits, workplace environment and exposures, and non work-related noise exposures in individuals who met the Occupational Safety and Health administration (OSHA) definition of material hearing impairment. Considerations for workplace environment and exposures included: industrial sectors where the participant worked the longest, most recent work exposures (i.e. lead and solvent exposures), occurrence of work-related injuries, and provision of hearing protective devices. The OSHA definition for material hearing impairment was defined as an average hearing loss equal to or greater than 25 decibels at 1000, 2000, and 3000 Hertz. Individuals classified as material hearing impairment, based on their most recent audiogram, were further classified as bilateral material hearing impairment (Group A1) and unilateral material hearing impairment (Group A2). Individuals with an average hearing loss less than 25 decibels at 1000, 2000, and 3000 Hertz on their most recent audiogram were classified as non-material hearing impairment (Group B). In the multivariate analysis, Groups A1 and A2 were compared to the reference response Group B.

CHAPTER 2: BACKGROUND

2.1 Diagnosis of Noise-Induced Hearing Loss

Noise-induced hearing loss has been used synonymously with occupational hearing loss and work-related hearing loss. Noise-induced hearing loss (NIHL) is a disease that gradually develops after chronic noise exposure (Morata et al., 1995). The pathophysiological mechanism for NIHL is destruction of the hair cells of the cochlea of the inner ear. These hair cells do not regenerate resulting in permanent hearing loss (AHRF, 2008, ACOEM, 2003, Morioka et al., 1997).

The clinical diagnosis of NIHL is made by a medical professional, such as an occupational physician, an audiologist, or an otolaryngologist. In addition to audiometric testing, the evaluation should include a physical examination, a lifetime occupational history, listing all jobs where the patient was exposed to loud noise including any time spent in the armed services, a health history including health habits, and exposure to non-occupational noise related activities (ACOEM, 2003).

A common finding on an audiogram of an individual with NIHL is "notching" at 3000, 4000, or 6000 Hertz with recovery at 8000 Hertz (ACOEM, 2003). The audiometric pattern observed for NIHL contrasts that of age-related hearing loss in that the latter pattern shows a slow slope without recovery at 8000 Hertz (ACOEM, 2003). People with NIHL typically have difficulty understanding the high-pitched voices of women and children because their voices are in the range where the characteristic "notch" occurs (AHRF, 2008). NIHL is a preventable condition (AHRF, 2008).

2.2 Risk Factors for Hearing Loss

2.2.1 Age, Race, and Gender

The incidence and degree of hearing loss varies among groups. The causes of the variability of hearing loss are likely to be multifactorial with many factors working independently or in tandem with other factors.

Age, race, and gender are non-modifiable risk factors for hearing loss. Age-related hearing loss, called presbycusis, is the process of decreased hearing thresholds due to the natural aging process (NIOSH, 1998). Studies of pure presbycusis have excluded participants known to have hearing loss caused by other factors (Rosenhall et al., 1995).

Phaneuf et al., 1990, discuss race in the literature from the late 1960s to the early 1980s. They discuss that while few epidemiological studies have investigated the role race plays in hearing loss, a few have investigated African Americans in comparison to whites (Phaneuf, et al., 1990). According to Phaneuf, et al., their review of an article by Lilly et al., 1977, suggested that African Americans are less susceptible to NIHL. Phaneuf et al., 1990, continue to discuss an article by Kryter et al., 1983, that suggests that the differences between African Americans and whites may be due to whites exposure to leisure time noise. In contrast, Ishii et al., 1998, found that after adjusting for years of employment that whites had more mild hearing loss than non-whites. Race as a risk factor for hearing loss has yet to be resolved.

According to the National Institute on Deafness and Other Communication Disorders (NIDCD), men are more likely than women to experience hearing loss (www.nidcd.nih.gov). Kryter et al., 1983, suggested that women are more likely to participate in less noisy leisure activities than men.

2.2.2 Cigarette Smoking

Cigarette smoking has been suggested as a risk factor for hearing loss. One hypothesis that has been proposed to explain the effects of cigarette smoking on hearing loss is a reduction in the blood supply to the cochlea caused by arterial vasospasm (Phaneuf et al., 1990). Toppila et al., 2000, in a cross-sectional study, investigated cigarette smoking as a risk factor for 685 Finnish workers in forest, shipyard, and paper mill industries. Individuals were classified as “never smoker,” “past smoker,” and “current smoker” (Toppila et al., 2000). Their results showed that the group of “never smoker” had better hearing at 4000 Hz ($r=0.138$, $p<0.001$) (Toppila et al., 2000). Cruickshanks et al., 1998, found that adults that began smoking during their teenage years were more likely to have a hearing loss than non-smokers. Additionally, non-smokers exposed to secondhand smoke were also more likely to have hearing loss than non-exposed persons (Cruickshanks et al., 1998).

2.2.3 High Blood Pressure

There have been both positive and negative studies that have shown that high blood pressure increases an individual's risk of hearing loss (Dixon Ward, 1995). Conversely, some literature suggests that noise exposure is a risk factor for the development of increased blood pressure. Cross-sectional studies cannot access the temporality of the association between high blood pressure and hearing loss.

In 2002, van Kempen et al. performed a meta-analysis using 43 observational studies, published between 1970 and 1999, on the association between noise exposure and blood pressure and/or ischemic heart disease. Their meta-analysis included studies with noise exposures from both environmental and occupational sources (van Kempen et al., 2002). The results of their meta-analysis showed statistically significant results for the occupational group for each 5 decibel increase in noise exposure, the systolic blood pressure increased 0.51 mm Hg (95% CI, 0.01-1.00) and the increase in the occurrence of hypertension was 14% (95% CI, 1.01-1.29) (van Kempen et al., 2002). This review article supports the hypothesis that noise exposure is a risk factor for increased blood pressure.

The following articles investigated the hypothesis that increased blood pressure is a risk factor for hearing loss. The articles ranged in population, location, and study design. Two were case-control (Lees et al., 1979, de Moraes et al., 2006), and two were cohort studies (Ylikoski et al., 1995, Rosenhall et al., 2006). Three of the four studies focused on occupational populations in various countries (Lees et al., 1979, Ylikoski et al., 1995, de Moraes et al., 2006) and two focused on elderly populations (Rosenhall et al., 2006 and de Moraes et al., 2006). The age ranges under consideration also varied from the Lees et al. study with individuals as young as 25 years old to Rosenhall et al. study with individuals as old as 85 years (Lees et al., 1979, Rosenhall et al., 2006).

Work by de Moraes et al. found an association between arterial blood pressure and hearing loss with an odds ratio of 1.73 ($p=0.03$) (de Moraes et al., 2006). Their study excluded individuals with a history of working in noisy work places and excluded individuals who had diabetes (de Moraes et al., 2006). Work by Ylikoski et al. observed a significant chi-square value of 25.4 ($p<0.001$) when looking at hypertension and severity of hearing loss (Ylikoski et al., 1995). These studies support the hypothesis that increased blood pressure is a risk factor for hearing loss.

2.2.4 High Cholesterol

High cholesterol may be a risk factor for hearing loss as cholesterol increases atherosclerosis, which in turn reduces the supply of oxygen to the cochlea (Chang et al., 2007). There have been inconsistencies in results of studies assessing the relationship between high cholesterol and hearing loss. Chang et al. published in 2007 the relationship between high cholesterol and noise-induced hearing loss. Their design was a case-control study of 4,071 cases of workers exposed to noise above 85 decibels during a one-year period (Chang et al., 2007). They found, after controlling for age and gender, that high triglyceride levels were associated with NIHL (aOR=1.28, 95% CI, 1.09-1.51) and high cholesterol was not associated with NIHL (aOR=0.95, 95% CI, 0.80-1.14) (Chang et al., 2007).

Stanbury et al. published in 2008 the relationship between high cholesterol and noise-induced hearing loss. Their design was a cross-sectional study of 3,551 participants of the 2003 Michigan BRFSS survey. They found that self-reports of high cholesterol was not associated with NIHL (aOR=1.11, 95% CI, 0.74-1.67) (Stanbury et al., 2008).

2.2.5 Diabetes

Diabetes as a risk factor for hearing loss has been investigated; however, there is still debate over the results (Daniel, 2007, Maia et al., 2005, Ishii et al., 1992, Hodgson et al., 1987). One hypothesis suggests that diabetes speeds up the atherosclerotic processes and affects the blood flow to the cochlea (Ishii et al., 1992). In a study by Hodgson et al., 1987, they were unable to show an effect of diabetic status on hearing thresholds. Stanbury et al., 2008, also researched the association between NIHL and diabetes. They found that diabetes was significantly associated with NIHL (aOR=1.72, 95% CI 1.01-2.91) (Stanbury et al., 2008).

2.2.6 Pain Medication Use

Non-steroidal anti-inflammatory medications (NSAIDS) can cause changes in the function of the inner hair cells of the ear leading to the development of tinnitus (Sun et al., 2009). Tinnitus is a ringing, roaring, or buzzing sound in the ears when there is no source of noise (www.mayoclinic.com). The change in the function of the hair cells may increase an individual's susceptibility to hearing loss from noise (www.mayoclinic.com). Toppila et al., 2000, in a cross-sectional study, investigated pain medication use as a risk factor for 685 Finnish workers in forest, shipyard, and paper mill industries. Their study found that over-the-counter and prescription pain medication correlated with NIHL ($r=0.118$, $p=0.06$ and $r=0.188$, $p=0.04$, respectively) (Toppila et al., 2000).

2.3 Risk Factors for Noise-Induced Hearing Loss

2.3.1 Noise Exposure

Chronic exposure to noise above 85 decibels is a risk factor in the development of NIHL (ACOEM, 2003). Noise exposure levels can vary by industry and occupation. Certain occupations have a greater risk for asymmetrical noise exposures; such as agricultural workers, public safety workers, and military personnel due to the source of the noise and the position of the individual (ACOEM, 2003). For example, agricultural workers using farm equipment will look over their right shoulder to watch their equipment and their left ear will be turned towards the machine engine. With chronic exposures to noise in excess of 85 decibels, the rate of hearing loss is maximized within the first 10 to 15 years of such exposures and then decreases thereafter (ACOEM, 2003).

2.3.2 Industrial Exposure to Chemicals, Solvents or Lead

Chemicals, solvents, and heavy metals found in industry, such as lead, toluene, styrene, and xylene, have been associated with hearing loss (Phaneuf et al., 1990). Exposure to toxic solvents may alter the central nervous system (Johnson et al., 1995). Industries that use solvents, typically involve noisy work processes, therefore it can be difficult to distinguish between these two risk factors (Johnson et al., 1995).

Bergstrom et al., 1986, conducted a 20-year longitudinal study and found that 23% of workers in the chemical division had hearing loss compared to 5-8% of company workers not exposed to chemicals. The chemical division had lower noise levels compared to elsewhere in the plant (80-90 dBA and 95-100 dBA, respectively) (Bergstrom et al., 1986).

More recently, Rabinowitz et al., 2008, conducted a retrospective longitudinal study on the effects of solvents on hearing thresholds. Their study found a significant odds ratio (OR=1.87, 95% CI 1.22-2.89) for the association between solvent exposure and high frequency hearing loss (Rabinowitz et al., 2008).

2.3.3 Employer Based Hearing Conservation Program

The National Institute for Occupational Safety and Health (NIOSH) published their revised criteria for occupational noise exposure in 1998 (NIOSH, 1998). This document upheld previous recommendations on noise exposure

(NIOSH, 1998). The recommended exposure limit (REL) for occupational noise is 85 decibels over an 8-hour time-weighted average (dBA) (NIOSH, 1998). Noise levels meeting or exceeding the REL are considered to be hazardous (NIOSH, 1998). For those workers in general industry where noise levels are above 85 dBA, the Occupational Safety and Health Administration (OSHA) requires a Hearing Conservation Program (HCP) to be in place. Components to a HCP include: exposure assessment, engineering and administrative controls, provision and use of hearing protective devices, audiometric testing and evaluation, education, and recordkeeping (NIOSH, 1998).

For those workers in construction, noise exposures are required to be monitored and hearing protective devices must be offered when noise exposures exceed 85 dBA (Morata, 2005). In construction, there are no requirements for a comprehensive hearing conservation program that includes education and audiometric testing (Morata, 2005). Farm owners and their family members are not covered by any hearing loss prevention regulations (Morata, 2005).

The following investigation results imply that hearing conservation programs started within the last 10 to 15 years may be showing benefits (Rubak et al., 2006). In a study of 788 workers in Denmark, Rubak et al., 2006, found that overall, there was an increased risk of hearing loss among noise exposed workers (OR=1.99, 95% CI 0.91-4.34) (Rubak et al., 2006). Workers exposed to noise in excess of 20 years had a significant increased risk of hearing loss (OR=3.05, 95% CI 1.33-6.99) (Rubak et al., 2006) while workers less than 30 years of age or had engaged in noisy work within the past 10 to 15 years did not show an increased risk of hearing loss (Rubak et al., 2006).

In 2008, Davies et al. published their study of 316,476 hearing test data representing 66,130 subjects between 1979 and 1996 in British Columbia. Their study found that using hearing protection increased from 72% in 1979 to 91% in 1996 (Davies et al., 2008). They also reported that the use of hearing protective devices was associated with age; younger workers had a higher percentage of using hearing protective devices (Davies et al., 2008). The study found that there was a protective effect for risk factors whose subject's baseline tests were conducted during the later years of the study period (Davies et al., 2008). Additionally, their study found that the continuous use of hearing protective devices delayed the age of threshold shift in the univariate analysis and reduced the risk by 30% in the adjusted model (Davies et al., 2008).

2.3.4 Exposure to Leisure Noise

Leisure noise can also cause NIHL. Hearing loss from non occupational noise is called sociocusis (NIOSH, 1998). Recreational hunting, target shooting, hobbies with power tools, lawn work, motor boating and snowmobiling, and listening to loud music are sources of leisure time noise exposures (NIOSH, 1998). Limitations of studies investigating leisure time noise exposures have been related to small sample size and not considering the effects of leisure time noise exposure along with occupational noise exposure (Phaneuf et al., 1990).

2.4 Prevalence

The prevalence of NIHL is likely to be underestimated. The National Health Interview Survey (NHIS) reported the national prevalence rate of hearing loss was 15% in 2003 (Lethbridge-Cejku et al., 2005). Estimates of the number of individuals with hearing loss in Michigan have been derived from the 2003 Behavioral Risk Factor Surveillance System (BRFSS) by Stanbury et al., 2008. According to the results of the 2003 BRFSS, 19% of the overall Michigan population had hearing loss with loss increasing with age (Stanbury et al., 2008). Prevalence estimates from the 2003 BRFSS, indicate that 375,000 of the 1.4 million Michigan adults with a hearing loss had work-related NIHL (Stanbury et al., 2008).

2.5 Treatment and Prevention

Once the hair cells in the cochlea have been destroyed, they do not regenerate. However, while the hair cells do not regenerate, an individual may benefit from the use of a hearing aid to amplify their remaining hearing capacity.

Prevention of NIHL can be targeted via required employer hearing conservation/prevention programs and education for wearing hearing protective devices when exposed to noise in excess of 85 dBA regardless of the source of exposure.

CHAPTER 3: METHODS

3.1 Michigan Work-Related Noise-Induced Hearing Loss Surveillance System

3.1.1 Background of the NIHL Surveillance System

Since 1992, the Michigan Department of Energy Labor and Economic Growth (MDELEG) has conducted surveillance for work-related noise-induced hearing loss. The MDELEG contracted with Michigan State University, Department of Medicine to serve as its agent in conducting this state-wide surveillance.

The legal authority of the surveillance system was based on the Michigan Public Health Code as amended in 1978 (Article 368, part 56, PA 1978). This law specified that any health care professional practicing in the state that either knows or suspects that their patient may have developed their condition due to their workplace environment must report that individual to the MDELEG within ten days. The primary sources of these reports were from audiologists, otolaryngologists and other health care providers and from companies or health care professionals providing services to companies. Whether the health professional was an independent or worked for a company, both were required to send reports to the MDELEG. Since 2003, in addition to the reporting form, those health care professionals reporting noise-induced hearing loss were also required to submit the most recent audiogram on the individual being reported.

For this study, the data source was the surveillance program for work-related noise-induced hearing loss in Michigan for the calendar years 2003 to 2006. This study was approved by the Michigan State University Human Subjects Review Board.

The Known or Suspected Occupational Disease Reporting forms were received at Michigan State University via regular postal service or through a secure internet submission. On receipt of the forms, the forms were abstracted and coded by one individual. Those forms with an International Classification of Disease, 9th Revision (ICD-9) code of 388 or 389 for hearing loss were data entered into the surveillance system and those individuals were followed up by surveillance staff, as described below.

Once an individual was identified, the individual was sent a letter with information and asked if they would agree to be interviewed. A standardized telephone-administered questionnaire was used to conduct the interview by a trained interviewer. The interviewer was unaware of the participants hearing test results at the time of the interview. The standardized questionnaire included information on demographics (age, gender, and race), health history (tinnitus, blood pressure, cholesterol, and diabetes), health habits (pain medication use, and smoking status), work places where the participant was exposed to noise (type of industry, duration, intensity, provision of hearing protection devices, work-related injuries, and chemical or solvent exposures), observations about the employer's efforts to control the sources of noise, and sources of non work-related noise exposure (hunting, target shooting, snowmobiling, hobbies with power tools, chain saw usage, listening to loud music, motor boat/jet ski usage, and lawn work with power tools). The most recent audiogram was obtained from the reporting health care provider.

3.2 Sample Characteristics

3.2.1 Description of Sample

Five thousand seven hundred fifty eight reports on individuals were submitted to the Michigan Department of Energy Labor and Economic Growth (MDELEG) during the time period for calendar years 2003 to 2006. One thousand two hundred thirty eight were submitted in 2003; 1,461 in 2004; 1,574 in 2005; and 1,485 in 2006.

For 4.9% (n=282) of participants, their audiograms were unavailable and their data was therefore excluded from further analysis as the outcome of interest was unknown. For the remaining 95.1% (n=5,476) participants, all available data was used.

Participants with unavailable audiograms were compared to those where audiograms were obtained (Table 1). Of the participants with missing audiogram results, 84.1% were male and 15.9% were female. Of the participants with audiogram results, 91.8% were male and 8.2% were female. Differences in gender were statistically significant (p<.0001, 95% CI 0.3371-0.6605). There were no differences in older versus younger participants (p=0.58, 95% CI 0.7161-1.1581). No differences were noted in race, comparing whites to non-whites (p=0.39, 95% CI 0.5146-1.2953).

3.3 Definition of Outcome, Covariates, and Other Variables of Interest

3.3.1 Outcome

3.3.1.1 Work-Related Noise-Induced Hearing Loss

Post-interview, the questionnaire and audiometric results were reviewed by an occupational physician and confirmed as work-related noise-induced hearing loss. This review was based on the case definition that was developed by Michigan State University (MSU) with the aid of the State's Advisory Committee. The case definition stated that the individual's audiometric results be consistent with noise-induced hearing loss and have a history of noise exposure at work adequate to cause hearing loss.

Participants confirmed with work-related noise-induced hearing loss were classified into three groups. The first group represented those individuals having an average hearing loss equal to or greater than 25 decibels in both ears at 1000, 2000, and 3000 Hertz, hereafter referred to as Group A1. This cut point meets the Occupational Safety and Health Administration's (OSHA) definition of material hearing impairment. The second group represented those individuals having an average hearing loss equal to or greater than 25 decibels in either ear at 1000, 2000, and 3000 Hertz, hereafter referred to as Group A2. The third group represented those individuals having an average hearing loss less than 25 decibels at 1000, 2000, and 3000 Hertz, hereafter referred to as Group B. Classification of groups were based on the most recent audiogram results available as provided by the reporting health care provider.

3.3.2 Covariates

3.3.2.1 Age

Age was calculated using the year the participant was entered into the surveillance system minus their year of birth. Participants were then grouped into four age categories: under 45 years of age, 45-64 years, 65-74 years, and 75 years and older.

3.3.2.2 Race

Race was determined by self-report as follows:

"Q.7 How would you be classified-the choices are:

1. White
2. African American
3. Asian/Pacific Islander
4. White Hispanic
5. Other
6. Alaskan/American Indian
7. African American Hispanic
8. Other Hispanic
9. Don't Know"

For data analysis, groups were combined to white (response #1), African American (response #2), and Other (responses #3, #4, #5, #6, #7, and #8).

3.3.2.3 Military Service

Military service was determined by self-report as follows:

"Q.8 Did you ever serve in the military?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.3.2.4 Health History

High blood pressure, high cholesterol, and diabetes were determined by self-report as follows:

> "Q.11 Has a health care provider told you that you have high blood pressure?
> Q.12 Has a health care provider told you that you have high cholesterol (fat) in your blood?
> Q.13 Has a health care provider told you that you have Diabetes?"

Answers were coded for all three questions as "1. no", "2. yes", "3. borderline", or "9. don't know". For data analysis, groups were combined to no (response #1) and yes (responses #2 and #3).

3.3.2.5 Pain Medication Use

Pain medication use was determined by self-report as follows:

> "Q.14 Do you take pain, headache, or arthritis medicine?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.3.2.6 Smoking

Smoking status was determined by self-report as follows:

> "Q.15 Have you ever smoked cigarettes? (No means less than 4 packs of cigarettes or 12 oz. of tobacco in a lifetime)"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.3.2.7 Type of Industry

The Standard Industrial Classification (SIC), 1987 manual, was used to classify the type of industry where the participant reported working the longest. Each job was classified as: agricultural production & services (01-08), mining (10-14), construction (15-17), manufacturing (20-39), transportation and communication services (40-49), retail trade (50-59), finance, insurance & real estate (60-69), services (70-89), or public administration (91-97).

3.3.2.8 Duration of Work-Related Noise Exposure

The duration of work-related noise exposure was calculated as the total number of years worked at any noisy jobs. Participants were then grouped into three duration of noise exposure categories: less than 10 years, 10 to 19 years, and 20 years or more.

3.3.2.9 Regular Hearing Testing

Regular hearing testing was determined by self-report as follows:

> "Q.16 Did the company give you a hearing test on a regular basis?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.3.2.10 Hearing Protective Devices and Type

Provision of hearing protective devices was determined by self-report as follows:

"Q.16 Were you given hearing protection?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

If participants were given hearing protection, they were also asked what type of protection was provided as follows:

"If yes, what type(s)? (circle all that apply)

1. Canal Caps
2. Custom Plugs
3. Foam Plugs
4. Pre-molded Plugs
5. Muffs
6. Other
9. Don't Know"

3.3.2.11 Chemical or Solvent Exposure

Exposure to chemicals or solvents was determined by self-report as follows:

"Q.16 Were you exposed to any of the following substances at this company? (circle all that apply)

1. Lead
2. Toluene
3. Xylene
4. Acetone
5. MEK
6. Trichlorethylene
7. Trichloroethane
8. Perchloroethylene
9. Styrene
10. Other Solvents
11. Pesticides
99. Don't Know"

A response of #99 was excluded from analyses. An index variable, 'Any Chemical/Solvent Exposure', was created. When a participant had one or more exposures to chemicals or solvents, they were counted only one time in the index variable.

3.3.2.12 Non-Work Noise Exposures

Non-work noise exposure was determined by self-report as follows:

> "Q.19 Do/did you do any of the following on a regular basis?
> a. Hunting
> b. Target Shooting
> c. Snowmobiling
> d. Hobby with Power Tools
> e. Chain Saw
> f. Listening to Loud Music
> g. Motor Boat/Jet Ski
> h. Lawn Work with Power Tools
> i. Other"

Answers were coded as "1. no", "2. yes", or "9. don't know". An index variable, 'Any', was created. When a participant indicated they engaged in one or more non-work noise exposures, they were counted only one time in the index variable.

3.3.3 Other Variables of Interest

3.3.3.1 Health Care Provider Diagnosis of Hearing Loss

Hearing loss diagnosis was determined by self-report as follows:

> "Q.9 Did a doctor or other health care provider tell you that you had a loss in your hearing?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.3.3.2 Tinnitus

Tinnitus, a symptom of hearing loss, was determined by self-report as follows:

> "Q.10 Are you bothered by ringing, roaring, or buzzing in your ears?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.3.3.3 Company Size

Company size was determined by self-report as follows:

> "Q.16 How many people do you estimate work in a noisy area at this company?
> 1. <25
> 2. 25-100
> 3. 100-500
> 4. 500+
> 9. Unknown"

3.3.3.4 Noisy Every Day

Noisy every day status was determined by self-report as follows:

> "Q.16 Was it noisy every day?
> 1. All the time
> 2. Most of the time
> 3. Sometimes
> 4. Seldom
> 5. Rarely/Never
> 9. Don't Know"

3.3.3.5 Noisy All Day

Noisy all day status was determined by self-report as follows:

"Q.16 When it was noisy, was it noisy all day long?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.3.3.6 Hearing Test on Hire

Hearing test at the time of hire was determined by self-report as follows:

"Q.16 Did the company give you a hearing test when you first started working there?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.3.3.7 Injuries at Work

Occurrence of work-related injury was determined by self-report as follows:

"Q.16 Did you have any work injuries at this company that caused you to lose work for a day or more or to be assigned to restricted or light duty work for a day or more?"

Answers were coded as "1. no", "2. yes", or "9. don't know".

3.4 Statistical Analysis

3.4.1 Software Used in Analysis

All data analysis was performed using SAS statistical software package 9.1.3.

3.4.2 Data Analysis

Demographic characteristics (age, gender, and race), health history (tinnitus, blood pressure, cholesterol, and diabetes), health habits (pain medication use, and smoking status), work places where the individual was exposed to noise (type of industry, duration, intensity, provision and use of hearing protection devices, work-related injuries, and chemical or solvent exposures), and nonwork-related noise exposures (hunting, target shooting, snowmobiling, hobbies with power tools, chain saw usage, listening to loud music, motor boat/jet ski usage, and lawn work with power tools) of the sample were generated to describe and compare the characteristics of those participants in groups A1 (n=1,791), A2 (n=1,497), and B (n=2,188). All available data was used for each univariate analysis. Missing data varied by select variable. Chi-square (χ^2) values were calculated for each frequency table to determine if there were differences in the characteristics by disease group. A χ^2 value was considered significant when the two sided p value was $\leq$ 0.05. Select variables were retained in the multivariate analysis based on statistical significance, at the 5% level, in the univariate analysis and/or scientific knowledge.

Responses of “don’t know” were recoded as missing. The rationale behind this recode was based on the uncertainty whether the participant responded to the question as “don’t know” or if upon data entry of the questionnaire, the response was truly missing and the data entry staff entered a response of “don’t know” to close out the question.

In the multivariate analyses, the study outcome was classified as bilateral material hearing impairment (Group A1, n=437), unilateral material hearing impairment (Group A2, n=327), and non-material hearing impairment (Group B, n=438). This three level outcome was analyzed by multinomial regression using the non-material hearing impairment group (Group B) as the reference response. The multinomial model models the logarithm of the ratio of the probability of response Group A1 divided by the probability of response Group B. In addition, a second logarithm of the ratio of the probability of response Group A2 divided by the probability of response Group B is modeled. Adjusted odds ratios (AOR) were examined using all available data. The AOR was considered significant if the 95% confidence interval did not include 1.00.

CHAPTER 4: RESULTS

4.1 Results

Five thousand seven hundred fifty eight reports on individuals were submitted to the Michigan Department of Energy Labor and Economic Growth (MDELEG) during the time period for calendar years 2003 to 2006. One thousand two hundred thirty eight were submitted in 2003; 1,461 in 2004; 1,574 in 2005; and 1,485 in 2006. For 4.9% (n=282) of participants, audiograms were unavailable and their data was therefore excluded from further analysis.

Overall, 60% of the participants in this sample met OSHA's definition of material hearing impairment. Of those 60%, 33% had a bilateral noise-induced hearing loss (Group A1) and 27% had a unilateral noise-induced hearing loss (Group A2). The remaining 40% had less severe hearing loss that did not meet OSHA's definition of material hearing impairment (Group B).

4.1.1 Gender, Age, and Race

Among participants, 91.8% were male and 8.2% were female (Table 2). Females made up 5.1% of the group with material hearing impairment in both ears (Group A1) compared to 11.0% in the group without material hearing impairment (Group B). The ratio of hearing loss between males and females increased with severity (94.9/5.1 versus 89.0/11.0, respectively). The difference among groups was statistically significant (χ^2=45.98, p <.0001).

Overall the ages ranged from 18 to 96 years and included retirees. The mean age was 55 years. Participants aged 45-64 accounted for the greatest percent of noise-induced hearing loss, 64.6% (Table 3). The 18-44 age group accounted for 19.5%. The 65-74 age group accounted for 11.5%. And the over 75 age group accounted for 4.4%. Those aged 65-74 were more likely to be in Group A1 (57.2%) as compared to 23.3% in the group with material hearing impairment in either ear (Group A2) and 19.6% in Group B. Younger participants, aged 18-44, were more likely in Group B (55.4%) compared to Group A2 and Group A1 (26.6% and 17.9%, respectively). The difference among groups was statistically significant (χ^2=564.38, p <.0001).

Thirty-five percent of all participants were white (Table 4). African Americans made up 5.9% and All Other Races made up 1.3%. Whites (38.2%) and other races (41.1%) were more likely to be in Group A1 and African Americans (44.0%) were more likely to be in Group B. For 58.2% of all participants race was missing. Whether the missing data was included or excluded, both were statistically significant (χ^2=50.92, p <.0001 and χ^2=11.63, p=0.02, respectively).

4.1.2 Company Health Care Provider

Reports were submitted to the MDELEG by company and non-company health care professionals. Overall, 60.9% of reports were submitted by company health care professionals (Table 5). Non-company health care professionals reported more participants in Group A1 as compared to Group B (51.2% and

33.2% respectively). Company health care professionals were more likely to report participants in Group B than non-company health care professionals (66.9% and 33.2%, respectively). For an additional 3 participants, source of report was missing. The difference among groups was statistically significant (χ^2=161.45, p <.0001).

4.1.3 Cigarette Smoking

Twenty-three percent of all participants indicated having ever smoked (Table 6). Similar percentages were seen across the three types of noise-induced hearing loss groups. There was a slightly higher non statistically significant percentage of ever smokers in Group A1 compared to Group B (39.0% and 34.6%, respectively) with the missing data excluded (χ^2=4.77, p=0.09). For 66.4% of participants, smoking status was missing.

4.1.4 Doctor Told Status

Twenty-five percent of all participants indicated that a doctor or other health care professional had told them they had a loss in their hearing (Table 7). A statistically significant greater percentage in Group A1 indicated being told they had a loss in their hearing (43.3%), whereas only 28.9% in Group B indicated as such. For 66.3% of participants the doctor told status was missing. Whether the missing data was included or excluded, both were statistically significant (χ^2=157.35, p <.0001 and χ^2=125.74, p < .0001, respectively).

4.1.5 Tinnitus

Tinnitus is a symptom of hearing loss. Statistically significant more participants in Group A1 indicated that they were bothered by ringing, roaring, or buzzing in their ears (41.4%) as compared to 30.9% in Group B (Table 8). For 66.5% of participants presence of tinnitus was missing. Whether the missing data was included or excluded, both were statistically significant (χ^2=55.81, p <.0001 and χ^2=26.32, p <.0001, respectively).

4.1.6 Health Related Conditions and Pain Medication Use

Table 9 shows the distribution of health related conditions and use of pain medication. A statistically significant greater percentage of participants in Group A1 indicated having been told they had high blood pressure (40.9%, χ^2=8.80, p=0.01 with missing excluded), high cholesterol (42.0%, χ^2=12.80, p=0.00 with missing excluded), and diabetes (46.6%, χ^2=12.55, p=0.00 with missing excluded) as compared to Group B (32.0%, 32.4%, and 28.7% respectively). Pain medication use had a statistically significant higher percentage in Group A1 as compared to Group B (40.4% and 33.1%, respectively; χ^2=7.99, p=0.02 with missing excluded). Either presence of health related conditions or pain medication use was missing for approximately 67.0% of participants.

4.1.7 Military Service

Overall, 21.0% of participants indicated they did not spend time in military service (Table 10). More participants in Group B did not spend time in the military as compared Group A1 (41.7% and 31.8% respectively). For 66.2% of participants military service was missing. Whether the missing data was included or excluded, both were statistically significant (χ^2=85.80, p <.0001 and χ^2=53.60, p <.0001, respectively).

4.1.8 Duration Work-Related Noise Exposure

Overall, 59.4% of participants indicated that they had an excess of 20 years work-related noise exposure (Table 11). Nearly 30% indicated having less than 10 years of work-related noise exposure, with 10.8% having 10-19 years. Group A1 had a higher percentage of 20+ years of work-related noise exposure (65.2%) as compared to Group B (54.6%). Group B had a slightly higher percentage of <10 years of work-related noise exposure (32.5%) as compared to Group A1 (27.0%). The difference among groups was statistically significant (χ^2=52.18, p <.0001).

4.1.9 Industry

Table 12 shows the distribution of industries where participants indicated they worked the longest number of years. Manufacturing comprised the vast majority of participants with 83.2% and then services (3.5%) and construction (2.9%). Participants working in agriculture, construction, and transportation were more likely to be in Group A1 (55.6%, 47.2%, and 45.4% respectively). Whereas participants working in services, manufacturing, and public administration were more likely to be in Group B (55.2%, 41.0%, and 38.6% respectively). Overall, for 5.7% of participants industry was missing. Nearly 51% of participants that were missing an industry classification were in Group A1. Whether the missing data was included or excluded, both were statistically significant (χ^2=109.46, p<.0001 and χ^2=57.66, p <.0001, respectively).

4.1.10 Company Size

Overall 73.3% of participants indicated working for a large company of 500 or more employees (Table 13). Similar percentages were seen across the three types of noise-induced hearing loss groups for the four company size categories. Of those participants that indicated working for a larger company, they were more likely to be in Group B (42.2%) compared to Group A2 and Group A1 (28.1% and 29.7% respectively). For 19.2% of participants company size was missing. When the missing data was included the difference in groups was statistically significant (χ^2=80.20, p <.0001). With the missing data excluded, the difference in groups was not statistically significant (χ^2=10.46, p=0.11).

4.1.11 Work-Related Noise Exposure Intensity

To determine the work-related noise exposure intensity, participants were asked, "Was it noisy every day?" Twenty-three percent of participants indicated the noise was “all the time” (Table 14). Another 8.3% indicated the noise was either “most of the time” or “sometimes”. For those participants that indicated noise was either “seldom” or “rarely/never”, they were most likely to be in Group B (43.5% and 51.5% respectively). Additionally, for those where noise intensity was missing, those participants were more likely to be in Group B (41.7%) than Group A2 (27.5%) or Group A1 (30.8%). For 67.3% of participants the measure of noise intensity was missing. When the missing data was included the difference in groups was statistically significant (χ^2=30.34, p=0.00). With the missing data excluded, the difference in groups was not statistically significant (χ^2=10.17, p=0.25).

Additionally, participants were asked, “When it was noisy, was it noisy all day long?” Overall, 26.9% of participants indicated it was noisy all day long (Table 15). Similar percentages were seen across the three types of noise-induced hearing loss groups. For 67.6% of participants the second measure of noise intensity was missing. When the missing data was included the difference in groups was statistically significant (χ^2=21.89, p=0.00). With the missing data excluded, the difference in groups was not statistically significant (χ^2=1.80, p=0.41).

4.1.12 Company Hearing Testing

To assess a company's participation in a hearing conservation program (HCP), participants were asked, “Did the company give you a hearing test when you first started working there?" Overall, 17.3% indicated receiving a hearing test at the beginning of their employment (Table 16). Of those participants that indicated not having a hearing test at the beginning of their employment, they were more likely to be in Group A1 (44.5%) as compared to Group B (29.7%). Those participants that indicated having a hearing test or where their status was missing were more likely to be in Group B (40.5% and 41.4% respectively). For 71.9% of participants the status of the initial hearing test was missing. Whether the missing data was included or excluded, both were statistically significant (χ^2=46.17, p <.0001 and χ^2=29.00, p <.0001, respectively).

Additionally, participants were asked, "Did the company give you a hearing test on a regular basis?" Of those participants that indicated not having regular hearing testing, they were more likely to be in Group A1 (42.2%) than Group B (32.5%) (Table 17). Of those participants where regular hearing testing was missing, they were more likely to be in Group B (41.7%). For 68.5% of participants the status of the regular hearing testing was missing. Whether the missing data was included or excluded, both were statistically significant (χ^2=32.69, p <.0001 and χ^2=9.05, p=0.01, respectively).

4.1.13 Hearing Protective Device and Type Used

Participants were asked about whether or not their company provided hearing protective devices (HPD). Overall, 27.6% of participants indicated their company did provide HPDs (Table 18). Participants that indicated not having been provided HPDs were more likely to be in Group A1 (49.3%) as compared to

Group B (26.8%). For 67.4% of participants provision of hearing protective device was missing. Whether the missing data was included or excluded, both were statistically significant (χ^2=47.01, p <.0001 and χ^2=22.74, p <.0001, respectively).

Participants were also asked what type of HPDs they were given. A non statistically significant majority of all participants indicated they were given canal caps (58.1%; χ^2=3.64, p=0.73) (Table 19). Custom plugs and foam plugs were also provided (19.4% and 17.4% respectively). To a much lesser extent pre-molded plugs were provided (5.2%). These percentages were similar across all three types of noise-induced hearing loss groups. For an additional 1.1% of participants the type of hearing protective device was missing.

4.1.14 Work-Related Injuries

To assess whether or not participants had work-related injuries, they were asked, "Did you have any work injuries at this company that caused you to lose work for a day or more or to be assigned to restricted or light duty work for a day or more?" Whether the participant indicated they had work-related injuries or not, the percentages across the hearing loss groups were similar (Table 20). For those participants were their injury status was missing, they were more likely to be in Group B (41.7%). For 67.7% of participants injury status was missing. When the missing data was included there was a statistically significant difference between groups (χ^2=23.34, p=0.00). However, when the missing data was excluded, the difference between groups was not statistically significant (χ^2=2.89, p=0.24).

4.1.15 Work-Related Exposure to Chemicals/Solvents or Heavy Metals

Overall, a non statistically significant percentage of participants (36.8%; χ^2=4.65, p=0.10) indicated having been exposed to a chemical or heavy metal that is potentially an ototoxin (Table 21). Where participants had indicated being exposed to chemicals/solvents and heavy metals of interest, participants were most likely to be in Group A1. For an additional 122 participants exposure to chemicals or solvents was missing.

4.1.16 Non-Work Noise Exposures

To assess noise exposure outside of the work environment, participants were asked about various activities/hobbies. Overall, a non statistically significant percentage of participants (28.3%; χ^2=2.48, p=0.29, with missing excluded) indicated they were engaged in at least one of the activities (Table 22). Participants that indicated being exposed to noise from hunting, snowmobiling, power tools, and chain saw use were more likely to be in Group A1. Those participants that indicated listening to loud music were more likely to be in Group B (51.1%) than Group A2 (27.3%) or Group A1 (21.6%) and was statistically significant when missing data were excluded (χ^2=43.70, p <.0001).

4.1.17 Multivariate Analysis

Select variables were retained in the multivariate analysis based on statistical significance, at the 5% level, in the univariate analysis and/or scientific knowledge. Results from the generalized logit model are presented in Table 23. Simultaneous logistic regression models were run in the generalized logit model and the non-material hearing impairment group (Group B) was the referent response. Overall, after adjusting for all other independent variables in the model, age group ($p<0.0001$), military service ($p=0.00$), and lack of provision of hearing protective devices ($p=0.01$) remained significantly associated with material hearing impairment compared to non-material hearing impairment. Additionally, gender ($p=0.10$) and industry ($p=0.07$) indicated marginal influence.

Examining the regression more closely, comparing Group A1 to Group B, there were independent variables in the model with significant 95% confidence intervals. The 75+ year age group was 38.68 (95% CI 9.90-151.17) times more likely than the youngest age group (18-44 years) to have bilateral material hearing impairment. The 65-74 year age group was 12.38 (95% CI 5.72-26.82) times and the 45-64 year age group was 3.65 (95% CI 2.02-6.60) times more likely than the youngest age group to have bilateral material hearing impairment. Men were 1.94 (95% CI 1.06-3.57) times more likely than women to have bilateral material hearing impairment. Those ever serving in the military were 1.70 (95% CI 1.23-2.33) times more likely than those were not in the military to be in Group A1. Those not receiving hearing protective devices were 2.02 (95% CI 1.21-3.36) times more likely than those receiving hearing protective devices to be in Group A1. And, those that listened to loud music were 0.63 (95% CI 0.40-0.98) times those not listening to loud music to have bilateral material hearing impairment.

Similarly, comparing Group A2 to Group B, there were independent variables in the model with significant 95% confidence intervals. The 65-74 year age group was 2.50 (95% CI 1.20-5.20) times more likely than the youngest age group (18-44 years) to have unilateral material hearing impairment. Those who were ever told they had high cholesterol were 0.72 (0.24-0.99) times those never told they had high cholesterol to be in Group A2. Those ever serving in the military were 1.43 (95% CI 1.02-2.00) times more likely than those were not in the military to be in Group A2. And, those in the services industry were 0.21 (95% CI 0.06-0.77) times those not in the services industry to have unilateral material hearing impairment.

CHAPTER 5: DISCUSSION

5.1 Discussion

This study investigated the risk factors associated with severe work-related noise-induced hearing loss in Michigan. The study looked at individuals with work-related noise-induced hearing loss in Michigan that were submitted to the Michigan Department of Energy Labor and Economic Growth (MDELEG) from 2003 to 2006. Overall, 60% of the participants in this sample met OSHA's definition of material hearing impairment. Of those 60%, 33% had a bilateral noise-induced hearing loss (Group A1) and 27% had a unilateral noise-induced hearing loss (Group A2). The remaining 40% had less severe hearing loss that did not meet OSHA's definition of material hearing impairment (Group B).

In the multivariate analysis, comparing material hearing impairment (Group A1 and Group A2) and non-material hearing impairment (Group B), three risk factors were found to be significant for severe noise-induced hearing loss. Increasing age, military service, and lack of provision of hearing protective devices were statistically significant when controlling for other potential risk factors.

For workers in general industry where noise levels are above 85 dBA, OSHA requires a hearing conservation program (HCP) to be in place. Components to a HCP include: exposure assessment, engineering and administrative controls, provision and use of hearing protective devices, audiometric testing and evaluation, education and recordkeeping (NIOSH, 1998).

To evaluate if the participant was in a hearing conservation program, they were asked a series of questions about elements of a hearing conservation program. These questions included information such as baseline hearing testing, regular hearing testing and provision and use of hearing protective devices. For this study, hearing protective device use was not collected and therefore employer provision of hearing protective devices was considered a surrogate for hearing protective device use. In the univariate analysis, the group with the more severe noise-induced hearing loss (Group A1) was more likely to be identified from non-company reports (51.2%) and smaller-sized companies (34.5%), although this risk did not remain in the multivariate analysis. Only 27.6% of participants indicated that their company provided hearing protective devices. Participants that indicated not having been provided with hearing protective devices were more likely to be in the more severe noise-induced hearing loss group (Group A1) as compared to those with non-material hearing impairment (Group B) (49.3% versus 26.8%, respectively). The results from the multivariate analysis estimated that those participants that were not provided hearing protective devices had a two-fold increased risk for severe bilateral noise-induced hearing loss (aOR=2.02, 95% CI 1.21-3.36) as compared to participants that were provided hearing protective devices. Additionally, the analysis of industrial sectors was consistent with the above study results. Industries less likely to have hearing conservation programs (i.e. agriculture and construction) had increased, although not statistically significant, risk of severe noise-induced hearing loss in the univariate analysis. Industrial sectors can be surrogates for the likelihood of the presence of a hearing conservation program.

In a recent Pub Med search for “hearing conservation effectiveness,” limiting results to adults aged 19 years and older, 15 studies were identified. Four of the fifteen studies identified studied hearing conservation effectiveness in military settings. In a study by Davies, et al., 2008 their investigation on the impact of hearing conservation programs found that the continuous use of hearing protective devices delayed the age of threshold shift by 2.4 years in the univariate analysis and reduced the risk by 30% in the adjusted model (RR=0.7, 95% CI 0.7-0.8) (Davies et al., 2008). Both the current study and the study by Davies et al. looked at severity of hearing loss. The current study had a three-level hearing ability outcome variable whereas the Davies et al. study had a six-level hearing ability outcome variable which also included noise exposure data and duration (Davies et al., 2008).

A study of the Finnish Defense Forces by Mrena et al., 2008 demonstrated the usefulness of hearing protective device regulations when looking at two distinct time periods; from 1984 to 1986 and 2003 to 2005. Since the inception in 1968 of regulations and guidelines for hearing protection, the Finnish Defense Forces (FDF) had revised and refined their guidelines in 1979, 1985, 1989, and in 1991 (Mrena et al., 2008). The revisions in 1979 required the use of muff-type hearing protective devices when shooting rifles in shelters and in 1985 refinements required the use of hearing protective devices when shooting live ammunition as well as blanks in shelters (Mrena et al., 2008). In their study of military personnel, Mrena et al., found that audiograms of non-commissioned officers showed significant improvement from the first time period to the second time period. Their study also showed improvement on audiograms of officers, however, the results were not statistically significant (Mrena et al., 2008). The above studies demonstrate the success of hearing conservation programs and the use of hearing protective devices.

Axelsson and Clark have reported that among professional groups, service members have the poorest hearing (Axelsson et al., 1995). Service members use the Department of Defense Hearing Conservation Program Instructions as a guideline to preserve hearing health (DoD instruction 6055.12). The manual includes information on evaluation, documentation, education and monitoring of noise exposures for service members. Hazardous noise exposure in military settings is difficult to control and there are barriers to administrative control.

In the current study, having ever been in the military had a significant χ^2 value in the univariate analysis and remained statistically significant in the multivariate analysis. The adjusted odds ratio estimated that those ever in the military had an excess risk of having bilateral noise-induced hearing loss (Group A1: aOR=1.70, 95% CI 1.23-2.33) or an excess risk of having unilateral noise-induced hearing loss (Group A2: aOR=1.43, 95% CI 1.02-2.00) as compared to those with non-material hearing impairment (Group B). In a recent Pub Med search for "military noise-induced hearing loss," limiting results to adults aged 19 years and older, 172 studies were identified. The current study findings are consistent with the findings of the Veterans Benefits Administration (VBA) Annual Benefits Reports for fiscal year 2004 that estimated that hearing loss is the fourth leading reason for medical referral for returning veterans (Veteran's Benefits Administration Annual Benefits Reports, 2005). The VBA also estimated that over 742,000 veterans were receiving compensation for service-connected auditory disability in fiscal year 2004 (Veteran's Benefits Administration Annual Benefits Reports, 2005).

The Institute of Medicine of the National Academies published a comprehensive book in 2006 called Noise and Military Service Implications for Hearing Loss and Tinnitus. The Institute was charged by the Veteran's Administration (VA) to examine noise hazards in the military and provide guidelines for whether veterans hearing disability is a result of time spent in the service (Institute of Medicine of the National Academies, 2006). The Institute concluded that the current state of the hearing conservation programs in the United States military services from World War II to 2006 have been inadequate (Institute of Medicine of the National Academies, 2006).

Age is a nonmodifiable risk factor for hearing loss. Age had a significant χ^2 value in the univariate analysis and remained statistically significant in the multivariate analysis. These study results are consistent with the literature.

In the current study, several potential risk factors in the multivariate analysis did not retain their statistically significant χ^2 values from the univariate analysis. These risk factors were male gender, race, high blood pressure, cholesterol, diabetes, pain medication use, smoking status, industry sector, duration of noise exposure at work, regular hearing testing at work, ototoxin exposure, and listening to loud music. It is reasonable that the health related conditions (i.e., high blood pressure, cholesterol, and diabetes) were no longer statistically significant in the multivariate analysis when controlling for age as the risk for these conditions also increase with age. Gender had a significant χ^2 value in the univariate analysis, however, it was not statistically significant in the multivariate analysis. These results are reasonable because this study was predominantly men (91.8%). In the multivariate analysis male gender was no longer statistically significant because generally there are more men in the military. Only twenty percent of the multivariate model was explained by the included variables in the multivariate analysis. These results suggest that there are other potential risk factors that warrant consideration that were not included in this study (i.e., genetic components, environmental exposures, and noise level measurements); or more quantitative and accurate measurements for the variables that were collected are needed.

Prevalence of noise-induced hearing loss can be reduced through increased public health awareness and implementation of prevention strategies. Health care professionals need to educate employees and the general public about potential sources of noise exposure at work and at home and common clinical findings. Prevention strategies include implementation of a hearing conservation program in the work place, engineering noise out of the work place, and provision of hearing protective devices.

5.2 Limitations

The current study has some limitations. Only reports of individuals submitted to the State of Michigan were analyzed. Those individuals that sought treatment from health care providers that were unaware of Michigan's disease reporting law or those who did not seek medical attention would not have been included in this study. Only a small percentage of all work-related noise-induced hearing is reported to the State and therefore in the sample. The 2003 BRFSS in Michigan estimated that 375,000 residents have work-related noise-induced hearing loss (Stanbury et al., 2008) and yet in the same year only 1,238 reports were received. Additional evidence that only a small percentage of cases are reported is that only two of 85 estimated otolaryngology/audiology group practices in Michigan and only 28 of the 490 practitioners not known to be associated with a group practice submitted reports to the State of Michigan in 2006. Demographic characteristics and risk factors of nonreported individuals may represent something other than what the current study found. It is likely that the missing individuals had less severe noise-induced hearing loss. It is also possible that the missing individuals did not have access to health insurance and therefore were less likely to have regular medical access and therefore less likely to have a hearing test. The current study may not be generalized to all individuals with more severe work-related noise-induced hearing loss.

In the current study, the outcome variable was classified into three levels: 1) bilateral material hearing impairment (Group A1), 2) unilateral material hearing impairment (Group A2), and 3) non-material hearing impairment (Group B). The non-material hearing impairment group (Group B) was the referent response in the multivariate model. The non-material hearing impairment group (Group B) had a degree of hearing impairment; however, the group did not meet OSHA's definition of material hearing impairment. Therefore, because the referent response group (Group B) also had noise-induced hearing loss to a lesser degree, that reference may under-estimate the estimates of this study.

The current study utilized reports of individuals submitted to the State of Michigan in accordance with the Public Health Act of 1978. Particular industries, such as the manufacturing sector, are more likely to have a hearing conservation program and are therefore more likely to submit reports on individuals to the State of Michigan. This differential reporting of individuals from industries likely to have a hearing conservation program (i.e., manufacturing) would indicate that the sample in this study is not a true representation of the population in Michigan with work-related hearing loss. Individuals in employer sponsored hearing conservation programs would be expected to be more common in the study sample then among all individuals in Michigan with work-related noise-induced hearing loss. Individuals from industries less likely to have hearing conservation programs (i.e., construction) may be less likely to be reported to the State of Michigan until their impairment is more severe. This bias would possibly cause an over estimate of the protective value of the use of hearing protective devices in reducing the risk of severe hearing loss.

The data have many missing values because participants have the right to refuse to answer any question or questions at any time during the telephone survey. Additionally, where participants were unable to be reached, their information was abstracted from the submitted reports, leaving many survey questions with missing values. The reports vary in the amount of information provided about an individual. For example, race is a required element on the occupational disease reporting form; however, it is rarely completed.

How much noise an individual is exposed to is a crucial factor in the development of hearing loss. Noise exposure levels were not captured with the current study. Noise exposure assessment was a self-report of the number of years worked in a noisy work environment, which may only be a crude surrogate of actual noise exposure.

The current study utilized self-reported information which is consistent with other studies of hearing loss prevalence, including data from the National Health Interview Survey (www.nihseniorhealth.gov/hearingloss/toc.html).

Lastly, using a cross-sectional design limits any clarification on the temporality for risk factors and disease outcome.

5.3 Conclusions

Hearing loss is common in Michigan. The current study identified three risk factors that increased the severity of work-related noise-induced hearing loss. These risk factors were increasing age, military service, and lack of hearing protective devices.

This study suggests that not providing employees with hearing protective devices is a significant risk factor in the development of severe noise-induced hearing loss. A useful prevention approach would be the implementation and execution of hearing conservation programs. OSHA does not require hearing conservation programs in construction. This study would support the benefit of requiring such programs in construction. This study emphasizes the importance of hearing protection in both the workplace and the military. Efforts to ensure the use of hearing protective devices are needed. This study also demonstrated that state surveillance data is useful in analyzing relationships and identifying risk factors for hearing loss.

Table 1: Comparison of Interviewed Participants with Audiogram Results and Interviewed Participants with Missing Audiogram Results in Michigan, 2003-2006

	Participants with Missing Audiogram Results (n=282)		Participants with Audiogram Results (n=5476)		P-Value
	Number	Percent	Number	Percent	
GENDER					
Male	233	(84.1)	5028	(91.8)	<.0001
Female	44	(15.9)	448	(8.2)	
AGE					
Older (GE 55 yo)	128	(45.4)	2613	(47.7)	0.45
Younger (< 55 yo)	154	(54.6)	2863	(52.3)	
RACE					
White	93	(79.5)	1889	(82.6)	0.39
Non-White	24	(20.5)	398	(17.4)	

Table 2: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Gender of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
GENDER	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Male	5028	(91.8)	1699	(94.9)	1382	(92.3)	1947	(89.0)
Female	448	(8.2)	92	(5.1)	115	(7.7)	241	(11.0)
TOTAL	**5476**	**(100.0)**	**1791**	**(100.0)**	**1497**	**(100.0)**	**2188**	**(100.0)**

$\chi^2 = 45.98$, $p < .0001$

Table 3: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Age Group of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
Age Group (Years)	Number	Percent[a]	Number	Percent[b]	Number	Percent[b]	Number	Percent[b]
18-44	1070	(19.5)	192	(17.9)	285	(26.6)	593	(55.4)
45-64	3537	(64.6)	1052	(29.7)	1030	(29.1)	1455	(41.1)
65-74	628	(11.5)	359	(57.2)	146	(23.3)	123	(19.6)
75+	241	(4.4)	188	(78.0)	36	(14.9)	17	(7.1)
TOTAL	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

$\chi^2 = 564.38$, $p < .0001$

[a]Column percent adds to 100.

[b]Row percents add to 100.

Table 4: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Race of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
RACE[a]	Number	Percent[b]	Number	Percent[c]	Number	Percent[c]	Number	Percent[c]
White	1889	(34.5)	722	(38.2)	499	(26.4)	668	(35.4)
African American	325	(5.9)	101	(31.1)	81	(24.9)	143	(44.0)
Other	73	(1.3)	30	(41.1)	22	(30.1)	21	(28.8)
Missing	3189	(58.2)	938	(29.4)	895	(28.1)	1356	(42.5)
TOTAL	**5476**	**(99.9)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

$\chi^2 = 50.92$, $p < .0001$

[a] $\chi^2 = 11.63$, $p = 0.02$; with missing excluded.

[b] Column percentage does not add to 100 due to rounding.

[c] Row percents add to 100.

Table 5: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Source of Report of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
COMPANY HEALTH CARE PROVIDER[a]	Number	Percent	Number	Percent[c]	Number	Percent	Number	Percent[c]
Yes	3332	(60.9)	874	(48.9)	996	(66.5)	1462	(66.9)
No	2141	(39.1)	915	(51.2)	501	(33.5)	725	(33.2)
TOTAL[b]	**5473**	**(100.0)**	**1789**	**(100.1)**	**1497**	**(100.0)**	**2187**	**(100.1)**

$\chi^2 = 161.45$, $p < .0001$

[a]Participant was reported to the surveillance system by a company health care provider.

[b]For an additional 3 participants company doctor was unknown.

[c]Column percentages do not add to 100 due to rounding.

Table 6: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Smoking Status of All Interviewed Participants, 2003-2006

	TOTAL		Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average $\geq$25 dB)				Non-Material Hearing Impairment (average <25 dB)	
			GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
EVER SMOKED[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
Yes	1243	(22.7)	485	(39.0)	328	(26.4)	430	(34.6)
No	595	(10.9)	202	(34.0)	163	(27.4)	230	(38.7)
Missing	3638	(66.4)	1104	(30.4)	1006	(27.7)	1528	(42.0)
TOTAL	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

$\chi^2 = 35.17$, $p < .0001$

[a] $\chi^2 = 4.77$, $p = 0.09$; with missing excluded.

[b] Participants were asked, "Have you ever smoked cigarettes? (No means less than 4 packs of cigarettes or 12 oz. of tobacco in a lifetime)"

[c] Column percent adds to 100.

[d] Row percents add to 100.

Table 7: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Impairment by Doctor Told Status of All Interviewed Participants, 2003-2006

	TOTAL		Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
			GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
DOCTOR TOLD[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
Yes	1381	(25.2)	598	(43.3)	384	(27.8)	399	(28.9)
No	465	(8.5)	95	(20.4)	107	(23.0)	263	(56.6)
Missing	3630	(66.3)	1098	(30.3)	1006	(27.7)	1526	(42.0)
TOTAL	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

χ^2 = 157.35, p <.0001

[a] χ^2 = 125.74, p <.0001; with missing excluded.

[b] Participants were asked, "Did a doctor or other health care provider tell you that you had a loss in your hearing?"

[c] Column percent adds to 100.

[d] Row percents add to 100.

Table 8: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Self-Report of Tinnitus of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
TINNITUS[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
Yes	979	(17.9)	405	(41.4)	272	(27.8)	302	(30.9)
No	856	(15.6)	282	(32.9)	213	(24.9)	361	(42.2)
Missing	3641	(66.5)	1104	(30.3)	1012	(27.8)	1525	(41.9)
TOTAL	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

χ^2 = 55.81, p <.0001

[a] χ^2 = 26.32, p <.0001; with missing excluded.

[b] Participants were asked, "Are you bothered by ringing, roaring or buzzing in your ears?"

[c] Column percent adds to 100.

[d] Row percents add to 100.

Table 9: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Presence of Health-Related Conditions of All Interviewed Participants, 2003-2006

	TOTAL		Average Hearing Threshold Level at 1000, 2000 and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
			GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
HEALTH-RELATED CONDITION	Number	Percent[e]	Number	Percent[e]	Number	Percent[e]	Number	Percent[e]
High blood pressure[a]	729	(13.3)	298	(40.9)	198	(27.2)	233	(32.0)
High cholesterol[b]	769	(14.0)	323	(42.0)	197	(25.6)	249	(32.4)
Diabetes[c]	279	(5.1)	130	(46.6)	69	(24.7)	80	(28.7)
Use pain medication[d]	863	(15.8)	349	(40.4)	228	(26.4)	286	(33.1)

[a] Participants were asked, “Has a health care provider told you that you have high blood pressure?” High blood pressure, χ^2 = 40.54, p < .0001; χ^2 = 8.80, p = 0.01 with missing excluded.

[b] Participants were asked, “Has a health care provider told you that you have high cholesterol?” High cholesterol, χ^2 = 43.23, p < .0001; χ^2 = 12.80, p = 0.00 with missing excluded.

[c] Participants were asked, “Has a health care provider told you that you have diabetes?” Diabetes, χ^2 = 44.09, p < .0001; χ^2 = 12.55, p = 0.00 with missing excluded.

[d] Participants were asked, “Do you take pain, headache or arthritis medicine?” Pain medication, χ^2 = 37.60, p < .0001; χ^2 = 8.00, p = 0.02 with missing excluded.

[e] Row percents add to 100.

Table 10: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Military Service Status of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
MILITARY[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
Yes	706	(12.9)	329	(46.6)	190	(26.9)	187	(26.5)
No	1147	(21.0)	365	(31.8)	304	(26.5)	478	(41.7)
Missing	3623	(66.2)	1097	(30.3)	1003	(27.7)	1523	(42.0)
TOTAL	**5476**	**(100.1)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

χ^2 =85.80, $p < .0001$

[a] χ^2 =53.60, $p < .0001$; with missing excluded.

[b] Participants were asked, "Did you ever serve in the military?"

[c] Column percentage does not add to 100 due to rounding.

[d] Row percents add to 100.

Table 11: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Duration of Occupational Noise Exposure of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
DURATION NOISE EXPOSURE[a]	Number	Percent	Number	Percent[b]	Number	Percent	Number	Percent
< 10 years	1630	(29.8)	483	(27.0)	436	(29.1)	711	(32.5)
10-19 years	592	(10.8)	141	(7.9)	169	(11.3)	282	(12.9)
20+ years	3254	(59.4)	1167	(65.2)	892	(59.6)	1195	(54.6)
TOTAL	**5476**	**(100.0)**	**1791**	**(100.1)**	**1497**	**(100.0)**	**2188**	**(100.0)**

$\chi^2 = 52.18$, $p < .0001$

[a]Duration of noise exposure was calculated using the total number of years spent in a noisy job(s).

[b]Column percentage does not add to 100 due to rounding.

Table 12: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Industrial Sectors of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average $\geq$25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
INDUSTRY (SIC)[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
Agriculture/Forestry (01-08)	18	(0.3)	10	(55.6)	4	(22.2)	4	(22.2)
Mining (10-14)	8	(0.2)	3	(37.5)	3	(37.5)	2	(25.0)
Construction (15-17)	161	(2.9)	76	(47.2)	36	(22.4)	49	(30.4)
Manufacturing (20-39)	4558	(83.2)	1399	(30.7)	1291	(28.3)	1868	(41.0)
Transportation (40-49)	119	(2.2)	54	(45.4)	26	(21.9)	39	(32.8)
Trade/Finance (50-67)	50	(0.9)	17	(34.0)	15	(30.0)	18	(36.0)
Services (70-89)	192	(3.5)	56	(29.2)	30	(15.6)	106	(55.2)
Public Administration (90-97)	57	(1.0)	17	(29.8)	18	(31.6)	22	(38.6)
Missing	313	(5.7)	159	(50.8)	74	(23.6)	80	(25.6)
TOTAL	**5476**	**(99.9)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

χ^2 = 109.46, p <.0001

[a] χ^2 = 57.66, p <.0001 with missing excluded.

[b] Standard Industrial Classification, 1987 manual.

[c] Column percentage does not add to 100 due to rounding.

[d] Row percents add to 100.

Table 13: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Company Size of All Interviewed Participants, 2003-2006

	TOTAL		Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
			GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
SIZE OF COMPANY[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
< 25 Employees	116	(2.1)	40	(34.5)	30	(25.9)	46	(39.7)
25-100 Employees	132	(2.4)	41	(31.1)	46	(34.9)	45	(34.1)
101-500 Employees	160	(2.9)	61	(38.1)	39	(24.4)	60	(37.5)
> 501 Employees	4015	(73.3)	1191	(29.7)	1129	(28.1)	1695	(42.2)
Missing	1053	(19.2)	458	(43.5)	253	(24.0)	342	(32.5)
TOTAL	**5476**	**(99.9)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

$\chi^2 = 80.20$, $p < .0001$

[a] $\chi^2 = 10.46$, $p = 0.11$; with missing excluded.

[b] Participants were asked, "How many people do you estimate work in a noisy area at this company?"

[c] Column percentage does not add to 100 due to rounding.

[d] Row percents add to 100.

Table 14: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Daily Occupational Noise Exposure Status of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
NOISY EVERYDAY[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
All the time	1263	(23.1)	473	(37.5)	342	(27.1)	448	(35.5)
Most of the time	222	(4.1)	85	(38.3)	65	(29.2)	72	(32.4)
Sometimes	228	(4.2)	72	(31.6)	60	(26.3)	96	(42.1)
Seldom	46	(0.8)	16	(34.8)	10	(21.7)	20	(43.5)
Rarely/never	33	(0.6)	9	(27.3)	7	(21.2)	17	(51.5)
Missing	3684	(67.3)	1136	(30.8)	1013	(27.5)	1535	(41.7)
TOTAL[b]	**5476**	**(100.1)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

$\chi^2 = 30.34$, $p = 0.00$

[a] $\chi^2 = 10.17$, $p = 0.25$; with missing excluded.

[b] Participants were asked, "Was it noisy every day?"

[c] Column percentage does not add to 100 due to rounding.

[d] Row percents add to 100.

Table 15: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Continuous Occupational Noise Exposure Status of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average $\geq$25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
ALL DAY LONG[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
Yes	1474	(26.9)	538	(36.5)	409	(27.8)	527	(35.8)
No	299	(5.5)	109	(36.5)	73	(24.4)	117	(39.1)
Missing	3703	(67.6)	1144	(30.9)	1015	(27.4)	1544	(41.7)
TOTAL	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

$\chi^2 = 21.89$, $p = 0.00$

[a] $\chi^2 = 1.80$, $p = 0.41$; with missing excluded.

[b] Participants were asked, "When it was noisy, was it noisy all day long?"

[c] Column percent adds to 100.

[d] Row percents add to 100.

Table 16: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Pre-Employment Hearing Test of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
HEARING TEST[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
No	589	(10.8)	262	(44.5)	152	(25.8)	175	(29.7)
Yes	949	(17.3)	299	(31.5)	266	(28.0)	384	(40.5)
Missing	3938	(71.9)	1230	(31.2)	1079	(27.4)	1629	(41.4)
TOTAL	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2199**	**(40.0)**

$\chi^2 = 46.17$, $p < .0001$

[a] $\chi^2 = 29.00$, $p < .0001$; with missing excluded.

[b] Participants were asked, "Did the company give you a hearing test when you first started working there?"

[c] Column percent adds to 100.

[d] Row percents add to 100.

Table 17: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Regular Hearing Testing of All Interviewed Participants, 2003-2006

	TOTAL		Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average $\geq$25 dB)				Non-Material Hearing Impairment (average <25 dB)	
			GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
REGULAR TESTING[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
No	526	(9.6)	222	(42.2)	133	(25.3)	171	(32.5)
Yes	1198	(21.9)	416	(34.7)	328	(27.4)	454	(37.9)
Missing	3752	(68.5)	1153	(30.7)	1036	(27.6)	1563	(41.7)
TOTAL[b]	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

$\chi^2 = 32.69$, $p < .0001$

[a] $\chi^2 = 9.05$, $p = 0.01$; with missing excluded.

[b] Participants were asked, "Did the company give you a hearing test on a regular basis?"

[c] Column percent adds to 100.

[d] Row percents add to 100.

Table 18: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Company Provision of Hearing Protective Device (HPD) of All Interviewed Participants, 2003-2006

	TOTAL		Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average $\geq$25 dB)				Non-Material Hearing Impairment (average <25 dB)	
			GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
HEARING PROTECTIVE DEVICE[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
No	276	(5.0)	136	(49.3)	66	(23.9)	74	(26.8)
Yes	1509	(27.6)	522	(34.6)	414	(27.4)	573	(38.0)
Missing	3691	(67.4)	1133	(30.7)	1017	(27.6)	1541	(41.8)
TOTAL	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

χ^2 = 47.01, p < .0001

[a] χ^2 = 22.74 p < .0001; with missing excluded.

[b] Participants were asked, "Were you given hearing protection?"

[c] Column percent adds to 100.

[d] Row percents add to 100.

Table 19: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Type of Hearing Protective Device (HPD) Used of All Interviewed Participants, 2003-2006

			Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average $\geq$25 dB)				Non-Material Hearing Impairment (average <25 dB)	
	TOTAL		GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
HEARING PROTECTIVE DEVICE TYPE[a]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
Canal caps	867	(58.1)	286	(33.0)	246	(28.4)	335	(38.6)
Custom plugs	289	(19.4)	104	(36.0)	82	(28.4)	103	(35.6)
Foam plugs	260	(17.4)	94	(36.2)	67	(25.8)	99	(38.1)
Pre-molded plugs	77	(5.2)	31	(40.3)	17	(22.1)	29	(37.7)
TOTAL[b]	**1493**	**(100.1)**	**515**	**(34.5)**	**412**	**(27.6)**	**566**	**(37.9)**

$\chi^2 = 3.64$, $p = 0.73$

[a]Participants were asked, if given hearing protective device "What type(s)?"

[b]For an additional 16 participants type of hearing protection used was unknown.

[c]Column percentage does not add to 100 due to rounding.

[d]Row percents add to 100.

Table 20: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Work-Related Injures of All Interviewed Participants, 2003-2006

	TOTAL		Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants					
			Material Hearing Impairment (average $\geq$25 dB)				Non-Material Hearing Impairment (average <25 dB)	
			GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
INJURIES[a,b]	Number	Percent[c]	Number	Percent[d]	Number	Percent[d]	Number	Percent[d]
Yes	847	(15.5)	318	(37.5)	238	(28.1)	291	(34.4)
No	921	(16.8)	329	(35.7)	240	(26.1)	352	(38.2)
Missing	3708	(67.7)	1144	(30.9)	1019	(27.5)	1545	(41.7)
TOTAL	**5476**	**(100.0)**	**1791**	**(32.7)**	**1497**	**(27.3)**	**2188**	**(40.0)**

$\chi^2 = 23.34$, $p = 0.00$

[a] $\chi^2 = 2.89$, $p = 0.24$ with missing excluded.

[b] Participants were asked, "Did you have any work injuries at this company that caused you to lose work for a day or more or to be assigned to restricted or light duty work for a day or more?"

[c] Column percent adds to 100.

[d] Row percents add to 100.

Table 21: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Work-Related Chemical or Solvent Exposure of All Interviewed Participants, 2003-2006

	Exposed at Longest Job With Noise Exposure		Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants: Material Hearing Impairment (average ≥25 dB)				Non-Material Hearing Impairment (average <25 dB)	
			GROUP A1 (Both Ears)		GROUP A2 (Either Ear)		GROUP B	
CHEM/SOLVENT EXP[a]	Number	Percent[n]	Number	Percent[n]	Number	Percent[n]	Number	Percent[n]
Other Solvents[b]	623	(25.4)	238	(38.2)	185	(29.7)	200	(32.1)
Lead[c]	371	(15.1)	147	(39.6)	111	(29.9)	113	(30.5)
Acetone[d]	361	(14.7)	141	(39.1)	99	(27.4)	121	(33.5)
Trichlorethylene[e]	323	(13.2)	133	(41.2)	97	(30.0)	93	(28.8)
Trichlorethane[f]	146	(6.0)	71	(48.6)	38	(26.0)	37	(25.3)
Toluene[g]	143	(5.8)	69	(48.3)	30	(21.0)	44	(30.8)
Xylene[h]	141	(5.8)	56	(39.7)	42	(29.8)	43	(30.5)
MEK[i]	114	(4.7)	52	(45.6)	28	(24.6)	34	(29.8)
Styrene[j]	91	(3.7)	43	(47.4)	22	(24.2)	26	(28.6)
Perchloroethylene[k]	83	(3.4)	38	(45.8)	21	(25.3)	24	(28.9)
Pesticides[l]	53	(2.2)	23	(43.4)	11	(20.8)	19	(35.9)
Any Chem/Solv Exp[m]	901	(36.8)	341	(37.9)	259	(28.8)	301	(33.4)

[a]Participants were asked, "Were you exposed to any of the following substances at this company?" For an additional 122 participants exposure to any chemical or solvent was unknown.
[b]χ^2 = 6.19, p = 0.05; [c]χ^2 = 5.98, p = 0.05; [d]χ^2 = 1.25, p = 0.53; [e]χ^2 = 8.45, p = 0.01; [f]χ^2 = 10.64, p = 0.00;
[g]χ^2 = 8.38, p = 0.02; [h]χ^2 = 2.01, p = 0.37; [i]χ^2 = 3.93, p = 0.14; [j]χ^2 = 4.41, p = 0.11; [k]χ^2 = 3.08, p = 0.21;
[l]χ^2 = 1.37, p = 0.50; [m]χ^2 = 4.65, p = 0.10. [n]Row percents add to 100.

Table 22: Comparison of Severity of Noise-Induced Hearing Loss in Michigan by Non-Work Noise Exposures of All Interviewed Participants, 2003-2006

	TOTAL		Average Hearing Threshold Level at 1000, 2000, and 3000 Hertz Among Participants: Material Hearing Impairment (average ≥25 dB) GROUP A1 (Both Ears)		Material Hearing Impairment (average ≥25 dB) GROUP A2 (Either Ear)		Non-Material Hearing Impairment (average <25 dB) GROUP B	
NONWORK NOISE EXPOSURE[a]	Number	Percent[l]	Number	Percent[l]	Number	Percent[l]	Number	Percent[l]
Hunting[b]	619	(11.3)	240	(38.8)	171	(27.6)	208	(33.6)
Target shoot[c]	387	(7.1)	142	(36.7)	95	(24.6)	150	(38.8)
Snowmobiling[d]	243	(4.4)	99	(40.7)	60	(24.7)	84	(34.6)
Power tools[e]	435	(7.9)	177	(40.7)	107	(24.6)	151	(34.7)
Chain saw[f]	385	(7.0)	150	(39.0)	102	(26.5)	133	(34.6)
Loud music[g]	282	(5.2)	61	(21.6)	77	(27.3)	144	(51.1)
Motor boat/jet ski[h]	227	(4.2)	78	(34.4)	71	(31.3)	78	(34.4)
Lawn work[i]	1319	(24.1)	487	(36.9)	362	(27.5)	470	(35.6)
Other[j]	275	(5.0)	97	(35.3)	71	(25.8)	107	(38.9)
Any[k]	1547	(28.3)	572	(37.0)	425	(27.5)	550	(35.6)

[a]Participants were asked, "Do/did you do any of the following on a regular basis?"
[b]χ^2=32.35, p<.0001; χ^2=2.09, p=0.35 with missing excluded. [c]χ^2=32.30, p<.0001; χ^2=2.09, p=0.35 with missing excluded. [d]χ^2=33.13, p≤.0001; χ^2=1.34, p=0.51 with missing excluded. [e]χ^2=32.93, p≤.0001; χ^2=2.99, p=0.23 with missing excluded. [f]χ^2=30.04, p<.0001; χ^2=0.62, p=0.74 with missing excluded. [g]χ^2=74.88, p≤.0001; χ^2=43.70, p<.0001 with missing excluded. [h]χ^2=33.79, p<.0001; χ^2=2.78, p=0.25 with missing excluded. [i]χ^2=30.54, p<.0001; χ^2=0.88, p=0.64 with missing excluded. [j]χ^2=29.89, p<.0001; χ^2=1.14, p=0.56 with missing excluded. [k]χ^2=32.28, p<.0001; Participants were counted as 'Yes' for the index variable 'Any' if the participant indicated they were engaged in at least one of the non-work hobbies. χ^2=2.48, p=0.29 with missing excluded. [l]Row percents add to 100.

Table 23: Adjusted Odds Ratios for Material Hearing Impairment[a] Compared to Non-Material Hearing Impairment[b] by Selected Demographic and Health-Related Characteristics in Michigan of All Interviewed Participants, 2003-2006				
	Group A1 (Both Ears) n=437		Group A2 (Either Ear) n=327	
	AOR	(95% CI)[c]	AOR	(95% CI)[c]
DURATION NOISE EXPOSURE				
< 10 years	1.00		1.00	
10-19 years	0.67	(0.34-1.33)	1.40	(0.73-2.72)
20+ years	0.95	(0.52-1.75)	1.73	(0.92-3.27)
AGE (years)				
18-44	1.00		1.00	
45-64	*3.65*	*(2.02-6.60)*[d]	1.30	(0.81-2.09)
65-74	*12.38*	*(5.72-26.82)*[d]	*2.50*	*(1.20-5.20)*[d]
75+	*38.68*	*(9.90-151.17)*[d]	2.63	(0.56-12.31)
GENDER				
Female	1.00		1.00	
Male	*1.94*	*(1.06-3.57)*[e]	1.14	(0.68-1.99)
RACE				
White	1.00		1.00	
Black	1.08	(0.62-1.87)	1.13	(0.65-1.98)
Other	1.75	(0.77-3.99)	2.19	(0.97-4.98)
CIGARETTE SMOKING				
Never smoked	1.00		1.00	
Ever smoked	1.03	(0.75-1.41)	0.91	(0.67-1.25)
HIGH BLOOD PRESSURE				
Never told high	1.00		1.00	
Ever told high	1.12	(0.81-1.56)	1.16	(0.82-1.63)
HIGH CHOLESTEROL				
Never told high	1.00		1.00	
Ever told high	0.89	(0.65-1.22)	*0.72*	*(0.24-0.99)*[e]
DIABETES				
Never told diabetes	1.00		1.00	
Ever told diabetes	1.42	(0.90-2.23)	1.03	(0.63-1.70)
PAIN MEDICINE USE				
Non-regular use	1.00		1.00	
Regular use	1.13	(0.84-1.53)	1.11	(0.82-1.50)

Table 23: Adjusted Odds Ratios for Material Hearing Impairment[a] Compared to Non-Material Hearing Impairment[b] by Selected Demographic and Health-Related Characteristics in Michigan of All Interviewed Participants, 2003-2006 (continued)				
	Group A1 (Both Ears) n=437		Group A2 (Either Ear) n=327	
	AOR	(95% CI)[c]	AOR	(95% CI)[c]
MILITARY SERVICE				
Never	1.00		1.00	
Ever	*1.70*	*(1.23-2.33)*[d]	*1.43*	*(1.02-2.00)*[d]
REGULAR HEARING TESTING				
Yes	1.00		1.00	
No	0.74	(0.49-1.12)	1.09	(0.73-1.63)
HEARING PROTECT DEVICE				
Yes	1.00		1.00	
No	*2.02*	*(1.21-3.36)*[d]	1.07	(0.61-1.85)
INDUSTRY				
Trade/Finance	1.00		1.00	
Agriculture/Forestry	7.98	(0.66-96.63)	0.90	(0.05-17.52)
Mining	3.82	(0.27-54.38)	1.53	(0.11-21.23)
Construction	2.38	(0.64-8.88)	0.56	(0.17-1.93)
Manufacturing	1.54	(0.46-5.12)	0.78	(0.27-2.23)
Transportation	1.68	(0.39-7.29)	0.48	(0.11-2.04)
Services	0.94	(0.25-3.55)	*0.21*	*(0.06-0.77)*[e]
Public administration	0.78	(0.16-3.70)	0.54	(0.14-2.11)
OTOTOXIN EXPOSURE				
No	1.00		1.00	
Yes	1.28	(0.95-1.73)	1.29	(0.96-1.75)
LISTEN TO LOUD MUSIC				
No	1.00		1.00	
Yes	*0.63*[d]	*(0.40-0.98)*[e]	0.94	(0.62-1.40)

[a]Average hearing threshold level at 1000, 2000, 3000 Hertz greater than or equal to 25 decibels.
[b]Average hearing threshold level at 1000, 2000, 3000 Hertz less than 25 decibels (n=438).
[c]From generalized logits model, with non-material hearing impairment (Group B) as the referent group for the dependent variable and duration noise exposure (p=0.24), *age group (p<0.0001)*, gender (p=0.10), race (p=0.45), high blood pressure (p=0.67), high cholesterol (p=0.13), diabetes (p=0.22), pain medicine use (p=0.68), smoking (p=0.74), *military (p=0.01)*, regular hearing testing (p=0.19), *HPD (p=0.01)*, industry (p=0.08), ototoxin exposure (p=0.16), and music (p=0.11) as the independent variables.
[d]Statistically significant in the overall multivariate model.
[e]Significant 95% confidence intervals in the individual logit model; the 95% confidence interval did not contain 1.

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